DESCRIPTION OF THE MEDITERRANEAN DRIFTER PROGRAM (MEDSVP) AS OF MAY 2008

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Approved by: ……………………………

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1. Introduction

Surface drifters are the most modern version of the drift-bottles used in the early 1900s to follow surface currents. Their overall positively buoyant structure – developed to reduce effects of wind and to maximize the drag area – and their low purchase costs make them appropriate instruments for the study of surface, or near surface, circulation in the world's oceans and seas.

In contrast with the Eulerian current meters – which measure velocities at a fixed point (e.g. the Acoustic Doppler Current Profiler or the more classic mechanical current meter) - drifters are of the Lagrangian type: they are mobile instruments which move with the body of water surrounding them.

Once deployed from research vessels or ships of opportunity (sometimes also from aircrafts), they are satellite tracked and can transmit their ocean observations for more than a year after deployment.

Since the early 1980s, drifters have been heavily deployed within several national and international projects. The GDP (Global Drifter Program) gathers from all the partnering institutions the collected drifter data. They are which is also retrieved for meteorological purposes (e.g with the use of 'hurricane drifters').

The returned environmental data are processed and analyzed together with the observed trajectories to characterize the surface circulation of the covered areas. It is possible to view, in near real time, the drifters' trajectory and environmental recodings, while the edited and interpolated data (processed in delayed mode) are disseminated on web and made available after authorized authentication through an e-database. The same product is offered at OGS as part of the Mediterranean Surface Velocity Program (MedSVP): the data that have been collected since the first deployments in the Mediterranean (1986) and Black Sea (1999) are archived and available to interested users. This report focuses on the description of the processing steps applied to the incoming raw data and on how the database is organized. It provides details on the MedSVP as it is organized now (May 2008).

In the first section, (Chapter 2) the experimental setup is described, focusing on the instruments used, the drifters, and the Argos positioning and data telemetry system. Chapter 3 provides a brief description of the projects that have been carried out in the Mediterranean and Black Sea within MedSVP. Finally, chapter 4 describes in detail the data analysis procedures applied to the incoming raw data: after the description of the first steps carried out automatically and in near real time to update the main MedSVP web page, the scripts that return the final edited and interpolated data are explained in detail. Some conclusions are included in chapter 5 and references can be found in chapter 6.

2. Experimental setup

Three main parts make up an environmental monitoring system: the set of sensors, which directly or remotely acquire the variables of interest, a mechanism for transmitting and receiving the recorded data, and the software, hardware and methodology to correctly elaborate and disseminate the measured values.

Here each component of the 'life cycle' of the data acquired by satellite tracked drifters are described, starting with a description of the instruments themselves – the drifters - followed by a brief description of the Argos system used to locate the active platforms. The latter is also a useful system for the transmission of acquired data.

2.1. Introduction to drifters

Surface drifters are sophisticated microprocessor-controlled oceanographic data collection instruments. They follow the two-dimensional surface flow reason why they are ideal for studying the dispersion of surface particles such as fish larvae or pollutants (e.g. oil spills).

In the early 1990s drift-bottles carrying a note indicating their launch location and time (Sverdrup et al., 1942) were used to estimate surface currents; today – after several technological and hardware enhancements which took place mostly during the '80s – standard common structures have been developed. Most drifters are composed of a drogue tethered to a surface float which generally does not extend far above the surface in order to reduce the effects of wind. All models host a temperature sensor, but others may have other kinds of sensors according to the goal of the experiments.

The introduction of satellite based methods for positioning platforms, this in the early 1970s, allowed large scale deployments of drifters. In 1982, the World Climate Research Program (WCRP) declared that surface drifters needed to be developed in a standardized way as they would be an invaluable resource for oceanographic and climate research (Lumpkin et al., 2006). Today, these easily deployed, low-cost instruments are used by several international research institutes to collect current data throughout most seas and oceans; in the following map, all active drifters are plotted so that it is possible to see their distribution on the globe as of 12 May 2008.

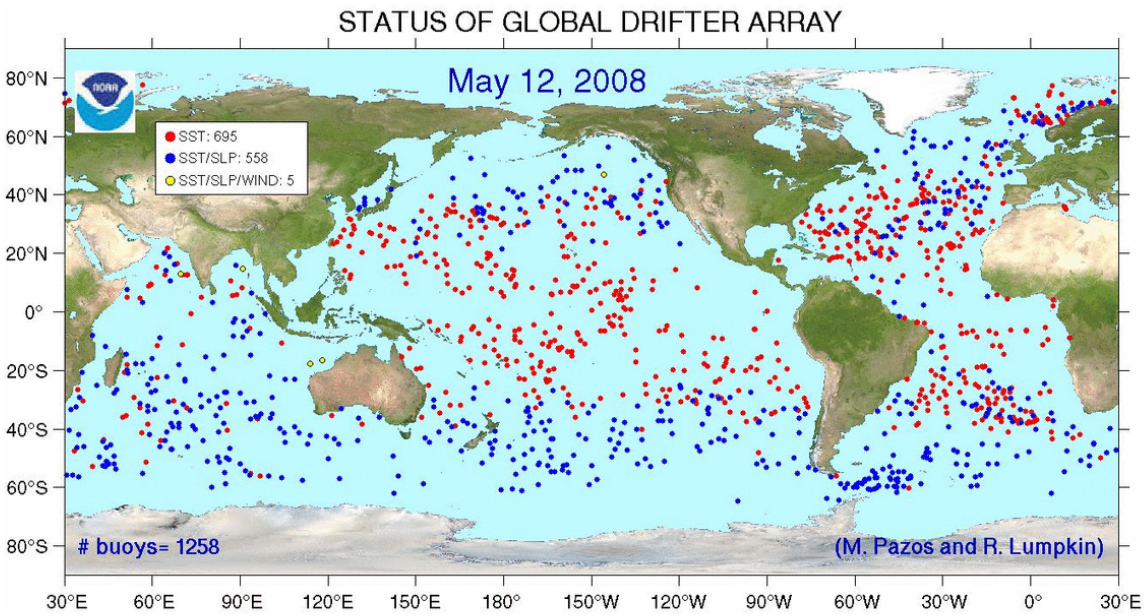

Figure 1. Status of Global drifter Array as from http://www.aoml.noaa.gov/phod/dac/gdp.html. The total number or satellite tracked drifters is 1258. All of these measure SST values. It is interesting to note how few are the those located along the Equator: geostrophic currents divert them north or south. A future goal would be to improve knowledge in remote regions, such as the Southern Ocean.

Drifters can be divided in two main categories, SVP (Surface Velocity Program) and CODE (Coastal Ocean Dynamics Experiment) drifters.

2.1.1. SVP drifters

SVP drifters are the standard design of the GDP. They consist of a surface buoy and a subsurface drogue, or sea anchor, attached by a long thin tether (Figure 2). The drogue is centered at a depth of 15 meters beneath the sea surface to monitor the mixed layer circulation of the world's ocean. It must be noted that they do not perfectly follow the water column averaged over the drogue depth because their water following behavior can be influenced by the wind-driven flows in the surface layer and by slip which is the direct effect of wind on the floating part of the drifter.

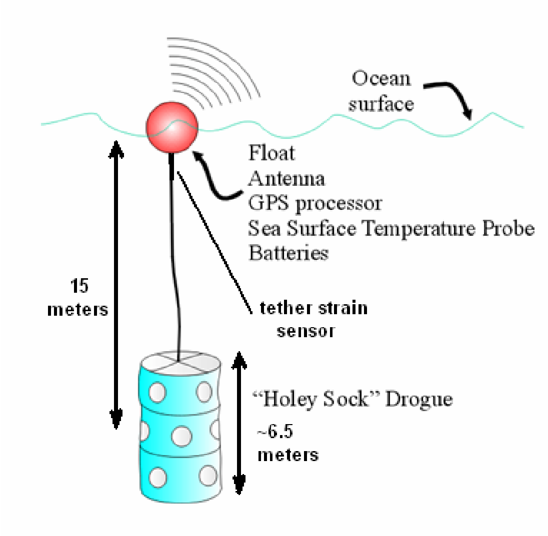

Figure 2. Schematic diagram (left, modified from Menna, 2003) and picture (right) of a typical SVP drifter. The temperature probe is located under the float in order to avoid direct radiative heat. Several rings support the drogue structure, maintaining its cylindrical shape. The drogue is a "holey-sock," with uniformly distributed holes (90° separate each hole) which are needed to disrupt laminar and avoid vortices which would make the drogue wrap up on itself.

At present, there are two basic sizes of SVP drifters: the original, with a relatively large drogue and the new "mini" version; the first weighs 45 kg while the latter about 20 kg. The floating part of the structure is a plastic shelled float ranging in size from 30.5 cm to 40 cm in diameter; it hosts the batteries (usually 4 to 5 packs each with 7–9 alkaline D-cell batteries), an antenna (also GPS is available) and the satellite transmitter (401.650 MHz ±10 kHz) for the transmission of the collected data, a thermistor for temperature measurements (20–30 cm beneath the sea surface) and in the lower part – in direct contact with the first portion of the tether (Figure 4) - there is a strain sensor which allows to monitor the drogue presence. Other models can measure additional environmental parameters such as the barometric pressure, wind speed and direction, salinity, and optical properties.. An important design parameter is the drag area (non-dimensional unit) which is the ratio of drag area ratio of the drogue over the drag area of all other components. While the size of the surface float and drogue vary, the drag area is kept to 40 units.

Studies have been carried out to estimate the water following capabilities of SVP drifters: measurements were done by attaching two neutrally buoyant vector measuring current meters to the top and bottom of the drogues and deploying the drifters in different wind and upper ocean shear conditions for periods of 2-4 h; results showed that when the drogue was attached to the SVP, the drifter could follow the water to within 1 cm s^{-1} in 10 m s^{-1} winds (Niiler et al., 1995).

The manufacturers' estimate for an original SVP drifter lifetime is 400 days although 'long living' drifters occur, such as Drifter 36256 which was recovered after 521 days during which it crossed the Atlantic Ocean. As it can be seen in Figure 3 (left), the drifter lost its drogue and accumulated biofouling.

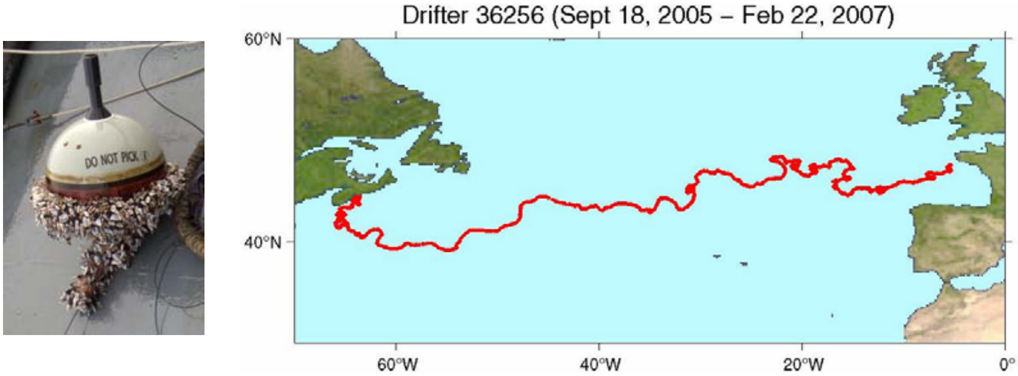

Figure 3. Drifter 36256 (picture after recovery on left and overall trajectory on the right from http://www.aoml.noaa.gov/phod/dac/gdp_information.html). It was deployed on Sep 18, 2005 out of Halifax - Canada and successfully recovered on Feb 21, 2007, at Brest - France, after a 521 days journey across the Atlantic ocean. Both SST and barometric pressure sensors were reporting good data until its recovery.

Before deployment, paper tape binds the drogue and tether (Figure 4) and before it is tossed in the water, a magnet is removed from the float in order to turn on the instrument. Once the drifter is thrown into the water, generally from the stern of a vessel, it may take up to an hour for the different parts to become loose (the tape dissolves in water) and for the drogue to reach its final depth.


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Figure 4. Before deployment paper tape binds the SVP drogue and tether. The latter can be wrapped around a cardboard ring to avoid kinking. The upper portion of the tether attached to the surface

buoy is clearly seen (black cone). (From http://www.aoml.noaa.gov/phod/dac/gdp_information.html).

Drifters have also been air-deployed out of Lockheed C-130 Hercules or from a C-141 Starlifter aircraft.

SVP drifters are manufactured by the following companies:

- Clearwater Instrumentation (USA - www.clearwater-inst.com)
- Marlin-Yug (Ukraine – www.marlin-yug.com)
- Metocean Data Systems (Canada - www.metocean.com)
- Pacific Gyre (USA - www.pacificgyre.com)
- Technocean (USA - www.technocean.com)

Large-scale deployments of the first modern SVP drifters took place in 1988 (World Climate Research Program) with the goal of mapping the tropical Pacific Ocean's surface circulation. Today the array of SVP drifters is known collectively as the Global Drifter Program, the main component of the Global Surface Drifting Buoy Array, a branch of NOAA's Global Ocean Observing System (GOOS) and a scientific project of the Data Buoy Cooperation Panel - DBCP).

Examples of SVP drifters equipped with additional sensors are the MINIMET (Wotan) which measures wind speed and direction, the SVP/OCM model (manufactured by Metocean Data Systems Limited) which measures upwelling radiance and downwelling irradiance at visible wavelengths together with SST. Drifters may also be equipped with a GPS receiver and upon request may have the drogue centered at any depth (e.g. 30 or 50 meters) to measure deeper currents.

2.1.2. CODE drifters

CODE drifters receive their name from the Coastal Ocean Dynamics Experiment in the early 1980's (Davis, 1985) which was undertaken to map and study currents and their variability. This experiment was conducted with 164 surface drifters north of the San Francisco bay from April 1981 to August 1982.

CODE drifters, as those manufactured by Technocean (www.technoecan.com), are Lagrangian current meters and move following near surface currents as deep as about 1 meter below the surface. Their drogue element is composed of two orthogonally intersecting vanes (1 square meter each) which depart from a 1 meter long sealed PVC tube hosting electronics and the battery pack for a nominal operating life of 9 months. On top of the tube there is one or two antennas (if the GPS receiver is included) for the determination of the position (Argos or GPS) and the transmission of recorded data. Antennas are always kept out of the water thanks to four spherical foam floats (10 cm in diameter) which keep the entire structure just below the sea surface providing net positive buoyancy considering that the central tube is negatively buoyant.

Comparison with current meter measurements (Davis, 1985) showed that the CODE drifters are following structures which follow currents within 3 cm/s – recently calculated to 2 cm/s - even during strong wind conditions.

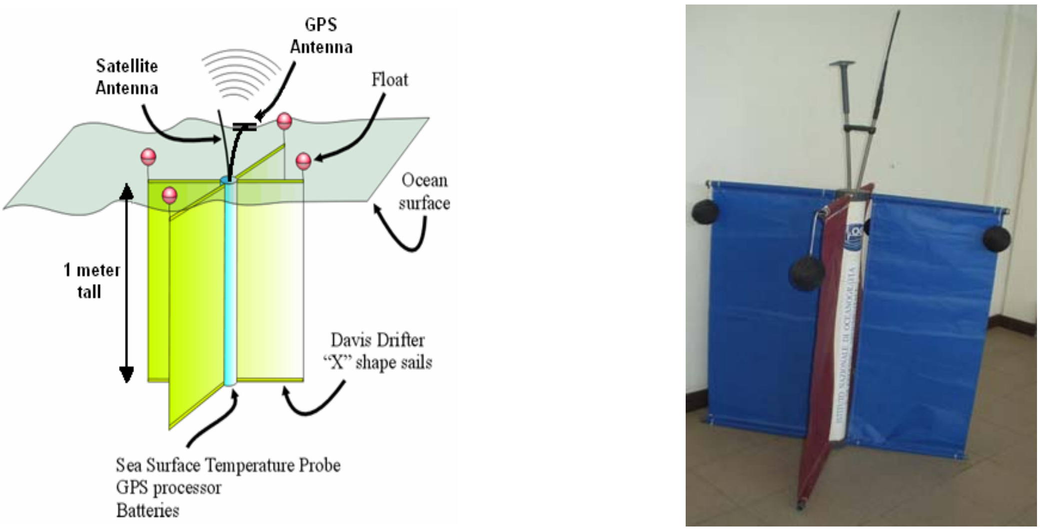

Figure 5. Schematic diagram (left – modified from Menna, 2003) and picture (right) of CODE type drifter. The antennas – Argos and GPS (if present) - are always kept out of the water for the transmission of recorded SST data. The drifter measures the currents within the first meter below the sea surface. The PVC tube hosts the SST probe, the GPS processor and batteries.

When shipped, the arms, floats and antenna(s) are folded and the entire unit is contained in a cardboard box which weighs approximately 9 kg. The unit may be dropped in the water with the box, or after it has been removed from it (Figure 6); CODE drifters may be deployed also from aircrafts, in this case a parachute is attached to the box prior to deployment. Before the instrument is thrown in the water, the transmitter is activated by removing a magnet which acts like an on-off switch.

Figure 6. Two possible ways of deploying a CODE drifter: closed in its cardboard box for protection (left) generally if it is thrown from a moving vessel or after it has been removed from it (right).

Examples of CODE drifters fitted with other sensors are the CODE-Tz (manufactured by Metocean) which have a thermistor chain to measure the water temperature at several depths; they also measure surface air pressure and temperature.

2.1.3. Other drifter models

Other Lagrangian current meters used to study surface currents are:

- the CMOD (Compact Meteorological and Oceanographic Drifter in Figure 7a), a sonobuoy which consists of a 60-cm-long aluminum cylindrical hull with a floatation collar. In addition to SST it measures atmospheric parameters such as air temperature and pressure;

- the TRISTAR drifter which has a drogue in the form of a corner-radar reflector centered at 15-m nominal depth (Niiler et al., 1989);

- the A111 (Figure 7b) and A104 (Figure 7c) drifters (manufactured by Brightwaters Instrument – USA). Model A111 houses the transmitter, antenna and batteries within a vertical cylinder; the drogue is tethered at 10 m depth and is a holey-sock type; it is equipped with a GPS receiver and is attached to a holey-sock drogue tethered at 10 m. Both models are similar in design to the CODE drifter without vanes.

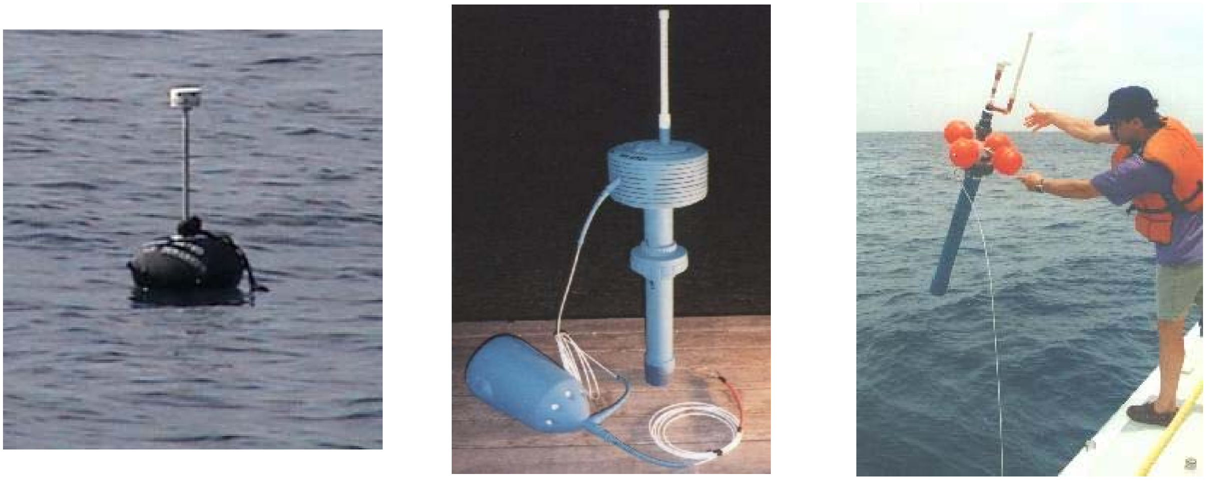

Figure 7. Pictures of the CMOD (left), the A111 (center) and A104 (right) drifters.

2.2. Argos positioning and data telemetry

The position of satellite-tracked drifters is inferred from the Doppler shift on their transmitted signals as seen by the polar orbiting satellites adopted by Argos: a satellite-based system for collecting and distributing data.

The Argos system is the result of an international cooperation, involving the French space Agency, the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the European meteorological organization (Eumetsat) and the Collecte Localisation Satellites (CLS). It is operated by CLS in Toulouse - France with a subsidiary (Service Argos, Inc.) in Maryland USA. Since 1978, the Argos system has been carried on the polar orbiting Environmental Satellites (POES) and other satellites, such as the Japanese Advanced Earth Observing Satellites II (ADEOS-II) which was operative from December 2002 to October 2003 or the European METOP satellites (since 2005). This set of satellites allowed to obtain global coverage.

Argos allows any platform equipped with a compatible transmitter – and associated to an Argos ID number specific to its transmission electronics - to be located across the world with an error of about 150-1000 meters; in addition to the position, Argos collects the data acquired by sensors located on the transmitting platforms. The fact that it requires little battery and a very small transmitter makes the system an appropriate and reliable method to receive data from the tracked instrumentation.

2.2.1. Working principle

The satellites are on a polar orbit at an altitude of 850 km, and follow a 'meridian' like orbit: each orbit passes over the North and South Poles at each revolution and transects the equatorial plane at fixed local solar times. Orbits are sun-synchronous and as a result each satellite passes within visibility of any given transmitter at almost the same local time each day. The time taken to complete a revolution around the Earth is approximately 100 minutes (14 orbits per day). At any given time, each satellite simultaneously "sees" all transmitters within an approximate 5000 kilometer diameter "footprint", or visibility circle. The period during which the satellite can receive messages from a platform is equivalent to the time during which the platform is within its visibility (10 minutes).

Figure 6 briefly describes each step of the procedure that brings acquired data and inferred position to final users.

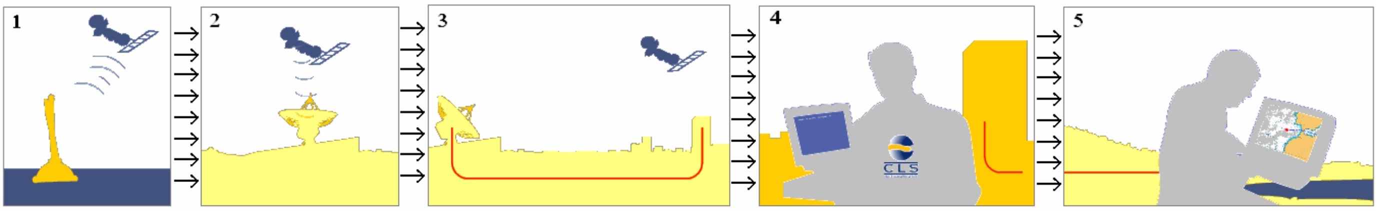

Figure 8. Transmitters send signals at a regular intervals (e.g. 90 s); polar orbiting satellites flying at an orbit of 850 km from the earth's surface collect and store the received data (1), the instrument is visible to the satellite for about 10 minutes. All the stored information is redirected in real-time through ground antennas (2) to the processing centers (3). Processing centers collect all incoming data (4), calculate the position of the transmitters, process the data measured by the sensors then distribute them to users (5) who can retrieve data also via the internet or log with username and password on to a secure website.

Over 40 antennas located around the globe collect satellite data. Data are stored on the satellite's onboard recorder and transmitted to the ground each time the satellite passes over one of the three main receiving stations: Wallops Island (Virginia, United States), Fairbanks (Alaska, United States), and Svalbard (Norway), or transmitted to one of the regional reception stations in the satellites' field of view (figure 8)

Figure 9. Position of the stations that form the real time L-band antenna-network. Each of these receive real time data from the satellites and retransmit them to processing centers. Two of the main receiving stations are in the USA (Wallops Island and Fairbanks) one in Norway (Svalbard).

Processing centers collect all incoming data, process them and distribute them to users.

There are two global Argos processing centers, one located in Southwestern France, and the other near Washington DC - USA. Once the data arrive at a processing center, locations are automatically calculated by using the Doppler effect on the transmission frequency: when the satellite approaches a transmitter, the frequency of the transmitted signal measured by the satellite's onboard receiver is higher than the actual transmitted frequency when it approaches and lower when it moves away (Figure 9). The absolute motion of the drifter introduces a negligible additional Doppler shift. This Doppler effect decays with increased distance from the drifter at a rate dependent upon the minimum satellite/drifter distance (greater distance equals to a slower decay).

The sign of this shift is estimated from least-squares fitting, from the previous history of the drifter, and gives the off-track direction. Argos estimates the accuracy of position fixes at 150–1000 m. The root-mean-square of the error is of 630 m zonally and 270 m meridionally (Lumpkin et al., 2006).

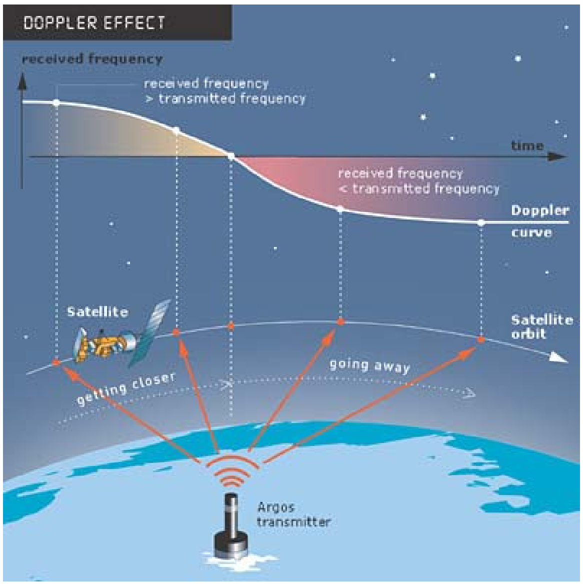

Figure 10. The Doppler effect is used to locate the instrument carrying the Argos transmitter. Each time the satellite receives a message from a transmitter, it measures the frequency and time-tags the arrival. The Argos processing centers compute the locus of possible positions by comparing the frequency measured on board the satellite with the transmitter's frequency. The Center finally defines the most probable positions using plausibility tests. A location class is calculated using the residual error and the satellite pass characteristics.

Argos users around the world receive data directly depending on their choice (for example by email, fax, web, cd-rom, or directly on mapping software) and they can access data also by connecting via the secure dedicated website (https://www.argos-system.org), or by sending a request via telnet – which is the procedure followed by the center at OGS. Data are stored by the processing center and expires after 9 days.

3. Drifter Projects

Since 1986, several different drifter projects have been carried out in the Mediterranean sea, while in 1999 started a drifter project in the Black sea. Many drifters have been released from ships of opportunity (ferry boats of small boats), or during oceanographic surveys. Among all, only the EGYPT project is still ongoing. The following spaghetti diagram (Figure 11), shows all the areas that have been covered by the drifters trajectories, while Figure 12 plots the number of active drifters per month/per project. The processed collected data (after editing and interpolation) have been made available through on-line databases; The data recorded in the Aegean and Tyrrhenian database will be available soon, as they are still being processed.

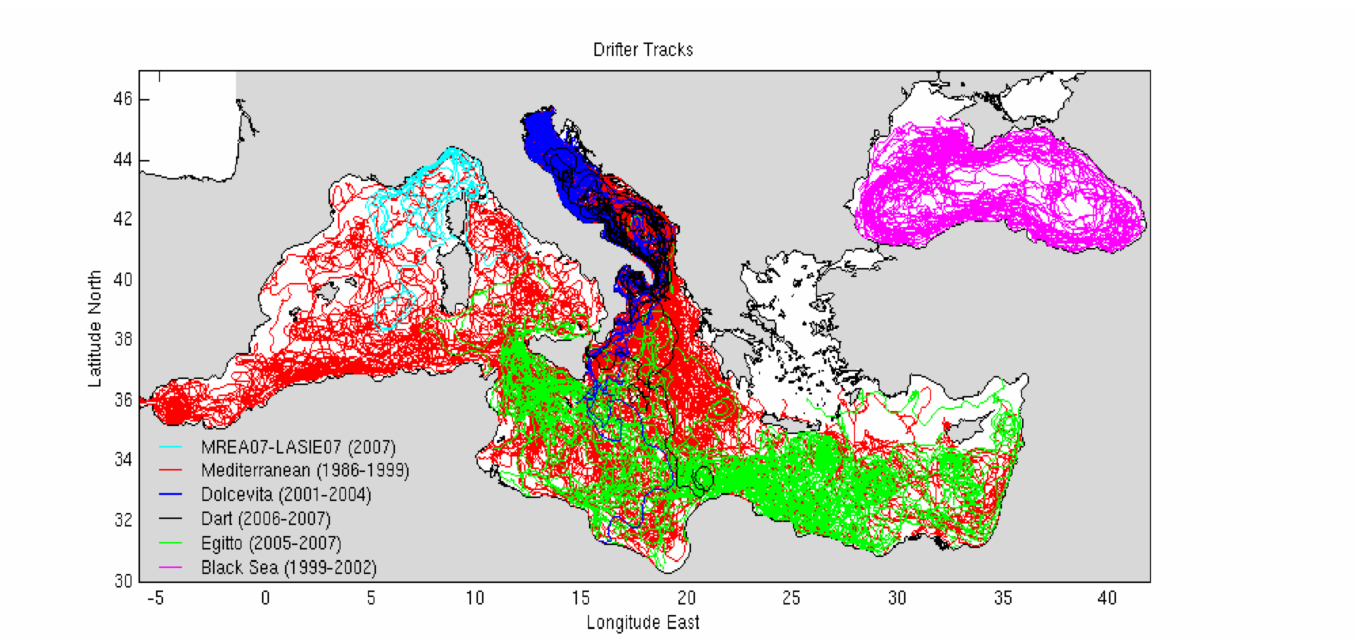

Figure 11. Spaghetti diagram of overall undertaken trajectories of deployed drifters since 1986 in the Mediterranean and Black Sea. MedSVP comprehends those projects started after 2005.

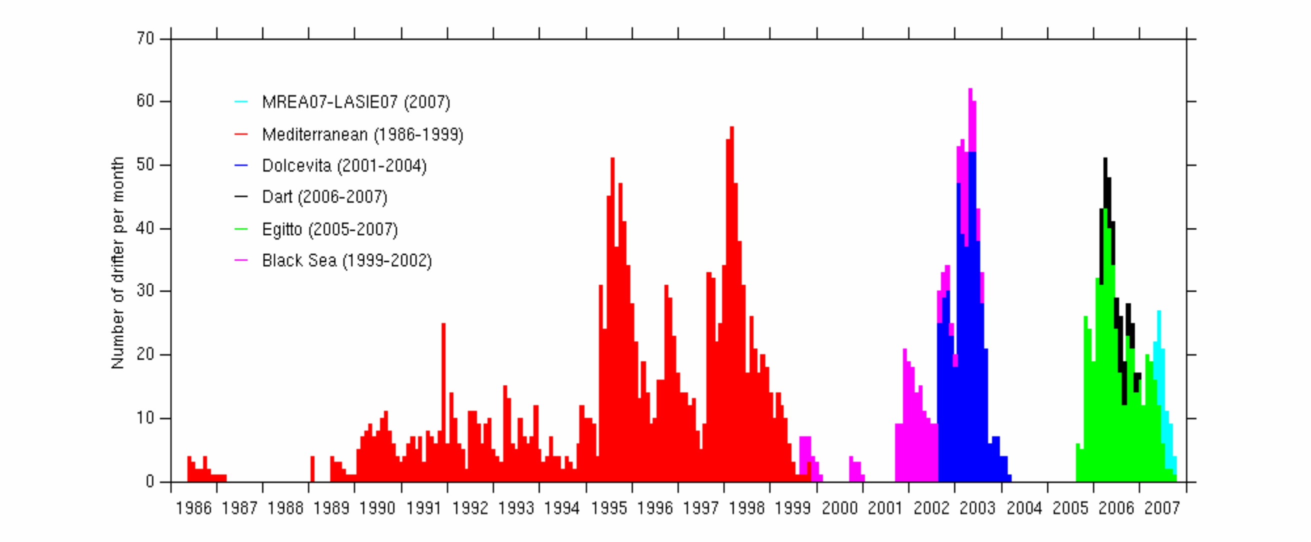

Figure 12. Histogram showing the number of active drifters per month / per project.

3.1. Ongoing projects

EGITTO – (September 2005 – Now)

The project was carried out with the objective of observing the surface circulation in the eastern basin of the Mediterranean Sea with a second goal of confirming previous results and studies found in bibliography which were based on in-situ observations, remote sensing data and models.

Environmental data were obtained from 106 satellite tracked drifters, satellite observations (e.g. SST, near -surface chlorophyll pigment concentration, sea surface dynamic topography), XBTs and Argo profilers (refer to Solari, (2008) for further information on Argo floats). The surface drifters were all SVP (ClearSat-III Custom Mini-Drogue) manufactured by Clearwater Instrumentation.

The project was carried out in collaboration with French oceanographers from (LOB – Laboratoires d'Océanographie et the Biogéochimie), Egyptian scientists from the National Institute of Oceanography and Fisheries (NIOF) and the Alexandria University Oceanography Department (AUDO) and local Tunisian (INSTM - Institut National des Sciences et Technologies de la Mer). Drifters were released across the Sicily Channel on a seasonal basis and in the southern part of the Levantine sub-basin between 20°E and 30°E during specific experiments (see e.g. EGITTO1 cruise on R/V OGS Explora; Poulain et al., 2006). The main OGS sponsor was the ONR (Office of Naval Research).

Further details can be found in the project's and database web site:

http://doga.ogs.trieste.it/sire/drifter/egitto_main.html

http://doga.ogs.trieste.it/doga/sire/egitto/database_egitto/.

3.2 Past projects

MREA 07 - LASIE 07 (May 2007 – June 2007)

OGS has participated to the MREA07 (Marine Rapid Environmental Assessment) experiments which were carried out in the Ligurian Sea during May-June 2007 in collaboration with other Italian and international institutions and, in particular, with the NATO Undersea Research Centre (NURC).

Eleven surface drifters were deployed to monitor the surface currents in both the open sea and the coastal areas outside the Gulf of La Spezia. All drifters were of the CODE type equipped with GPS receivers. Data were telemetered through the Argos satellite system (for units deployed in open sea) and cellular phone network (GSM/GPRS) for the coastal units. The goal of the project was to investigate dispersion properties at the sea surface.

Further details refer to the following reports: Poulain et al., (2007) and the MREA main web page: http://doga.ogs.trieste.it/sire/glider/mrea07-lasie07.html

DART (March 2006 -January 2007)

The DART (Dynamics of the Adriatic in Real Time) project carried out during winter and summer 2006 in the area close to the Gargano Peninsula allowed to monitor surface currents. All 17 drifters were satellite tracked (14 also with a GPS receiver) and were equipped with SST and optical sensors. They were contributed by NURC and OGS. Sea trials were carried out onboard NRV Alliance.

Most of the deployed drifters were of the CODE type, two of which were CODE-Tz with a thermistor chain with 10 thermistors spanning the water column down to 50 m. Only two were the SVP design with radiometers to measure downwelling irradiance and upwelling radiances at visible wavelengths (SVP-OCM).

The goal of the DART project was to obtain drifter measurements as close as possible (in both space and time) to the other in-situ measurements (ship-based and moored).

The main sponsor was the ONR.

For further details refer to Haza et al., (2007) and the DART main web page http://doga.ogs.trieste.it/sire/drifter/dart_data.html

DOLCEVITA (October 2001-September 2004)

DOLCEVITA (Dynamics of Localized Currents and Eddy Variability in the Adriatic) was an international project focused on the Adriatic Sea.

The main objective of the project was to quantify the kinematic and dynamic properties of the northern and middle Adriatic (NMA) Sea. Data were provided by several models of drifters (e.g. CODE, CODE-Tz, WOCE-SVP, SVP/OCM, MINIMET-WOTAN, and CMOD–XAN3 drifters), high-frequency coastal radars and ship-based instruments (towed vehicle, hydrographic, optical and turbulence measurements).

Most drifters were released between September 2002 and November 2003 during oceanographic surveys onboard NRV Alliance, R/V Knor and R/V Hidra, while others were released from ship-of-opportunity (ferry boats or the R/V OGS Explora when transiting through the same areas).

ONR and NURC sponsored the project which involved several oceanographers of the United States and Europe.

For further details refer to Lee et al., (2005), Mauri et al., (2007), Ursella et al., (2004), Poulain et al., (2003), Poulain and Barbanti (2003) and the DOLCEVITA main web page: http://doga.ogs.trieste.it/doga/sire/dolcevita/

BLACK SEA (September 1999 – August 2003)

During this project, organized to study the surface circulation of the Black Sea, 54 satellite-tracked surface drifters were released during oceanographic surveys (onboard R/V Akvanavt) and ships of opportunity connecting Sevastopol (Ukraine) to the Bosphorus.

The deployed buoys were of different kinds, including SVP, SVP-B and CMOD (XAN-3) drifters. Temperature data (surface and at depth by means of chains of thermistors) and atmospheric pressure (with SVP-B) were measured by the drifters. All drifters were tracked by, and transmitted data to, the Argos system.

The project partners were: Marlin-Yug Ltd (Ukraine), IO-RAS (P.P. Shirshov Institute of Oceanology – Russia), MHI (Marine Hydrophysical Institue - Ukraine), Naval Oceanographic Office and the OGS.

For further details refer to Barbanti and Poulain, 2004 and the Black Sea main web page: http://doga.ogs.trieste.it/doga/sire/database_blacksea/

TYRRHENIAN SEA (December 2001 – August 2003)

72 satellite tracked CODE drifters (4 with also a GPS antenna) were released in the Tyrrhenian Sea with ships of opportunity connecting Naples to Palermo, Naples to Cagliari and Civitavecchia to Bocca di Bonifacio in the island of Sardinia.

The main goal of the study was to characterize the mean surface circulation of the Tyrrhenian Sea.

The project partners were Parthenope - University of Naples (Italy), NURC (Italy) and OGS.

Further details can be found in Menna (2003) and the Tyrrhenian sea e-database:

http://doga.ogs.trieste.it/sire/drifter/database_tirreno/index.html

MEDITERANNEAN SEA (June 1986 – November 1999)

The Mediterranean Project collects data acquired by several projects. In total, more than 500 satellite tracked drifters were deployed in the Mediterranean Sea in order to deepen the knowledge of the general surface circulation patterns. They were of different types: the CODE drifter, WOCE-SVP and GDP-MINIMET, TRISTAR drifter.

The Argos data telemetry system provided the positioning and transmission system for all acquired data.

The project was mainly sponsored by the ONR while the operating partners were the OGS, NURC, Naval Oceanographic Office (USA), CSIC (Consejo Superior de Investigaciones Cientificas - Spain), ENEA (Ente per le Nuove tecnologie, l'Energia e l'Ambiente - Italy), Telespazio (Italy), CNRS (Centre National de la Recherche Scientifique - France) and the Pathenope University of Naples (Italy).

For further details refer to P.-M. Poulain et al., (2004) and the Mediterranean main web page: http://doga.ogs.trieste.it/drifter/database_med/

4. Drifter data analysis

All the raw data acquired by the drifters undergo several steps before they are ready to be handled and analyzed. Each of these steps is carried out automatically by running specific programs or manually by the operator. The overall primary datasets consist of the following variables: time series of the drifters geographical position (through Argos or GPS) and sea surface temperature measurements. Additionally battery level, drogue presence indicator (where applicable) and temperature data are part of the transmitted data. Additionally other parameters collected by the different sensors can be transmitted (e.g. optical sensors).

As soon as the drifter is turned on, a satellite-drifter connection is established. Every 90 seconds the transmitter hosted in the drifter starts sending to any orbiting satellite equipped with the Argos system, all the acquired information.

Before the drifter is thrown in the water, date, time, geographical coordinates of the deployment point are recorded. This information will allow to clearly determine the starting point of the trajectory.

When possible, drifters are turned well before the expected deployment time, in order to check, before launch, their overall performance. It is also an opportunity to verify the good functioning of the transmitter.

4.1 Near Real Time processing

The first processing steps carried out on the acquired data are automatic and in near real-time. At OGS, a cron job is run at 4am local time of each day to retrieve and elaborate the received files.

4.1.1. Retrieval of satellite data – incoming files

As written in section 2 (Argos telemetry), all the acquired data are sent from the Argos processing station to the user; these are automatically saved in an incoming file.

The incoming file contains the data acquired by all the active instruments operating within specific projects of interest (set by the center who request data). In particular, the OGS receives data for all drifters that are operating within a specific project (e.g. the projects described earlier).

Immediately, after the incoming file is read, the data are sorted by drifter and appended in individual files specific to each drifter, named *bfiles*, in the main data directory, found at the fpllowing path: */home_sire/drifter/data* (Figure. 13).

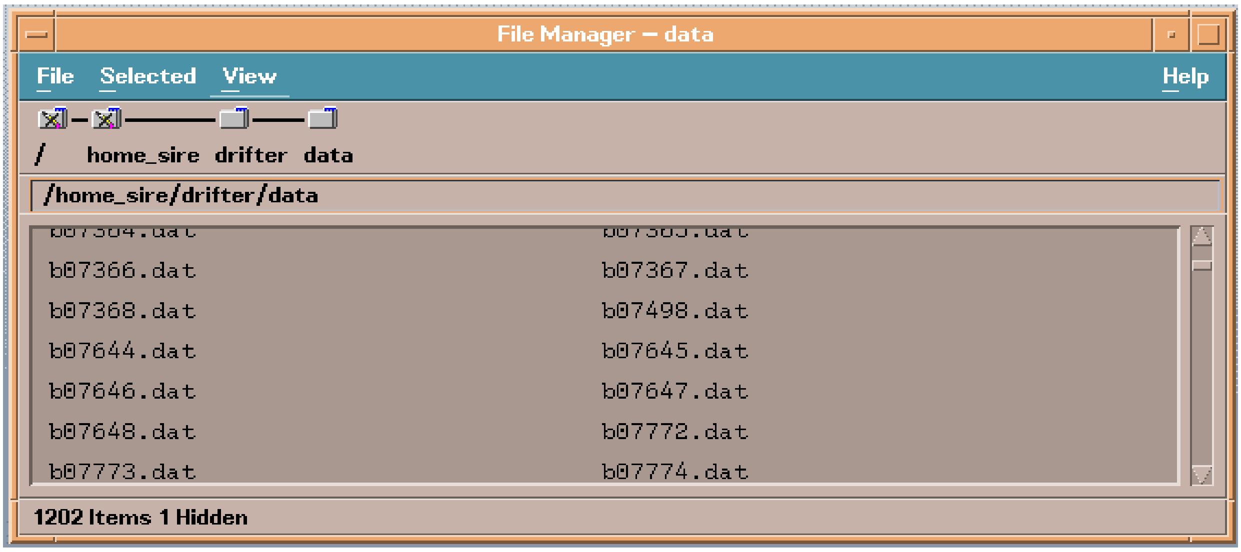

Figure 13. Under the main data directory, individual drifter *.dat files – named *bfiles* - are found. These are updated automatically on a daily basis, as soon as the data are downloaded from the Argos Processing Center.

4.1.2. bfiles.dat

The names of each drifter-specific file have a common structure: all start with the 'b' character, followed by the drifter PTT (Platform Terminal Transmitter) ID number.

Every time the incoming file is received and processed, new data are appended in the respective file. Three portions of different *bfiles* are listed below. A color code highlights the common parts. It must be noted that each *bfile*, contains the whole history of transmissions – sometimes keeping record of software/communication tests prior to deployment (see Figure 15, yellow colored track).

Being in ASCII format each **.dat* file can be viewed with any word editor.

1. Example of CODE drifter raw data:

```
01559 33202    4   4 L 1 2002-02-24 23:45:53  39.694   15.532   0.000 401652622
      2002-02-24 23:42:13  1          00          244           120           00
      2002-02-24 23:43:41  1          00          244           112           00
      2002-02-24 23:45:09  1          00          244           112           00
01559 33202    3   4 K
      2002-02-25 16:51:34  1          00          244           114          128
```

```
      2002-02-25 16:57:26  1         00          244         114         192
01559 33202   3  4 K 3 2002-02-25 18:36:26  39.686   15.527  0.000 401652620
      2002-02-25 18:31:18  1         00          244         113         192
      2002-02-25 18:34:14  1         00          244         113         192
```

2. Example of SVP-decimal drifter raw data:

```
01627 59748   3 31 K 2 2005-06-21 22:13:34  42.368  288.803  0.000 401637862
      2005-06-21 22:10:30  4         13          254         208
      2005-06-21 22:18:10  5         15          254         212
01627 59748   2 31 D
      2005-06-21 22:59:34  1         15          254         217
01627 59748   3 31 J
      2005-06-21 23:13:22  1         15          254         216
      2005-06-21 23:16:26  3         15          254         216
01627 59748   4 31 K 3 2005-06-21 23:52:28  42.367  288.804  0.000 401637785
      2005-06-21 23:54:46  5         15          254         211
      2005-06-21 23:56:18  1         15          254         205
      2005-06-22 00:11:38  1         16          254         196
```

3. Example of SVP-hexadecimal drifter raw data:

```
01627 76806   3 31 L 3 2007-07-31 19:51:44  42.369  288.802  0.000 401639905
      2007-07-31 19:48:40  2         FF          FE          A2
      2007-07-31 19:56:20  4         11          FE          B0
01627 76806   3 31 K 3 2007-07-31 20:21:38  42.367  288.800  0.000 401639904
      2007-07-31 20:19:20  2         11          FE          B9
      2007-07-31 20:25:28  4         11          FE          BD
01627 76806   3 31 D
      2007-07-31 21:03:48  1         13          FE          C5
      2007-07-31 21:05:20  1         13          FE          CA
```

Red	Argos program number
Blue	PTT (Platform Terminal Transmitter) ID – Drifter ID
Green	Number of lines per satellite transmission
Capital letter	Satellite ID letter
Purple	Probabilistic quality index - location class
Pink	Decompression index
Orange	Latitude and longitude of drifter
Brown	Drifter's transmitter emission frequency

Figure 14. Common parts of the messages contained in a *bfile*.

Argos specifies the accuracy of position fixes depending on a location class classified according to the estimated positioning error, and the number of messages received during the satellite pass – roughly: class zero (>1000 meters error), class one (350-1000 meters error), class two (150-350 meter error) and class three (less than 150 meter error). The satellite ID letter depends on the orbiting satellite which received the data : A=METOP, C=NOAA-7, E=NOAA-8, F=NOAA-9, G=NOAA-10, H=NOAA-11, D=NOAA-12, I=NOAA-13, J=NOAA-14, K=NOAA-15, L=NOAA-16, M=NOAA-17, N=NOAA-18.

Refer to the Argos user manual for further details.

The total number of lines per satellite transmission is a checksum and is used to validate the integrity of the Argos message.

The bold line –named header or leading line - corresponds to the information collected by the satellite at each pass every time the connection with the drifter is established. The following shorter lines (‘sensor lines’) contain the data acquired by the instruments: the time and all the recorded values (battery level, SST, drogue presence if applicable or other sensors). Both ‘leading lines’ and ‘sensor lines’ contain information on date and time, the first related to the drifters position, the second to the sensor measurements. The sensor recordings may be in decimal or hexadecimal format (compare example 2 and example 3).

For cross reference and to validate the integrity of an Argos message, the leading line contains a checksum of the number of total transmitted lines (‘sensor lines’) plus one. It must be noted that sometimes there is not correspondence with the real number of lines and it often happens that leading lines are truncated, as a result a position reading is not available (as it can be seen in all three examples).

4.1.3. RG_medsvp_dat2mat.m

The MatLab script automatically executed daily – *RG_dat2mat.m* - converts the raw data written in each *bfile* to the corresponding engineering units, this by using the information found in the Drifter_info.txt document (see below); mainly: the drifter type and output data format (e.g SVP, with hexadecimal output) and the date and position of deployment.

This phase is crucial, as the data that will undergo the following editing and interpolation procedures depend on this last automatically executed step.

All measurement previous to deployment are removed, the script creates a MatLab binary file and each Argos message is reduced to a single value per variable: at each satellite pass that provides a buoy location (Argos or GPS positioning) several transmissions of the hosted sensors are recorded. For each of these groups of transmissions the median value is calculated and associated to the corresponding location, if available, otherwise replaced by NaN. By opening one of the *bfile.mat* document (contained in the *bfiles_mat* directory) the following variables are found, where **n** is the total number of received messages.

Variable name	Dimension	Definition
project	1x5 (char)	project ID number
id_argos	1x6 (char)	drifter PTT ID
class	1x**n** (double)	satellite location class
drogue_presence	1x**n** (double)	measurement of the drogue presence sensor
frequency	1x**n** (double)	frequency of the drifter's transmission
lat_argos	1x**n** (double)	inferred drifters latitude
lon_argos	1x**n** (double)	inferred drifter longitude
num_mess	1x**n** (double)	number of transmitted messages
satellite	1x**n** (double)	satellite ID number
sst	1x**n** (double)	sea surface temperature measurement
time_argos	1x**n** (double)	position date and time (GMT)
time_sensor	1x**n** (double)	sensor's date and time (GMT)
volt	1x**n** (double)	battery level

The following lists the information selected from Drifter_info.txt.

Variable	Dimension	Definition
instit	1x5 (char)	name of institute that deployed the drifter
deploy_lat	1x1 (double)	latitude of deployment
deploy_lon	1x1 (double)	longitude of deployment
deploy_time	1x1 (double)	date and time of deployment (GMT)
last_time_sensor	1x1 (double)	last recorded sensors' date and time
recovery_time	1x1 (double)	date and time of drifter recovery
drifter_type	1x3 (double)	Model of the drifter
wmo	1x3 (double)	World Meteorological Organization Identification Number

RG_medsvp_Dat2mat.m in steps

Briefly the script does the following:

1. Reads the data from Drifter_info.txt
2. Calls a different converter-script, according to the drifter type and output format, which:
    a. Replaces missing Argos locations with NaN
    b. Converts measured variables to their corresponding engineering units
3. Decompresses sensor data by using the given decompression index, and shifts repeated records back in time by successive 90 second increments.

4. Calculates the median of sensor values obtained after decompression.
5. Saves the newly converted and organized data into individual **.mat* files, one for each drifter in the *bfiles_mat* folder

All dates are converted to MatLab time, where day 1 corresponds to 01-Jan-0000, and the deployment date and position are added manually as first record with a location class equal to NaN.

The letter with which the file name starts, is taken from the Drifter_info.txt document, and depends on the drifter deployment history: 'a'=first deployment, 'b'= second, 'c'= third, etc; follows the drifter ID number. Every time a new drifter is added to the database, or a drifter starts a new deployment (see section on splitting trajectories) then a different file is created for that same drifter, and its content updated until the instrument provides data or it becomes stranded. For this reason, more *bfile_mat* file may correspond to the same drifter ID.

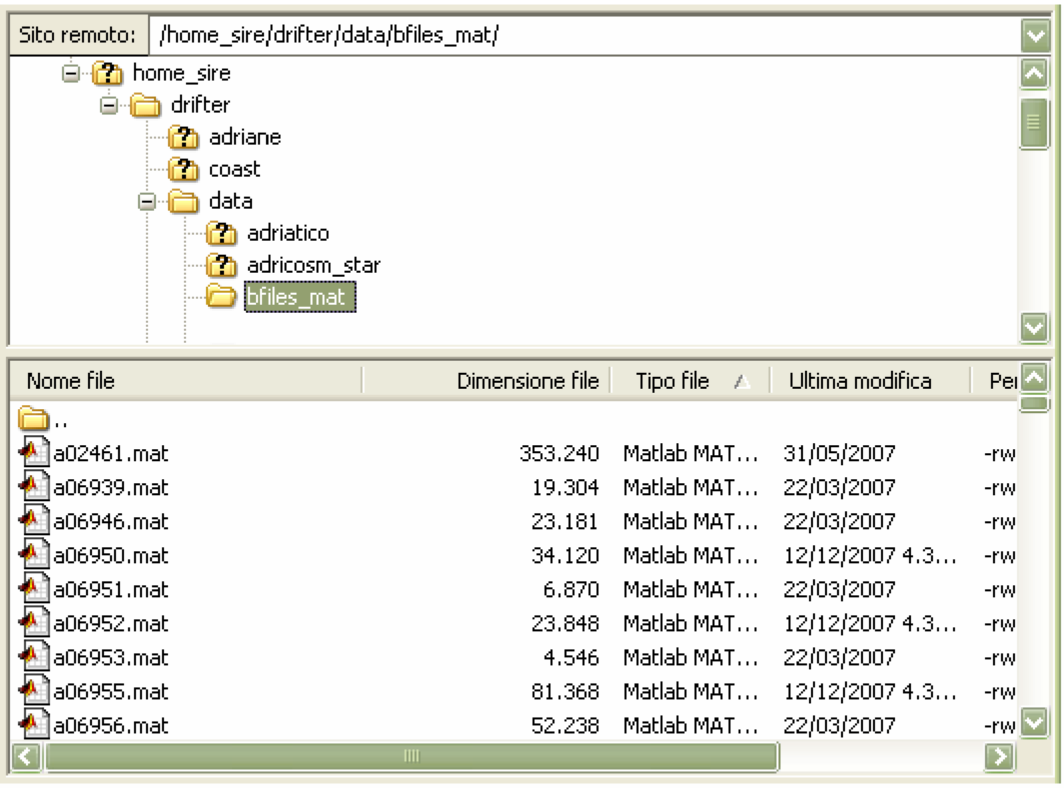

Figure 15. *bfile_mat* folder. The starting letter depends on the drifter's deployment history. Each file is drifter specific, and contains only data consecutive to deployment.

Drifter_info.txt

This document, is a hand written text file, located un der the main data folder. The following records are here annotated:

- **Prog :** Project number
- **Instit:** Name of Institute which has deployed the drifter
- **WMO** World Meteorological Organization Identification Number
- **Argos**: *bfile* name of the drifter (b#####)
- **Type** Drifter type
- **Exa:** Drifter output format (1=exa, 0=decimal)
- **Deploy Date**: Date and time of deployment (GMT)
- **Lat:** Latitude of deployment
- **Lon:** Longitude of deployment
- **Recovery Date:** Date and time of recovery (GMT)
- **SaveAs:** Letter representing the order of deployment

Prog	*Instit*	*WMO*	*Argos*	*Type*	*Exa*	*Deploy date*	*Lat*	*Long*	*Recovery date*	*SaveAs*
01627	OGS	61842	b59743	SVP	0	27-May-2006 12:39	37.867	12.067	NaN	a
01627	LOB	61867	b57321	SVP	1	23-Feb-2008 18:34	33.336	23.829	NaN	d

Table I. Example of Drifter_info.txt content. Drifter 59743 is an SVP. It is in use for the first time (saveAs='a') and has been launched in May 2007, off the city of Trapani - Sicily. As it is one of the drifters in the list, it is still transmitting. Drifter 57321 is carrying out its fourth mission or trajectory (SaveAs 'd').

Splitting trajectories

When a drifter is stranded, picked up by a boater or recovered, the trajectory is splitted, and considered separately. This is done manually by plotting the trajectory of the drifter (Figure 15 and 16) and visually locating potential splitting points. Often, these 'artificial' trajectories are supported by anomalies in temperature recordings.

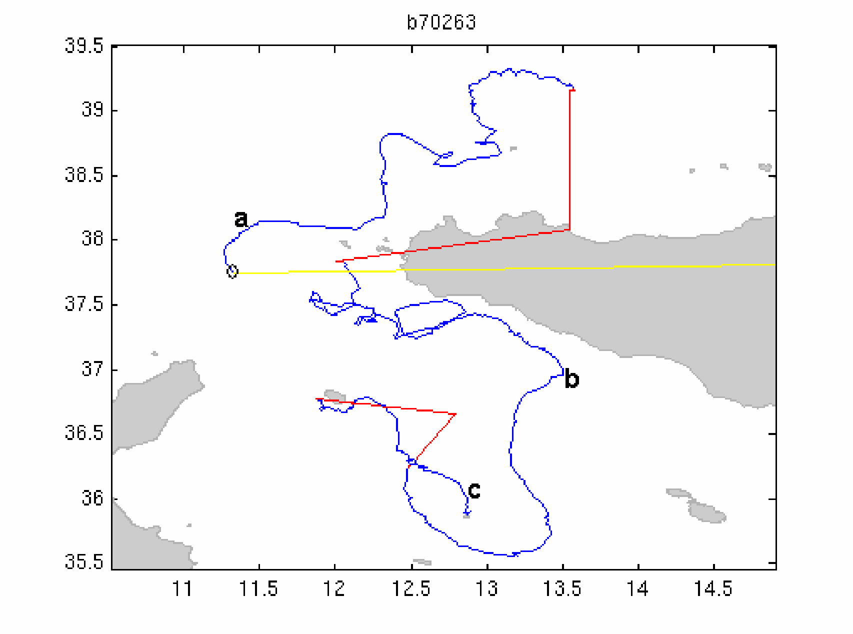

Figure 16. Overall trajectory of drifter 70263 as in **.dat* (raw data). Red lines show 'artificial' displacements. They are easily recognized, as they are long straight lines. In yellow, the space covered by the drifter from the place of manufacturing to the place of deployment. It must be noted that this portion of the total trajectory is automatically removed by comparing all the available data with the date of deployment written in Drifter_info.txt. A small black circle denotes the first drifter deployment, on the 27 Jan 2007, within the EGYPT project (http://doga.ogs.trieste.it/sire/drifter/egitto_data.html).

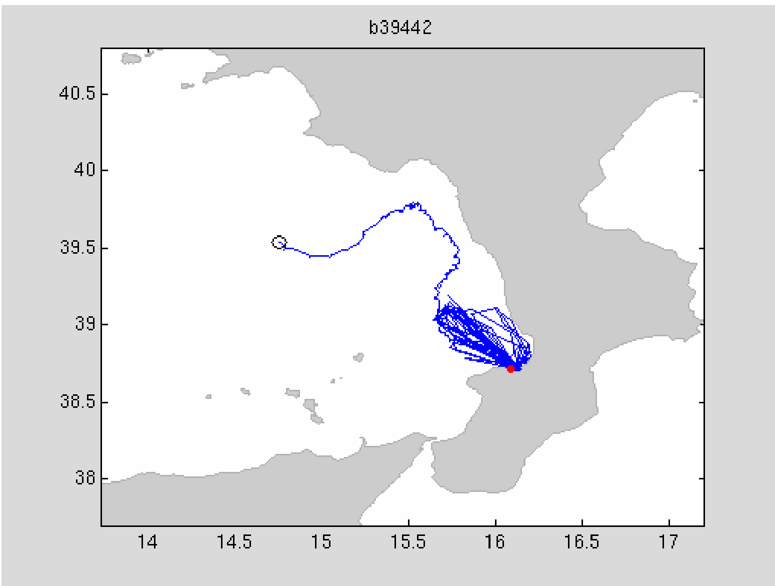

Figure 17. Overall trajectory of drifter 39442 as in **.dat* (raw data). The fountain looking trajectory, starting in the Gulf of Sant'Eufemia, approximately where the red dot is drawn, is a typical 'virtual' trajectory of a grounded drifter. It is quite easily recognized, as it often has a fountain or star-like shape. A small black circle denotes the drifter deployment position the 09 Sept 2003, within the Tyrrhenian Sea project (site under construction).

Once the splitting point/s have been decided, the Drifter_info.txt document is updated by inserting the following 'SaveAs' letter, a new deployment date and first position. Its status (dead or stranded depending on the case), last transmission date and last geographical coordinates are written in another document which is used when the main Drifter Web Page is updated. This procedure, if necessary, is repeated only every time the trajectory of the drifter is not consistent with the expected drifting behavior.

Finally, the 'old' drifter is automatically removed from the list and replaced by the 'new' one where the ID number is the same, but the letter is the following one. From here on, all data will be stored in a new *bfile_mat* file.

Finally, the 'old' drifter is automatically removed from the list and replaced by the 'new' one where the ID number is the same, but the letter is the following one. From here on, all data will be stored in a new *bfile_mat* file.

These first steps described first steps are carried out every-day in near real time, together with the scripts that refresh the main drifter web-page (http://poseidon.ogs.trieste.it/sire/medsvp/). The *bfile.mat* files are a common starting point of the database and main drifter webpage updating.

4.2. Updating the Main drifter Webpage - MedSVP

Every day, after the first steps described above are accomplished, other MatLab scripts are run automatically on the files contained in the *bfiles_mat* folder, in order to update the main MedSVP web page.

MedSVP is responsible for the coordination of surface drifter operations at the Mediterranean level. This includes the coordination of drifter deployments in the Mediterranean Sea, the processing of the drifter data, and the preparation and distribution of drifter products and services. MedSVP is part of the Italian GNOO (Gruppo Nazionale di Oceanografia Operativa) and of the MOON (Mediterranean Operational Oceanography Network). The main page may be reached at the following link:

http://doga.ogs.trieste.it/sire/medsvp/index.html

The following scripts are run only on the drifters listed in the previously described Drifter_info.txt document:

RG_medsvp_plot_head.m: retrieves information on the drifters status (active, dead and type of death) and on the date of last transmission. The dot corresponding to the most recent recorded coordinates can be a filled in black or just a circle. In the second case it corresponds to a less recent position (younger than five days).

RG_medsvp_plot_trajectories.m: plots all the accomplished trajectories, the ones of the active drifters (that have transmitted in the past five days) and the up-to-date position of the active drifters with their most recent trajectories (last 5 days). The following link redirects to the web page where these trajectories can be seen:

http://doga.ogs.trieste.it/sire/medsvp/trajectories.html)

RG_medsvp_table_all.m: here all drifters are listed - since their first deployments - with their deployment and recovery dates/position. Each drifter is associated to a differently colored dot, according to its status (red=dead, green=alive, black=stranded, yellow=working without position). By clicking on the drifter ID number it is possible to view the individual drifter trajectories (color coded with SST), the measured temperature, the status of the drogue, the battery level and the plot of latitude vs. time, and longitude vs. time.

The following link redirects to the table with all the drifters:

http://doga.ogs.trieste.it/sire/medsvp/table_all.html

RG_medsvp_table_active.m: creates a table where the status information for each active drifter (in the last five days) is written. Stranded drifters are not included: the script in fact removes from the table all drifters that have been manually listed in a separate document (drifters_stranded.txt). The following link redirects to the here described table:

http://doga.ogs.trieste.it/sire/medsvp/table_active.html)

RG_medsvp_plot_individual_trajectories.m creates the individual plots which can be accessed from the master table. The following link, for example, redirects to the information gathered by drifter 76802 (during its first mission):

http://doga.ogs.trieste.it/sire/medsvp/traiettorie/a76802.html

RG_medsvp_month_plot.m: This script is run manually in order to summarize the covered trajectories per month. The following link redirects to the monthly maps page:

http://doga.ogs.trieste.it/sire/medsvp/monthly_maps.html)

It must be noted that in the plotted trajectories only the most obvious position spikes have been removed.

4.3. Delayed mode processing: updating the drifter database

About once every three months, the database collecting all the data retrieved by the deployed drifters is updated. The procedure is carried out manually, by running in chronological order, specific MatLab scripts. The output are the edited and kriged data which are available on each project individual web page.

4.3.1. Mat2raw: bfiles_mat to the 'raw' folder

This first step, carried out to update the Database, uses the *RG_mat2raw.m* script, which creates a text file, with the **.arg* extension. This newly organized data, contains only certain variables of interest. This information is stored in a folder named raw_mmm_yyyy – as it can be seen in Figure 15.

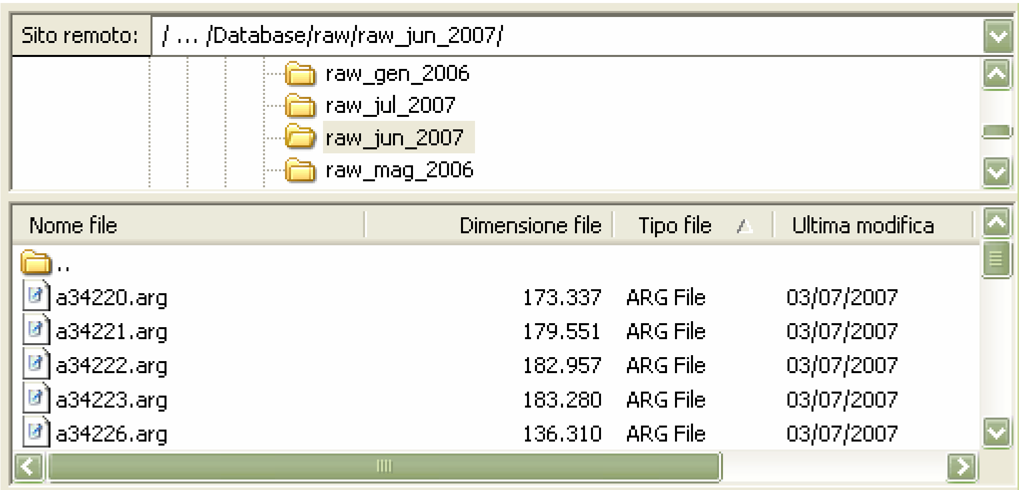

Figure 18. RAW folder. Every time the database is updated, a new subfolder is created, which contains all the drifter files that will be edited. Each file is written in a ASCII format.

Once the procedure is completed, each **.arg* file contains the following variables is sequential order:

- Time_argos Position date and time (MatLab time)
- Lat_argos Latitute inferred by Argos
- Lon_argos Longitude inferred by Argos
- Class Location class
- Satellite Satellite ID number
- Time_sensor Date and time as recorded by the drifter (serial)
- Num_mess Number of retrieved messages
- Drogue_presence: Binary number: 1 for present, 0 if lost
- Volt Battery level of drifter

- SST Sea surface temperature

Everytime the database is updated, a new raw_mmm_yyyy folder is created.

The newly created *.*arg* file is in ASCII format and can be viewed with any text editor (see Figure 19). It has the following format. Each value (organized per columns) corresponds to the variables listed above. Each argos message is now concentrated to a single line for each transmission.

```
733498.150000 37.161000 11.193000 NaN NaN 733498.150000 NaN NaN NaN NaN
733498.150035 37.155000 11.214000 3 11 733498.151030 4 1.000000 12.600000 15.250000
NaN NaN NaN NaN 12 733498.175451 6 1.000000 12.600000 15.250000
733498.220313 37.171000 11.221000 2 11 733498.220266 6 1.000000 12.600000 15.250000
NaN NaN NaN NaN 12 733498.243218 3 1.000000 12.600000 15.250000
NaN NaN NaN NaN 11 733498.287037 1 1.000000 12.600000 15.250000
733498.367500 37.196000 11.291000 1 13 733498.368993 4 1.000000 12.600000 15.250000
NaN NaN NaN NaN 1 733498.397535 2 1.000000 12.600000 15.250000
```

Figure 19. Example of data in a *.*arg* file for drifter a76803

4.3.2. Editing

Raw values that violate applied editing criteria are edited out from the data series. Spikes are removed automatically by a MatLab script (*RG_mainedit.m*) by comparing, for every couple of successive points (x_i, x_{i+1}), the drifter total displacement and velocity (calculated from the ratio of covered distance over discrete times), bearing angle and measured temperature gradient to the following threshold values:

a. Maximum speed allowed between consecutive points : 50 cm/sec
b. Maximum angle allowed between consecutive displacement vectors: 180°+-45° (see Figure 20)
c. Maximum position gradient: 0.05° per hour (~ 150 cm/sec)

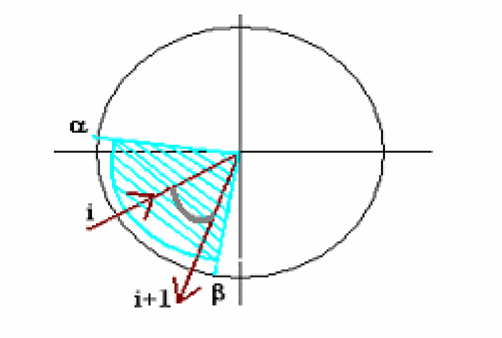

Figure 20. If the first direction of drifter motion is **i**, then the consecutive point **i+1** is accepted only if the difference between the two bearings (in grey) falls outside the shaded area, where the limits are
α= (bearing of **i**)+180°-45°, and **β** = (bearing of **i+1**)+180°-45°.

Once the difference between each couple of values is calculated, x_{i+1} is removed if conditions a,b,c occur at the same time. First and last values are considered good.

RG_mainedit.m in steps

The script executes (on each **.arg* file) the following steps:

1. All good positions (corresponding to positive time values) are kept and drogue (if applicable) and battery level (volts) values corresponding to a temperature value equal to 99.99 (associated to the position of deployment) are replaced with NaN.
2. For position coordinates (refer to Figures 21 and 22 to view generated plots):
    a. Plots all raw data (long vs. time, lat vs. time, lat vs. long) in red (see Figure 21 and 22).
    b. Calculates distance and time interval between consecutive points.
    c. Removes all points corresponding to consecutive velocities and bearings that are greater than maximum accepted values (see above).
    d. Plots a black triangle around edited out.
    e. Repeats steps b,c,d on obtained values, and plots removed points with a black circle.
    f. Points with displacement greater than 1 km and speed > 200 cm/sec are plotted with green stars and final edited position points with a blue line.
    g. The obtained edited position data series is returned.

After the position vectors are edited, the script processes temperature measurements by using the maximum temperature gradient accepted (4° C deg per 12 hours). After the edited position data series are returned, the script executes the following steps:

3. For temperature recordings (refer to Figures 23 and 24 to see generated plots):
    a. Plots raw points.
    b. Calculates time difference, temperature differences and gradients between successive points.
    c. Computes flags in order to remove temperature spikes, without removing middle point where there are 2 continuous spikes.
    d. Plots edited out points with a black triangle.
    e. A Blackmann running mean is iterated 5 times, removing at each run, values which depart from the maximum values by a decreasing amount (starting with 5), assuming that first and last 10 temperatures are acceptable. Edited out points are pointed out by a shape which changes at each iteration: 1st iteration: blue diamond, 2nd iteration blue circle, 3rd iteration =blue x, 4th iteration = blue +, 5th iteration=blue *.
    f. Steps a and b are repeated to remove further temperature spikes. These are plotted with black squares (Figure 24) and final, edited temperature values are plotted with a blue line.
4. New edited data – previous to the database updating date – are stored in individual files with the *.ed extension, in the edi folder. All edited out points are replaced with the NaN value. Only points with good positions are kept, those with bad position and good temperatures are replaced by NaN.
5. Finally the scripts reports for each edited drifter - in a mainedit.log file- the following statistical values:
    a. Total number of points with good position.
    b. Total number of edited out points for position spikes.
    c. The total number of points with speed greater than 200 cm/sec and displacement greater than 1 km.
    d. Starting number of points with positive or negative temperature values.
    e. Total number of points edited out for temperature spikes).
    f. Total number of points with good position and temperature values.

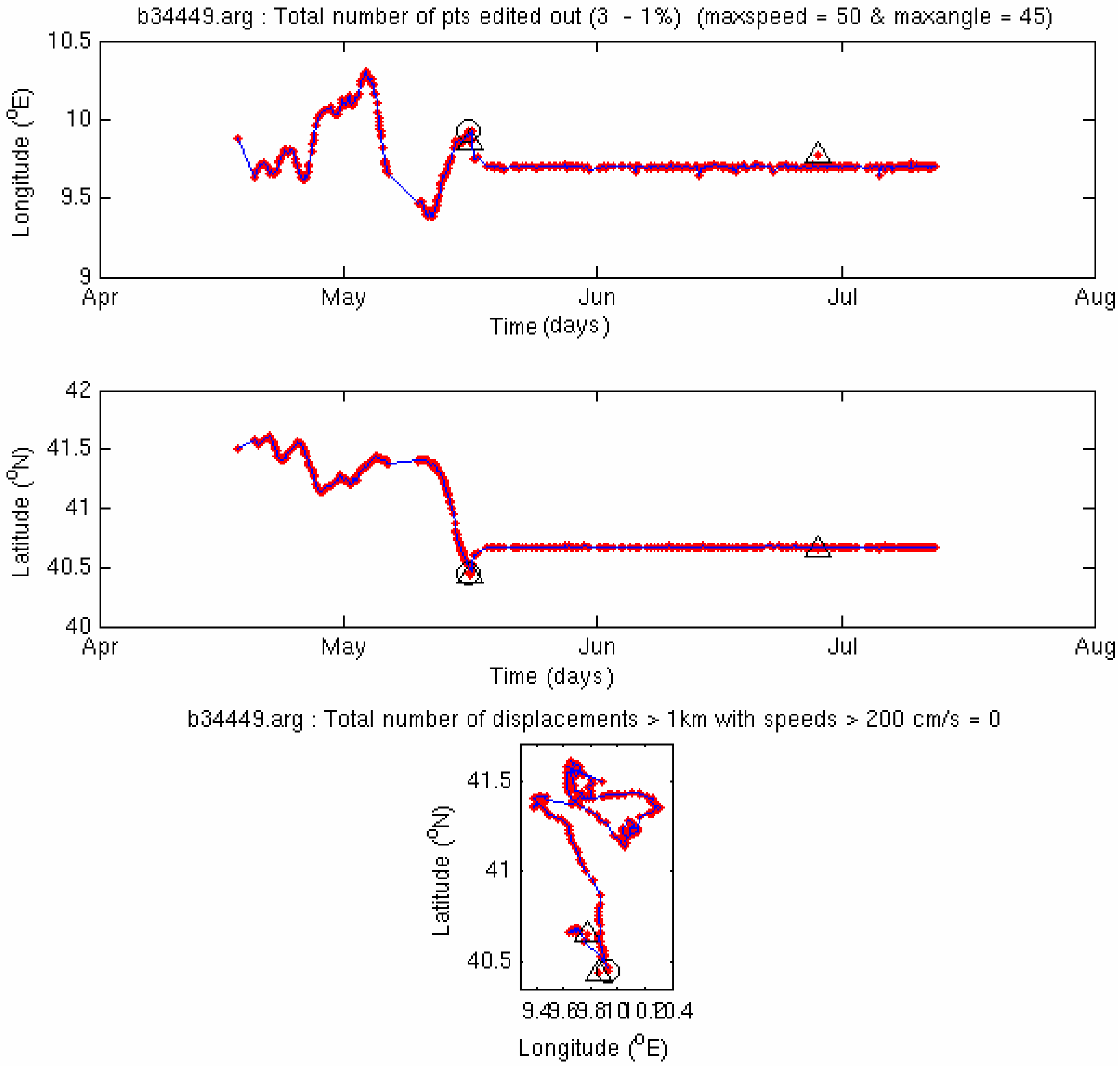

Figure 21. Plot generated from the automatic editing procedure of drifter b34449, deployed in the Tyrrhenian Sea. Red dots correspond to the raw data, black triangles are drawn over position spikes (step 2. c). The black circles are drawn over spikes removed at step 2.e, the final edited positions are drawn with a blue line (step 2.f).

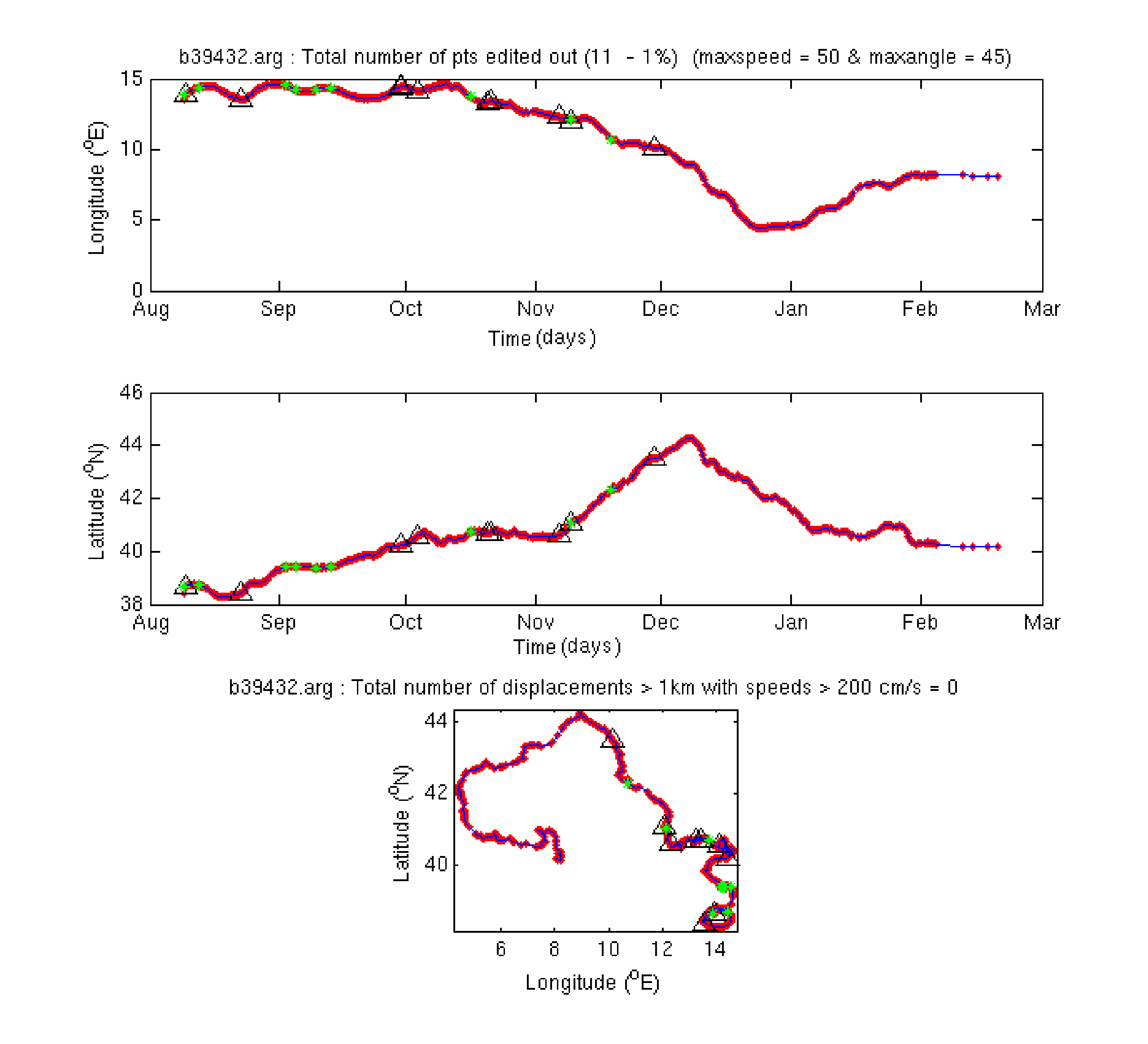

Figure 22. Plot generated from the editing procedure of drifter b39432, deployed in the Tyrrhenian sea (Aug. 2003). Plot from editing procedure. Marker size and shape as previous figure excepts for green asterisks which indicate displacements greater than 1 km with speed over 200 cm/sec (step 2.f).

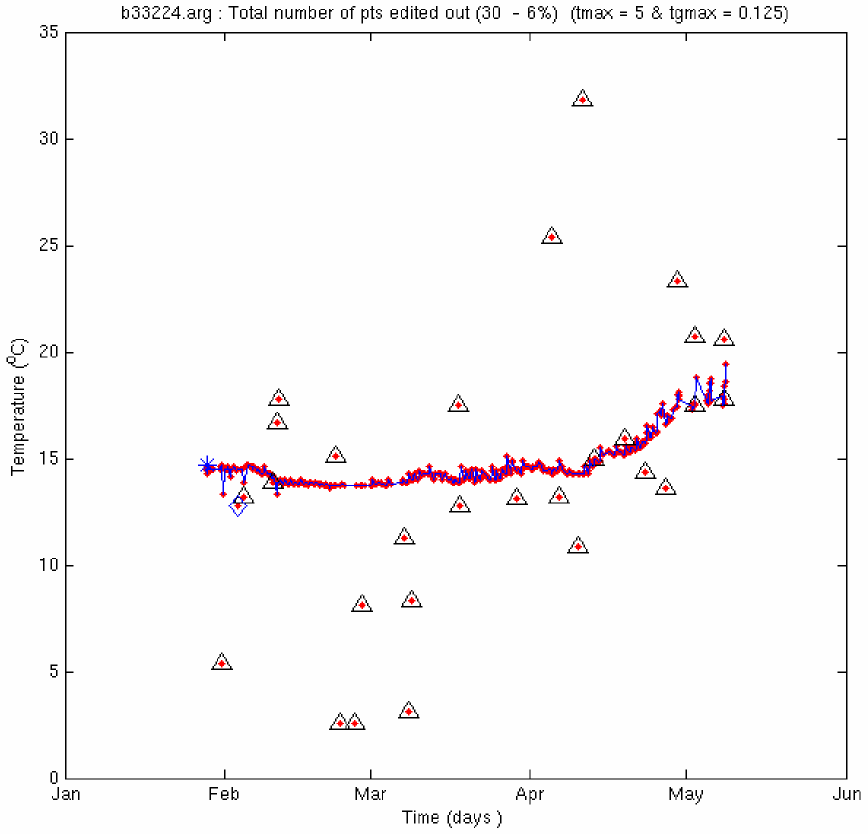

Figure 23. Plot generated from the main editing procedure of the temperature recorded by drifter b33224, deployed in the Tyrrhenian Sea (Jan 2001). Red dots correspond to raw data (step 3.a), black triangles are drawn over temperature spikes (step 3.e). Blue triangles show points edited out after iterating the Blackmann running mean (step 3.f): blue diamonds correspond to the 2nd iteration, blue asterisks to the 5th iteration when temperature values deviate from the Blackmann running mean by 1 unit.

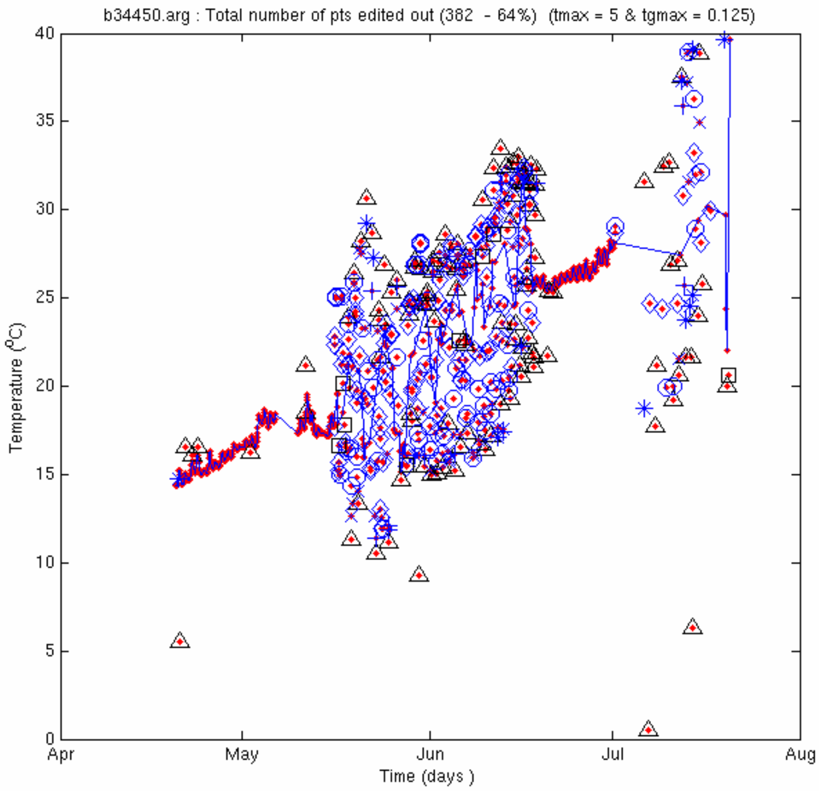

Figure 24. This plot results from an incorrectly split trajectory. In the central part of the graph, it possible to see how points are removed at each iteration. Each different shape depends on the i-th iteration that has removed it.

In addition to the above described automatic editing procedures, obvious remaining position and temperature spikes are removed manually.

Both in the temperature (with *RG_edit_temp_manual.m*) and position (with *RG_edit_pos_manual.m*) manual editing procedure, the user selects points that need to be removed by clicking on them directly with the mouse pointer. The coordinates (or temperature values) of points that need to be edited out are automatically replaced by NaN. Files that have been edited for position have the '*_p.ed' extension, while those edited for temperature have the '*_t.ed' extension (also '*_p_t.ed' is possible.

Once the manual editing procedure is concluded, then the *RG_metti_NaN_su_drogue_e_volt.m* script is run, which replaces with NaN the values of drogue and battery level corresponding to the edited temperature measurements. Figure 24-a, b, c shows the major steps of manual editing. The data considered range between the date of deployment and the database updating date. The deploy_mmm_yyyy.txt file, where deployment and recovery dates and locations are reported, enables to restrict data series to the last day of transmission or recovery, if previous to the database updating date.

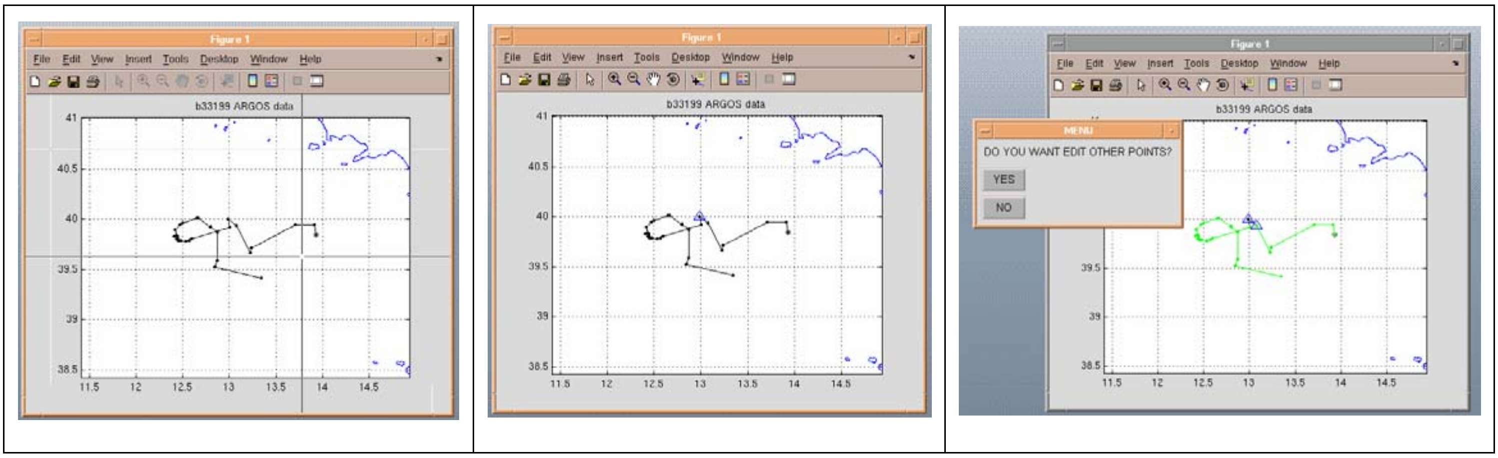

Figure 25. Position can be manually removed by clicking on them with the mouse cursor. The script automatically highlights the selected points with a triangle and the resulting new trajectory in a new color. If the user confirms, the coordinates corresponding to these points are replaced with NaN by the script.

4.3.3. Interpolation of edited data

Once all position and temperature spikes are removed (automatically or manually), the resulting edited data series need to be interpolated. The data available up to here are the best available in terms of both location and temperature, and therefore are most appropriate for uses such as point-wise matchups to satellite SST measurements. However they are irregularly distributed in time, and aren't appropriate for many types of studies such as spectral analysis. The kriging method is use to objectively interpolate the data at uniformly distributed times (fixed time interval). It interpolates each variable independently (as a one dimensional time series).

The most recent versions of the edited files (deriving from the mainedit processing procedure or the manually edited ones if it was necessary) are manually moved into a *finaledited* folder: here the '_p' or '_t' extensions are removed from the filenames (e.g. the filename a34226_p.ed – manually edited for position - is here saved as 'a34226.ed').

The kriging method

The kriging interpolation methodology bases its calculation on a structure function or semi-variogram (constructed from the data series that need to be interpolated using *RG_structure_function.m*) from which an optimal set of weights is determined. These weights are used to interpolate the variable using observations near the interpolation time. The x-axis of the semi-variogram measures distance in time between points, while the y-axis the variance of each single point with respect to the rest.

The advantage and interesting feature of this method, is that each interpolated point is associated to an uncertainty value, represented as a vertical bar drawn through each interpolated point. These error bars identify large gaps across which the data have been interpolated. The shape of the uncertainty bars depends on the calculated weights (which are higher, the closer points are within each other), which is on how far from each other are measured values. Figure 26 shows an example of a long interpolation gap. The interpolated points near the middle are highly uncertain.

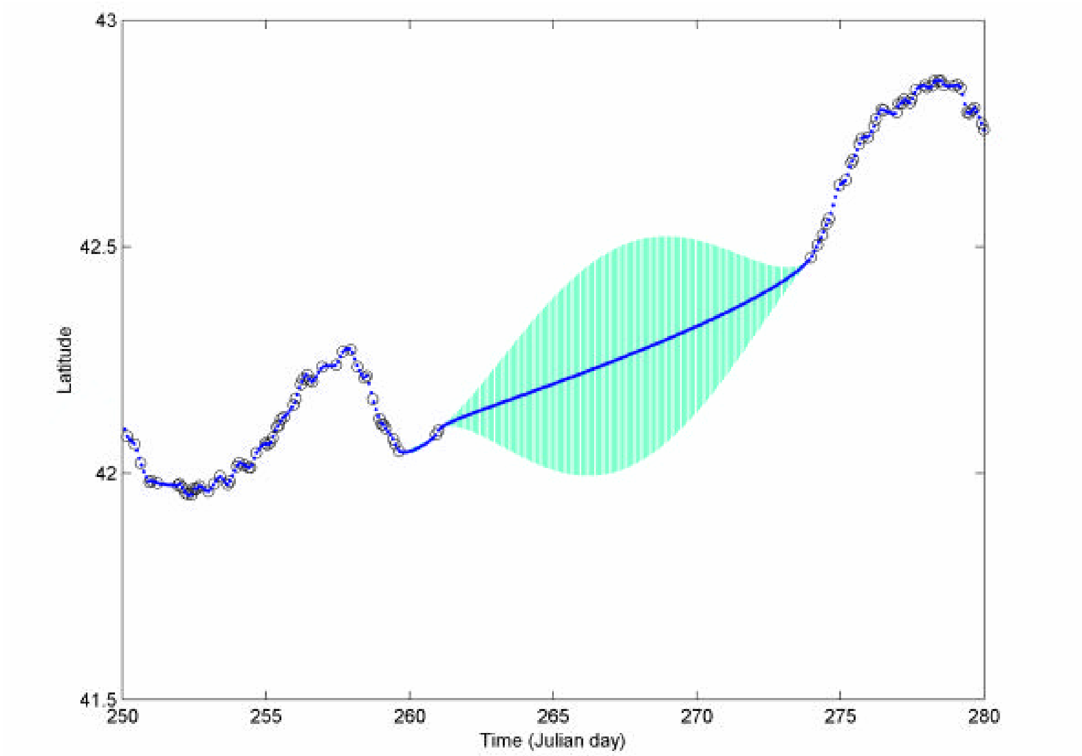

Figure 26. Example of the result of latitude interpolation (in time) over a long temporal gap. Observed measurements are drawn with circles, filtered and interpolated values with dots. Error bars are drawn in green. Drifter 16332 was one of the instruments deployed in the Black Sea. (Figure from Barbanti and Poulain (2004)).

This is one of the reasons why drifter trajectories are split when long gaps occur, in order to reduce the number of interpolated points with large uncertainty. A related advantage of having an estimate of uncertainty (when values are interpolated in space) would be to know from recorded data, where further sampling is needed (Barbanti and Poulain, 2004).

The edited positions and temperature measurements were interpolated by using a specific MatLab script (*RG_mainkri.m*) which calculated values for specific time interval depending on the frequency in time of the observed data (e.g. values retrieved during the Black Sea, Tyrrhenian and Mediterranean Sea projects were kriged every 2 hours, those for the Adriatic and Aegean Sea every 30 minutes). The program was developed keeping into account the following assumptions (Hansen and Poulain, 1996):

- Each observation is the sum of the true value and an error (randomly distributed and unbiased, with a mean value equal to zero).
- Weights ($\mathbf{w_i}$) are calculated in order to minimize the root-mean-square difference between the true value and the concurrent interpolated value; furthermore, the total number of weights must sum to unity so that interpolated values are not biased by the number of available measurements.
- The interpolated values are described by a structure function (**1)** known from prior data or determined from the observations themselves. The empirical values are modeled with **(2)**:

  $$\mathbf{S_{i,i+1} = \frac{1}{2} < (x_i - x_{i+1})^2 > = \frac{1}{2} < [x(t_i) - x(t_{i+1})]^2 >} \qquad \textbf{(1)}$$

  $$\mathbf{S = \alpha \cdot \tau^{\beta}} \qquad \textbf{(2)}$$

  Where $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$ ($1 \le \boldsymbol{\beta} < 2$) are parameters to be determined empirically, $\boldsymbol{\tau}$ is time.

- Interpolated values ($\mathbf{x_0}$) are obtained through a linear combination of a number of observations ($\mathbf{x_i}$) multiplied by the i-th weight:

  $$x_0 = \sum_{i=1}^{n} w_i \cdot x_i \qquad \textbf{(3)}$$

- The number of observations preceding and following the interpolation point is chosen to be equal to 5.

RG_mainkri.m in steps

The *RG_mainkri.m* MatLab script operates only on the files contained in the *finaledited* folder where all spikes have been removed, and interpolation can be carried out. The program briefly does the following:

1. Retrieves data from each drifter file. Sorts each line according to its Argos time and removes all duplicates. Does the same for the sensor's recordings.
2. Corrects values corresponding to drogue presence, so that the column vector contains 1 if the drogue is present, 0 if it was lost.

3. If the value corresponding to drogue presence is 0, then retrieves the date at which the drogue was lost. This new date is written in the dati_deploy_mmm_yyyy.txt document otherwise a NaN value is written in its place.
4. Defines two hour intervals in the data set
5. Calculates the structure function for the specific area (with defined values of α, β, and the mean square error – mse - which corresponds to 172 m for latitude measurements, and 277 m for longitude).
6. Calculates and returns the latitude and longitude of the new interpolated values (and the corresponding error). Interpolation is carried out by using 5 neighboring values before and after the point to be interpolated.
7. Repeats steps 4-6 for temperature values and its corresponding battery level and drogue presence.
8. Following interpolation, the zonal and meridional components of the velocity are calculated by using forward bearing values.
9. The new data are then low-pass filtered with Hamming working on eight neighboring values of each point (preceding and following). This step is repeated twice.
10. Each variable (position, temperature, drogue presence and battery level) is sub-sampled every six hours. This is done by creating uniformly distributed time intervals starting from the interpolated values.
11. Creates a new file with the **.kri* extension for the interpolated+filtered+subsampled values, and for each drifter places a file in the *dati_kri_2h_e_kri_int_6h* (e.g. kriged every 2hrs and interpolated every 6) and *Dati_kri_6h* (kriged every 6 hours) where outputs from intermediate steps are stored.

Figure 27 shows the data series resulting from each of the described steps. In black the edited data (resulting from the automatic and manual editing procedure), in blue the interpolated values (one dot value every 2 hours) in red are plotted values resulting from the filtered procedure (36 hours) and in green subsampled values every 6 hours.

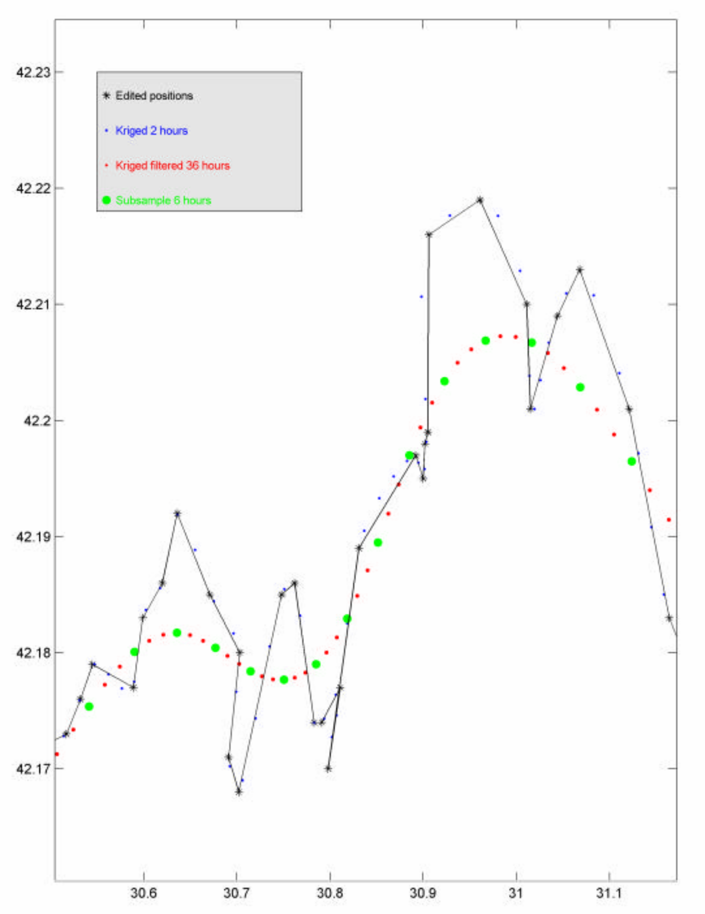

Figure 27. Example of interpolation. Edited values are in drawn in black, interpolated values (here every 2 hours) are in blue while the filtered data (with a 36 hours filter) are in red. Green dots correspond to the final values subsampled at every 6 hour interval (figure from Barbanti et al, 2004).

Figures 28 shows temperature and position plots for drifter a70255: in blue the raw data as in the *bfiles*, in green the edited time series, while in red the final interpolated and filtered data. At every elaboration step, the time series results more and more smoothed out.

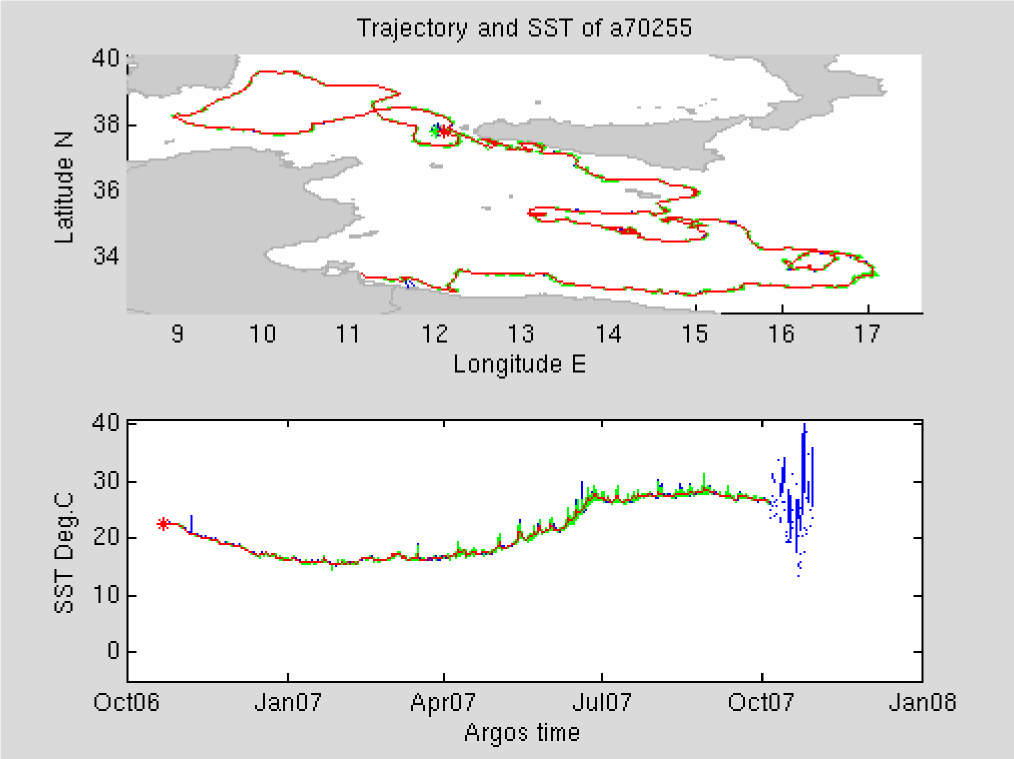

Figure 28. Drifter 70255 was deployed in October 2006 within the EGYPT project. The raw time series is plotted in blue, in the edited data while in red the final kriged data. It is interesting to see that the stranded status of the drifter at the end of its trajectory is supported by anomalous temperature recordings. The latter have been cut before interpolation.

All processed data series (edited and kriged data) are then archived and disseminated on the web, in each individual projects webpage. Data can be retrieved by entering the project specific database page. Data access is possible only after authorized authentication.

5. Conclusions

In the first section, the experimental setup – drifters and the Argos positioning and data telemetry system are presented then the data processing steps necessary to elaborate the drifters trajectories and their environmental measurements have been described.

The overall procedure has been divided in two main parts. The first is the one carried out on daily basis and which is needed to update in near real time the main MedSVP web page where drifter tracks and their temperature recordings are viewable; the same MedSVP web site collects for each project carried out by OGS, related pages where technical and scientific information can be found.

The second described processing routine is the one carried out in delayed mode, which is aimed at updating each project specific database where the edited and kriged data (both for trajectories and temperature) are stored. The report described in detail the automatic and manual editing procedures, and the following kriging methodology which comprises a low-pass filtering (36 hours) and sub-sampling (every six hours) steps.

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