Automated surface marine observations from European data buoys

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Abstract

Since the mid-20th century, a growing number of automated weather buoys have been deployed for the purpose of providing a continuous monitoring of weather conditions at the marine surface. Thanks to advances in global telecommunications by satellite in the 1970s, these platforms have spread to cover remote regions, while delivering data in near-real-time. Today oceanographic and meteorological buoys are found in coastal regions, in the high oceans, and in challenging polar regions or even on sea-ice. The data are typically collected within minutes. This paper will present the achievements of the data buoys within E-SURFMAR, the surface marine operational service of the observation programme of EUMETNET (a grouping of European National Meteorological Services). Two types of buoys will be discussed: moored buoys and drifting buoys. The former provide fixed-point time-series and multivariate information. Several variables are collected, from the lower atmosphere (air pressure, air temperature, air humidity, wind, radiation, precipitation…) to the deeper ocean. The latter type of buoys follow trajectories at the mercy of the ocean currents, and report generally fewer variables, such as ocean surface current, sea-surface temperature, and atmospheric pressure. The relative merits, limits, and applications of both types of systems will be reviewed, along with their sustainability. Ongoing developments will also be discussed, along with challenges ahead.

1. Introduction

The first weather buoys collecting measurements at sea were probably deployed around the times of World War II. One finds reports in German U-Boot log books of deploying such equipment in the North Atlantic [1]. It is not sure what parameters were collected by these buoys, but the meteorological information was indeed crucial for the planning and the conduct of war operations on all sides of the conflict.

Autonomous weather buoys were hence born out of necessity, to answer a crucial question: what is the weather like at any given time, at a remote marine location?

Today's buoys are still built under the same specifications. They have to withstand difficult conditions, deliver the data as expected, and not break down in between the maintenance schedule, as access is extremely difficult and costly.

A key turning point was in the 1970s with the development of systems for reliable and distant data transmission, as well as positioning. One system was initially developed coupling both capabilities, called RAMS [2]: the initial report of this mission indicates various applications, including not only buoys but also long-range stratospheric balloons. This first mission was followed by the Argos Data Collection and Location System on polar-orbiting meteorological satellites, which has provided services for nearly 30 years now [3].

Since these pioneering trials, there have been tremendous developments in the miniaturization of electronics and the reliability of radio transmission systems and atomic clocks. This has enabled the Global Positioning System (GPS) to take shape, as well as constellations of satellites acting as data relays, such as Inmarsat or Iridium. Both technologies have matured in the 2000s with small and low-consumption devices (chipsets) that can be integrated on electronic circuit boards, thereby providing accurate spatio-temporal tagging, and near-instant data relay.

This paper presents the buoys used by European national weather and oceanographic services for operational applications, focusing on those within the remit of E-SURFMAR, the surface marine operational service of the observation programme of the Economic Interest Group of European National Meteorological Services (EUMETNET). The subsequent sections of manuscript are organized as follows: 2) buoy types, 3) data transmission segment, 4) applications, and 5) prospects for evolution, including challenges and sustainability questions, and finally 6) conclusions.

2. Buoy types

Today, two types of buoys co-exist: moored ones, and drifting ones.

2.1 Moored buoys

As their name suggest, moored buoys are not mobile and meant to keep fixed positions. This is not exactly correct in practice as the mooring lines need to allow for some slack as the sea-level may vary (according to tides, storms, and waves). Consequently, the deeper the bathymetry at the mooring position, the greater the radius the buoy may evolve within. This can be up to 5 km in some situations. Buoys can also be moored in shallow-waters, for coastal applications. Operational applications refer here to those requiring data in near-real-time (within a few hours maximum of delay). The parameters measured by moored buoys for operational applications include meteorological ones and oceanographic ones.

The meteorological parameters measured by meteorological moored buoys generally include air temperature, air humidity, air pressure, and wind. They can also include radiation and precipitation. If one ignores the slight horizontal displacements mentioned above, then the time-series can be considered to be at a fixed point, and exploited for climate analysis. However, this requires careful exploitation of the metadata. Indeed, the equipment employed is generally replaced once a year, meaning that the continuity of the measurements is far from guaranteed. There is also the issue of vertical placement or change of configuration on the buoys, which can affect the immediate environment measured by the sensors.

The oceanographic parameters generally include sea-surface temperature. They can also include sub-surface sensors (measurements of temperature at various depths), measurements of salinity, and (Eulerian) measurements of sea current. The sea-state is also of interest for several applications. This can be measured by the displacement of the buoy, assuming that it responds to waves without affecting the measurement. This is hence only true for waves that carry a minimal energy (large enough to move the buoy). For that reason, wave buoys specialized to measure swell and wind-generated waves of all sizes are generally designed as rather small (e.g., under 2 m diameter). Larger buoys will indeed tend to suppress or dampen the small waves, and the readings for small waves will need to be considered with caution. Several European sites also measure biogeochemistry parameters, such as turbidity, chlorophyll, sound velocity, partial pressure of Carbon Dioxide or Oxygen in sea water, but these are outside the scope of this paper. A collection of such sites are indeed labelled as part of OceanSITES and/or FixO3 (Fixed-point Open Ocean Observatories).

A schematic picture of a moored buoy is shown thereafter for one moored buoy whose maintenance is partially supported by E-SURFMAR (below, left, Drawing courtesy of FUGRO) , and another one moored in the North Sea (below, right; mooring line omitted) in more shallow waters.
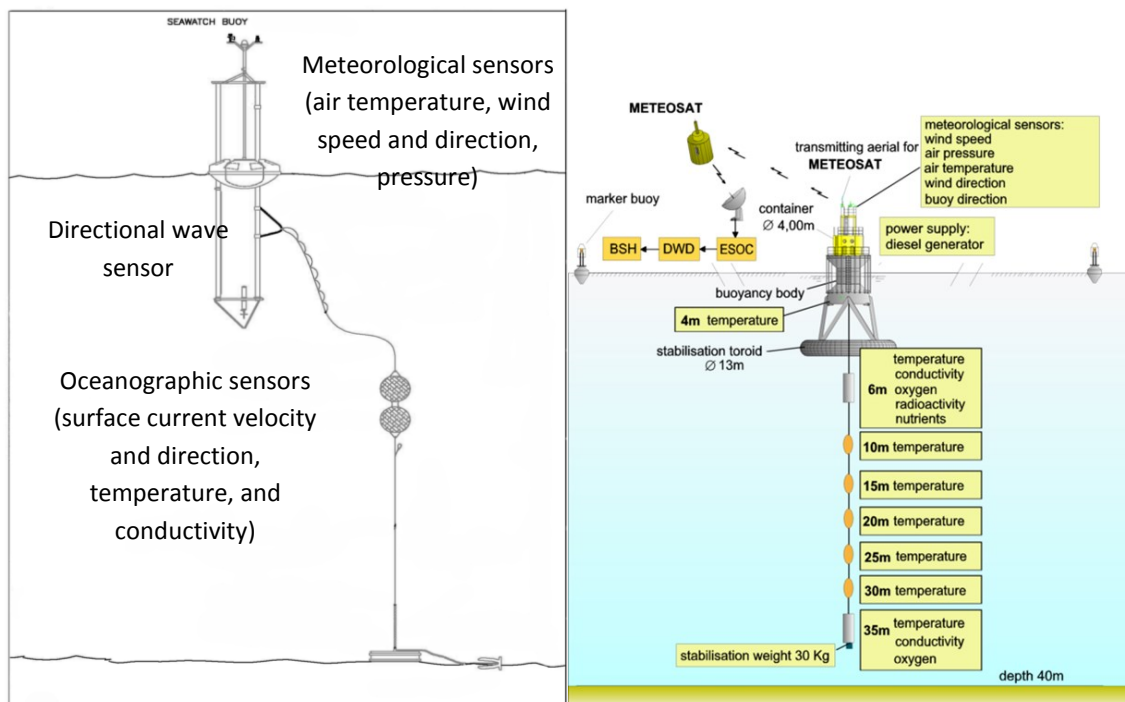
The hull of the buoy ensures buoyancy and protection from the elements. The expected lifetime of such buoy exceeds typically 10 years (more likely around 15-20 years). The other essential components of a moored buoy are the power segment, the instrumentation and data processing segment, the safety segment, and the transmission segment. The instrumentation and data processing segment are generally bundled in Automatic Weather Station (AWS). For example, several European countries have developed AWS systems for moored buoys, by looking for synergies with other AWS systems used on land or on ships. Also, some moored buoys use two sets of electronics and instruments in the AWS, to decrease the likelihood of one observed parameter going missing between two maintenance schedules. The safety segment is meant to prevent collisions and continue reporting the buoy position in case the mooring line breaks. The data transmission segment is detailed in the following section.

2.2 Drifting buoys

Unlike moored buoys, drifting buoys are designed to track currents in a quasi-Lagrangian way. There are various sizes and types of drifting buoys, depending on the type of ocean-advected feature one wishes to track. For example, for oil spill, a common buoy type is the CODE/DAVIS to track currents at the very surface, given that the relatively low costs allow employing many platforms to capture small-scale phenomena.

For tracking larger-scale ocean surface currents (i.e. at a lower depth), the standard is the Surface Velocity Programme (SVP) platform. Of a hemispheric shape, it includes a holey sock drogue at a standardized depth of 15 meters below the surface [4]. Due to the physical stress (wind vs current) this drogue is typically lost within a few months, whereas the mean lifetime of a functional drifting buoy is (at time of writing) around 500 days.

The largest drifter program in the world is NOAA's Global Drifter Program (GDP). It counts over 1300 buoys, including a contribution by several European countries.

Additionally such buoys can report sea-surface temperature, but also nowadays air pressure. More rarely the platforms measure sea-surface salinity and sub-surface temperatures. Trials have been made to also report wind and waves. The figure on the right-hand-side shows a schematic picture of a drifter as employed by E-SURFMAR (Drawing courtesy of metOcean Telematics, drawn by Paul Jakobsen).

The drifting buoys use their own systems for data processing, and are generally not bundled in what one could refer to as a stand-alone AWS. Yet, there have been successful attempts to use drifters as AWS on ships (so-called 'deck-drifters'). These solutions enable to give beached (but still functioning) drifters a second (useful) life, while also providing data from ships devoid of a weather reporting solution (AWS or human observer with near-real-time transmission to shore).

The lifecycles of these buoys do not foresee maintenance at present. Only in rare cases have buoys been recovered, and the calibration of the instruments verified [5].

The data transmission from drifters is usually organized via Argos, but nowadays an increasingly number of operators uses Iridium satellites.
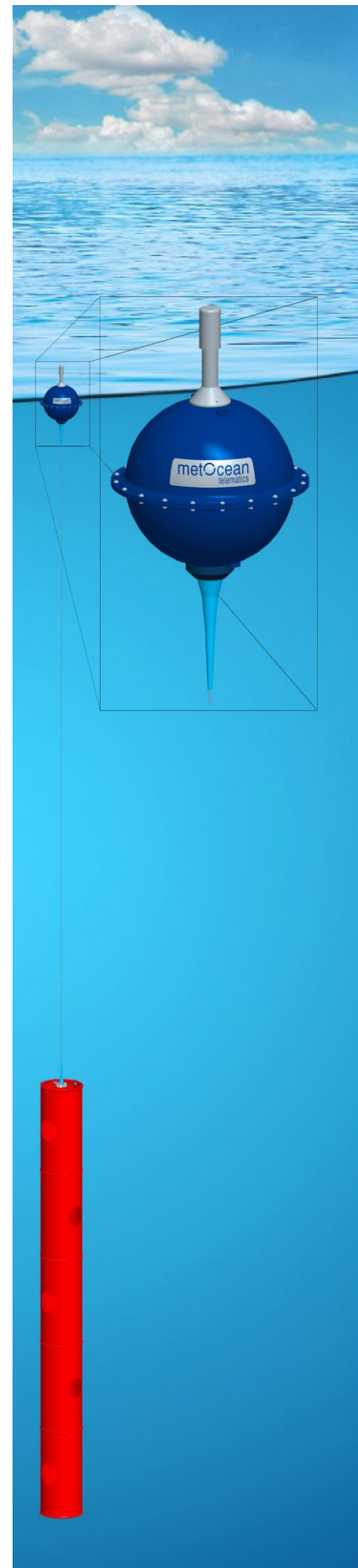
3. Data segment

The data sent by operational buoys are relayed in a few minutes to a Data Assembly Center (DAC), which depends on the buoy type, owner, and transmission choice. The DAC generally decodes and controls the messages received, before posting them on the WMO Global Telecommunications System (GTS).

In European waters, the map in the right-hand-side shows positions of moorings and drifters, for data received on the GTS during the 15 days preceding 13 September 2017. Note that some of the oil platforms equipped with AWS are included. Moored buoys are otherwise indicated with black symbols, while drifting buoys tracks (over the 15 days) are indicated in colors.

The buoy data reported on the GTS have the status of essential data products under WMO Resolution 40 Annex I, meaning that they are provided on "a free and unrestricted basis", as "necessary for the provision of services in support of the protection of life and property and the well-being of all nations" [6].
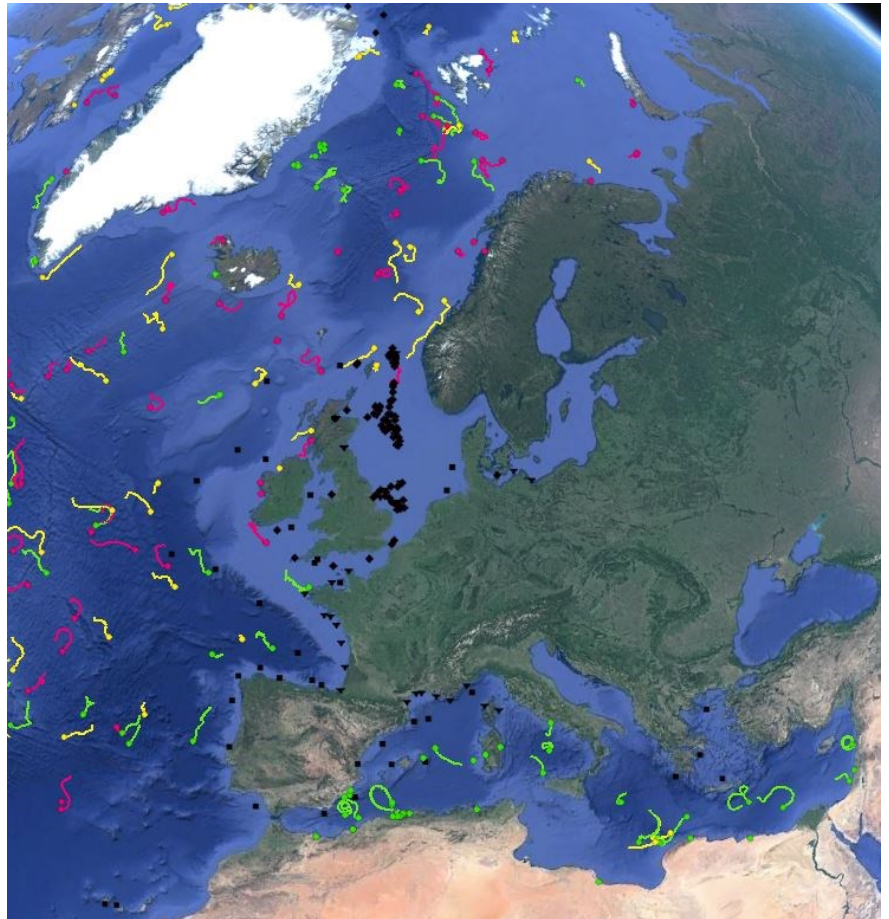
4. Applications

The data sent by buoys serve at least five broad classes of applications.

4.1 Weather prediction

The data reported by moored buoys are used by marine weather forecasters to assist in their appreciation of numerical weather forecast scenarios. The meteorological data are also assimilated in numerical weather prediction models. The knowledge of the pressure field for initial conditions influences the quality of global forecasts up to several days, and high-resolution limited-area forecasts as well. For longer time-scales, the knowledge of the sea-surface temperature (SST) field is more critical. For this variable, the SST buoy data are used to improve the satellite estimates.

4.2 Satellite validation and calibration

The data reported by moored and drifting buoys are used by satellite agencies to calibrate and validate products derived from satellites measurements. This applies to retrievals of sea-surface temperature (*e.g.,* derived from passive infrared radiometers), sea-surface salinity (*e.g.,* derived from passive microwave radiometers), sea-state (*e.g.,* significant wave height derived from altimeters), and sea surface wind (*e.g.,* speed and direction derived from scatterometers).

In all these cases, the past years have seen experiments, sometimes with partial support from space agencies, dedicated at collecting additional data to evaluate and then further improve the corresponding satellite products.

4.3 Climate studies

Data collected by the DACs and then further ingested in ICOADS [7] are typically used in weather and climate reanalysis [8].

A process is underway to build a 3-tier architecture in the framework of the Marine Climate Data System (MCDS), based on DACs, GDACs, and Centres for Marine-Meteorological and Oceanographic Climate (CMOCs) such as ICOADS.

4.4 Oceanography

The ocean surface current data estimated from drifter trajectories are used to help improving the retrieval of ocean current information from satellite altimeters. Conversely, the expert use of both data can help detect when drifters have lost their drogues [9].

4.5 Industrial applications

Ground truth estimates of the wind are essential for the conduct of wind farm operations. The same is true for the conduct of oil exploitation operations. Moored buoys may be used for this purpose. However, one notes the gradual interest towards powered mobile measuring platforms that can adopt a fixed position and be steered from one position to the next.

5. Challenges and evolution prospects

For moored buoys, one challenge amounts in protecting them from assaults and increased vandalism. Indeed, buoys attract fish, which attract fishermen; the fishing lines and nets (when not boarding the buoy) cause costly damages. Another challenge consists in spacing the maintenance interval, to make ship visits more seldom. This will help reduce operation costs and raise the prospects for continued measurements by moored buoys. Manufacturers should assist in this by aiming to design moored buoy systems that require fewer visits. For example, a challenge would be to design a system guaranteed to function for 2 years without intervention.

The prospects for moored buoys are to include more sensors so each site reports a host of parameters relevant to more applications such as marine wildlife and understanding of the ecosystem. One may cite for example the equipment of some moorings with acoustic sensors to detect nearby passages of fish equipped with such beacons.

For drifting buoys, the prospects are to equip them more routinely with more sensors, so that each buoy journey reports a multi-variate picture of the environment travelled. For example, the GDP has an objective of reaching 100% of all drifters reporting air pressure. Also, there have been successful trials of wave measurements from drifters, reported at the 32nd session of the Data Buoy Cooperation Panel (DBCP-32).

For both buoy types, there is an interest to increase the underlying metrology, so the measurements can be used as references to calibrate and validate satellite products. This realization of benefits through greater integration between in situ and satellite segments is one of the cornerstones of the evolution towards the Tropical Pacific Observing System in 2020 (TPOS-2020).

The challenges for both platform types concerning sustainability are somehow different. While it may be easier for a mooring not to leave behind any trace of its presence once the mission finished, drifters pose specific problems. Their trajectories are not known in advance, and cease to be known once the buoys stop working. For these reasons, it is extremely difficult to aim to recover drifters at the end of their useful/operating life. Options to improve this aspect include developing recycling schemes for those drifters that are recovered (e.g. beached), and looking to introduce a greater share of recyclable materials in the manufacturing process.

One must note that today E-SURFMAR only uses alkaline-based batteries for its drifters, in spite of some manufacturers of oceanographic equipment still proposing the options of using lithium batteries, known to be far detrimental to the marine environment, if not recovered.

6. Conclusions

This paper reviews the types of buoys used for operational applications by (mainly) the meteorological community. Moored buoys are rather complex systems, which can even integrate redundant sets of AWS, to guarantee a high data return rate. Drifting buoys are relatively leaner in design in comparison, but present a far shorter lifetime, with no expected maintenance cycle.

The advantages of buoys as autonomous platforms to collect data at sea will remain strong for as long as no other surface autonomous is able to propose similar services for an equivalent cost. One may expect however that challengers in this category will appear in the coming years, with autonomous surface vehicles or drones, offering the possibility to recover the equipment and to visit well-identified areas on demand.

References

[1] Records from the German Naval Archives microfilmed by the United States Navy, Office of Naval Intelligence (ONI) at the Admiralty, London. T1022/Roll 2932/PG30079.

[2] Nimbus 6 Random Access Measurement System Applications Experiment (RAMS), 1982, Eds. C. Cote, R. Taylor, and E. Gilbert. *NASA SP-457*, pp. 107 (on-line: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19830006564.pdf, last accessed 14 September 2017)

[3] The Argos system: monitoring the world's environment, 1990, by K.R. Swenson and A.E. Shaw III. *Oceanography* 3(1):60–61. DOI:10.5670/oceanog.1990.29.

[4] Water-following characteristics of a mixed-layer drifter,1987, by P.P. Niiler, R. Davis, and H. White. Deep Sea Res., 34, 1867–1882. DOI:10.1016/0198-0149(87)90060-4.

[5] Météo-France/E-SURFMAR HRSST (re)calibration, 2016, by P. Poli, G. Emzivat, P. Blouch, R. Férézou, and A. Cariou. *Scientific and technical workshop on traceability of drifter SST measurements (SST-Drift)*, La Jolla, CA, USA, 13-14 October 2016. DOI:10.5281/zenodo.890279.

[6] WMO Resolution 40, WMO Cg-XII, 1995, on-line: http://www.wmo.int/pages/prog/www/ois/Operational_Information/Publications/Congress/Cg_XII/res40_en.html (last accessed 14 September 2017)

[7] ICOADS Release 3.0: a major update to the historical marine climate record, 2017, by E. Freeman, S.D. Woodruff, S.J. Worley, S.J. Lubker, E.C. Kent, W.E. Angel, D.I. Berry, P. Brohan, R. Eastman, L. Gates, W. Gloeden, Z. Ji, J. Lawrimore, N.A. Rayner, G. Rosenhagen, and S.R. Smith. *Int. J. Climatol.*, **37**: 2211–2232. DOI:10.1002/joc.4775

[8] The observation feedback archive for the ICOADS and ISPD data sets, 2015, by H. Hersbach, P. Poli, and D.P. Dee. *ERA Report Series* **18**, pp. 31 (on-line: https://www.ecmwf.int/sites/default/files/elibrary/2015/9871-observation-feedback-archive-icoads-and-ispd-data-sets.pdf, last accessed 14 September 2017)

[9] Use of Altimeter and Wind Data to Detect the Anomalous Loss of SVP-Type Drifter's Drogue, 2012, by M.-H. Rio. *J. Atmos. Oceanic Technol.*, **29**, 1663–1674. DOI: 10.1175/JTECH-D-12-00008.1