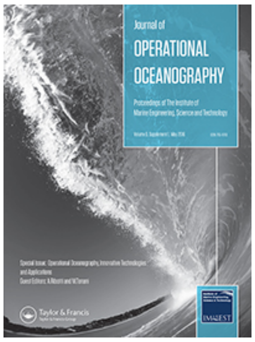

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The RITMARE Italian Fixed-Point Observatory Network (IFON) for marine environmental monitoring: a case study

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ABSTRACT
The Italian Fixed-Point Observatory Network (IFON) integrates well-established coastal and ocean infrastructures (buoys, platforms, moorings, mast platforms, etc.), most of them providing real-time multidisciplinary monitoring for a number of marine and atmospheric variables. Here, we describe the network characteristics and then discuss an example of its operation during the cold spell of winter 2012. One of the goals of the Italian Flagship Project *Ricerca Italiana per il mare* (RITMARE) is to create a common, validated IFON database able to fulfil both public and private demands, including validation of remotely sensed data and numerical models, environmental planning and management, and time-series analysis of climate and oceanographic data.

Introduction

Global changes affect the frequency of the occurrence of extreme meteorological events which may be particularly detrimental to coastal areas and endanger the sustainability of marine and coastal environments in supporting human needs (Bondesan et al. 1995; Nicholls et al. 1999; Ulses et al. 2008; Rabalais et al. 2009; Lipizer et al. 2012; Appiotti et al. 2014), thus leading to a growth in treaties and conventions to improve observational and prediction capabilities for various ecosystems from local to global scales (Baüer et al. 2006; Kintisch 2007). A significant growth in coastal and ocean observing system planning (e.g. IOOS, GOOS, OCEAN.US, IOCARIBE, IAS-GOOS, etc.) has resulted from this effort, improving the level of detection and forecast of climatic changes (Mooers et al. 2002). Moreover, the advent of real-time observations using various platforms, expanded coordinated observations, and cooperative efforts from federal governments, universities, industries and various agencies has improved the prognostic calculations of important physical, chemical and biological mechanisms in oceanic and coastal regimes (UNESCO 2005).

The Italian Fixed-Point Observatory Network (IFON) integrates the well-established ocean infrastructures managed by numerous national research institutions (Ravaioli et al. 2012). Within the framework of the Italian Flagship Project *Ricerca Italiana per il mare* (RITMARE), the main aims of Work Package 3 (WP3, Italian scientific network of fixed sites for sea observation) are the development, integration and consolidation of IFON. WP3 is part of SubProject5 (SP5), which focuses on observation systems for the Italian seas with the goal of reinforcing and combining them following the concepts of 'integrated network' and 'observatories'. The main target of WP3 is to create a common, validated IFON database accessible both within the IFON network and for external users following the rules proposed in the RITMARE data policy (RITMARE 2014). Moreover, the IFON network is implemented in order to ensure high-quality real-time observations based on common sensor calibration procedures and quality control (QC) and quality assessment (QA) procedures for a number of variables included in the essential ocean variables (EOVs; see UNESCO 2011) The application of common QC

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procedures in real time for all observing sites of the network ensure a high quality of data distributed to users through exchanges at the national and international levels.

The remainder of this paper firstly describes the IFON characteristics and configuration and then gives an overview of a specific inter-case study, the effects of the cold spell that occurred during winter 2012, merging datasets from the different sites. Finally, conclusions and future developments are discussed.

The Italian Fixed-Point Observatory Network (IFON)

IFON integrates 15 fixed monitoring systems, with another 2 operative from 2015, and an oceanographic transect (Senigallia–Susak; Figure 1), providing multidisciplinary monitoring of coastal and deep marine environments, with high temporal resolution, for a number of marine and atmospheric variables. Here we present a brief description of the different systems and sites. The locations of and parameters measured by the systems are listed in Table 1.

MAMBO meteoceanographic buoy

The ENVironmental Operative Monitoring (MAMBO), operative since 1998, is located at the outer limit of the Marine Protected Area of Miramare (Gulf of Trieste) over a bottom depth of 18 m and provides near real time (NRT) data acquired at a half-hour frequency. The system is equipped with surface meteorological sensors to measure atmospheric pressure, air temperature and humidity, wind speed and direction, and incident PAR radiation, and oceanographic sensors to measure temperature, salinity, dissolved oxygen and pH at both 1 and 10 m depth, and pCO_2, turbidity and chlorophyll-*a* at 10 m depth. MAMBO is part of the coastal marine observatory site of the Gulf of Trieste which also includes a biological time-series station which is sampled on a monthly basis for the acquisition of biological and biogeochemical data.

PALOMA mast platform

The Advanced Platform Oceanographic Laboratory Adriatic Sea (PALOMA) mast platform is located 12 km offshore in the centre of the Gulf of Trieste at a bottom depth of 25 m. The system acquires meteorological data, atmospheric CO_2 concentration at 10 m above the mean sea level, seawater pCO_2, temperature, salinity dissolved oxygen at 3 m water depth, and temperature at 15 m and 24 m depths. Atmospheric CO_2 is acquired every 2 h, seawater pCO_2 every 6 h and the other parameters every 10 to 15 min. The site has been implemented with a focus on air-sea CO_2 fluxes (Cantoni et al. 2012) and instrumental data are integrated with monthly ship surveys to measure the inorganic carbon species and the main biogeochemical parameters along the water column.

Acqua Alta oceanographic tower

The Acqua Alta oceanographic tower is located 15 km offshore of Venice in the northern Adriatic Sea, at a bottom depth of 16 m. The platform is fully equipped with a large set of autonomous instrumentations that acquire atmospheric, hydrological and oceanographic data with several meteorological stations and sensors (including different measurement systems of waves and currents). At the site, biological and chemical measurements are routinely acquired, with periodic sampling of the water column.

S1 and E1 meteoceanographic buoys

The S1 buoy is located offshore of the Po River delta, over a bottom depth of 21.3 m. The station is made up of a surface buoy with a logging system, NRT transmission devices, a power system, a meteorological station and a submersed moored line accommodating oceanographic instrumentation at two depths: 1.6 m and 18 m. The S1 buoy is located in a key monitoring area for studying the interaction between the northern Adriatic Sea and the Po River (Bortoluzzi et al. 2006).

The E1 buoy is located offshore of Rimini over a bottom depth of 10.5 m. It accommodates oceanographic instrumentation at two water depths: 1.5 m and 8 m. The E1 site is a key monitoring point for studying hypoxic and anoxic events in the north Adriatic Basin.

Tele–Senigallia pylon and Senigallia–Susak transect

The section from Senigallia to Susak Island (Central Adriatic) has been periodically surveyed since 1988 in order to collect Conductivity, Temperature and Depth (CTD) data and samples for dissolved oxygen and nutrient analyses. The Tele–Senigallia pylon is located at the western edge of the Senigallia–Susak transect. It is equipped with a meteorological station and several oceanographic sensors at water depths of 2 m, 10 m and 16 m. The joint system is in a key area to observe near-coastal processes (upwelling, stratifications, biological productivity) and the water masses transiting to or from the northern Adriatic.

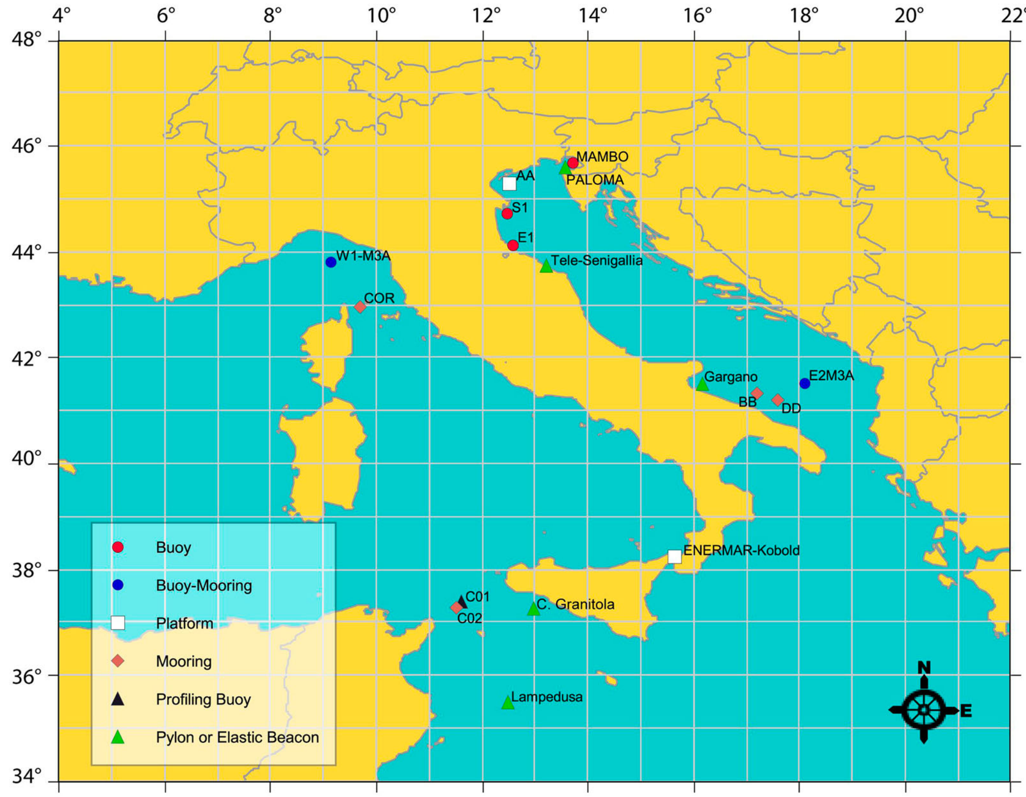

Figure 1. Map of the site locations of the Italian Fixed-Point Observatory Network (IFON).

Gargano pylon

The Gargano pylon is a coastal buoy located in the Gulf of Manfredonia (southern Adriatic Sea) at about 10 nautical miles from the coast at a bottom depth of 17 m. The Gargano pylon is equipped with a datalogger, a meteorological station, a sea-surface temperature sensor (2 m depth), a CTD probe and oxygen-turbidity-chlorophyll sensors at 5 m depth and a current metre at 16 m depth. The data acquisition system produces data every 10 min and transmits them to the mainland station every hour.

E2M3A observatory

The E2M3A observatory is located in the deepest part of the southern Adriatic. It is a two-component array, composed by a surface buoy allowing real-time data transmission and a subsurface mooring. The E2M3A is equipped with physical sensors at different nominal depths (2, 15, 350, 550, 750, 900, 1000, and 1200 m) and acoustic current profilers located at 320 m and 1200 m. The observatory has been deployed with the aim of monitoring air-sea interactions and the physical as well as biochemical properties of the water mass, as well as investigating the convective events in the open sea (Bensi et al. 2013, 2014).

Moorings BB and DD

Two subsurface moorings, located in the Bari canyon (site BB) and on a sediment wave field (site DD) along the dispersal path of the descending north Adriatic Dense Water (NAdDW), have been deployed for the long-term monitoring of the dense water cascading able to transfer sediment, O_2, nutrients and organic compounds to the benthic ecosystems of the deep southern Adriatic. Mooring instrumentations are self-recording (data in delay mode) and get serviced twice a year.

Kobold platform

The Kobold platform is a prototype to study the potential of extracting energy from marine currents. The plant is moored at 25 m depth in the Straits of Messina, Italy, where tidal currents are the strongest in the Mediterranean Sea. The Kobold platform hosts an automatic monitoring system including a meteorological station, a sea surface temperature sensor and an Acoustic Doppler Current Profiler (ADCP) that provides NRT data to the turbine controller (Bergamasco et al. 2011).

Table 1. Location and parameters measured by each system.

Site name	Image	Data series start	Latitude [dd.xx]	Longitude [dd.xx]	Measured parameters[a]	NRT Data
MAMBO Meteoceanographic buoy		1999	45.70	13.70	**CAPH, CDTA, CHUM, CSLR, EWSB**, TEMP, PSAL, CNDC, DOXY, ALKY, PCO2, TSED, VSRW, CPWC.	Yes
PALOMA Mast platform		2008	45.62	13.56	**CAPH[b], CDTA, CHUM[b], CSLR[b], EWSB[b], ACO2**, TEMP, PSAL, CNDC, DOXY, PCO2, ALKY, NTRI, AMON, NTRA, SLCA, PHOS, DOCC, VATX, PYTT.	Yes
Acqua Alta oceanographic tower		1992	45.31	12.51	**CAPH, CDTA, CHUM, CSLR, EWSB, SAOT, SWLR, ATDP**, TEMP, PSAL, SIGT, DOXY, PREX, PCO2, TDIN, WVST, ASLV, HEAV, GWDR, CPWC, NTRI, AMON, NTRA, SLCA, PHOS, CING, CORG, NTOT, ZATX, PATX, CATX, AATX, VATX, PYTT, CYEU, WCPH, FATX.	Yes
S1 meteoceanographic buoy		2004	44.74	12.46	**CAPH, CDTA, CHUM, CSLR, EWSB**, TEMP, PSAL, CNDC, SIGT, DOXY, ALKY, CPWC, HMSB, OPBS, RFVL, ASLV, HEAV, WVST.	Yes
E1 meteoceanographic buoy		2006	44.14	12.57	**CAPH, CDTA, CHUM, CSLR, EWSB**, TEMP, PSAL, CNDC, SIGT, DOXY, CPWC, HMSB, OPBS, RFVL.	Yes
Tele–Senigallia pylon		2006	43.75	13.20	**CDTA, EWSB**, PREX, TEMP.	Yes
GARGANO pylon		2012	41.52	16.15	**CAPH, CDTA, CHUM, EWSB**, TEMP, CNDC, SIGT, DOXY, CPWC, HMSB, EXUV.	Yes
E2M3A observatory		2006	41.53	18.09	**CAPH, CDTA, CHUM, EWSB, CSLR, OPBS, LWRD**, TEMP, PSAL, CNDC, SIGT, DOXY, PCO2, ATTN, LERR.	Yes

(Continued)

Table 1. Continued.

Site name	Image	Data series start	Latitude [dd.xx]	Longitude [dd.xx]	Measured parameters[a]	NRT Data
BB mooring		2010	41.34	17.19	TEMP, PSAL, SIGT, SVEL, PREX, OPBS, RFVL, MSFX, TCFX, LIFX, IRFX.	No
DD mooring		2009	41.22	17.58	TEMP, PSAL, SIGT, SVEL, PREX, OPBS, RFVL, MSFX, TCFX, LIFX, IRFX.	No
Kobold platform		2008	38.26	15.63	**CAPH, CDTA, CHUM, CSLR,** TEMP, RFVL, LRZA, OMET, UVRD.	Yes
Profiling buoy system **Yo-Yo**		2014	37.38	11.59	TEMP, PSAL, RFVL.	Yes
C02 mooring		1993	37.29	11.5	TEMP, PSAL, RFVL.	No
CORS01 mooring		1985	43.02	9.68	TEMP, PSAL, DOXY, RFVL.	No
W1M3A multidisciplinary observatory		2000	43.83	9.12	**CDTA, CHUM, EWSB, CSLR,** LWRD, CPRP, TEMP, CNDC, DOXY, PCO2, WVST, NOYS, NTRI.	Yes

Note: [a]Parameter codes are in accordance with BODC Parameter Usage Vocabulary (SeaDataNet, 2015); [b]Data acquired in collaboration with the Civil Protection Agency and Regional Environmental Protection Agency (ARPA-OSMER). Atmospheric parameters are in bold.

Moorings in the Corsica and Sicily Channels and the 'Yo-Yo' profiling buoy system

The Corsica and Sicily Channels are monitored by three underwater stations: CORS01, located at the Corsica Channel sill at a depth of 450 m (established in 1985), and C01 and C02, located at the western Sicily Channel sill, between Sicily and Tunisia, on the Sicilian side at a depth of 350 m (C01) and on the Tunisian side at a depth of 530 m (C02). They are equipped with single-point current meters, ADCPs and fixed CTD probes, and provide long-term monitoring of surface and intermediate water mass exchanges through the channels, along with their hydrological characteristics. Mooring instrumentations are self-recording (data in delay mode) and get serviced twice a year.

In June 2013 and for about four months, the CORS01 was the test site for an autonomous profiling buoy system named 'Yo-Yo', transmitting daily hydrological vertical profiles in NRT through the built-in Iridium transceiver. In November 2014 the Yo-Yo system was permanently installed in C01.

W1M3A multidisciplinary observatory

The W1M3A observatory is constituted of a spar buoy and a subsurface mooring close by and it is moored in the Ligurian Sea (seabed of 1200 m, 80 km from the coast). Its position and structural characteristics make the system ideal for conducting air-sea interactions studies. The fixed platform monitors a complete set of near-surface

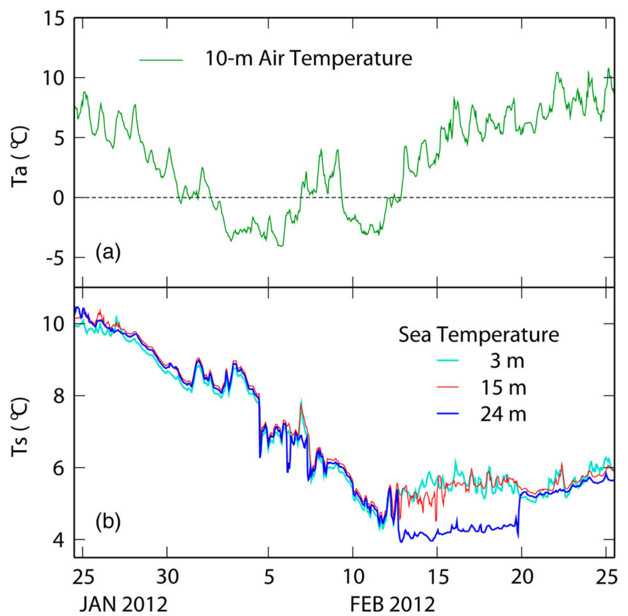

Figure 2. PALOMA station hourly data from 25 January to 25 February 2012, showing (a) air temperature and (b) sea temperature at 3 m depth (light blue line), 15 m depth (red line), and 24 m depth (blue line).

meteorological parameters on a long-term basis, as well as physical and biogeochemical variables form the surface down to the ocean interior (0–1000 m depth). All measurements collected by the sensors installed on the surface buoy are transmitted ashore in NRT (Canepa et al. 2015).

Capo Granitola beacon and Lampedusa air-sea observatory

The Capo Granitola elastic beacon was installed at the end of October 2014 in the Sicily Channel, 10 nautical miles offshore the Sicily coasts at 54 m depth. The onboard instrumentations include a meteorological station, several oceanographic sensors and a suite of radiometers and became operative in 2015. A second fixed buoy was installed in summer 2015 close to the island of Lampedusa, in the southern sector of the Mediterranean basin. The buoy is an elastic beacon type and will host instruments to monitor air-sea interactions.

The inter-site case study of winter 2012

From the end of January to mid-February 2012, a strong and persisting Bora wind affected the Adriatic Sea area and particularly the Gulf of Trieste. Such long-lasting and intense windy weather was the consequence of a persistent atmospheric pressure gradient related to both a stable anticyclone extending from Russia westward over Central Europe and the generally cyclonic conditions over the Mediterranean Sea (Raicich et al. 2013; Davolio et al. 2015).

The time-series of air and sea temperatures at PALOMA from 25 January to 25 February 2012 are displayed in Figure 2. As a result of the cold air ingression, the air temperature decreased until 3 February, then a steady phase took place followed by an increase between 6 and 9 February, followed by another sharp cooling on 11 February (Figure 2(a)). The last two fluctuations correspond to the wind weakening and the subsequent abrupt strengthening described by Raicich et al. (2013) for the same period. At PALOMA, the water column was well mixed and exhibited a general cooling trend throughout the event, with a slower rate until 4 February and a more rapid one afterwards (Figure 2(b)). A remarkable feature is that the cold waters, formed on the shallow northern shelf of the Gulf of Trieste, sank into the deepest part around PALOMA after Bora ceased to blow, causing strong vertical stratification. The cold waters remained in the deep layer of the gulf from 13 to 20 February, after which another windy period on 20 to 23 February induced vertical mixing. The temperature at a depth of 24 m at PALOMA reached a minimum of 3.93°C on 13 February.

The profound changes in the properties of the seawater in the Gulf of Trieste in February 2012 were also detected in the northernmost part of the basin by the MAMBO sensors deployed at a depth of 10 m. February 2012 was characterised by a remarkable temperature decrease in comparison with the 1999–2010 climatology, with the lowest values (3.97°C, 12 February) ever measured and by a parallel increase in salinity with a maximum of 38.58 recorded on 4 February (Figure 3). Temperatures well below the long-term mean (on average 2°C lower) lasted for most of the month and the concomitant high salinities triggered the formation of very dense waters (reaching the maximum density anomaly of 30.59 kgm^{-3} on 12 February), which sank to the bottom and spread outside the Gulf area, merging with dense waters formed on several shelf areas of the Adriatic (Milhanović et al. 2013).

Similar modifications were detected in the Gulf of Venice by the two CTDs deployed at the surface and near the bottom at the Acqua Alta oceanographic tower, where a strong mixing occurred at the end of January, with both surface and deep water temperatures dropping to a minimum of 6°C with a synchronous increase of salinity that reached levels over 38.5 at the beginning of February, following a marked decrease in air temperature (Figure 4). These data were utilised to perform a calibration of the numerical model describing the exceptional northern Adriatic dense water formation event in winter 2012. A time-series of turbulent heat fluxes was estimated from measurements in the oceanographic tower together with modelled heat fluxes computed by ALADIN/HR and

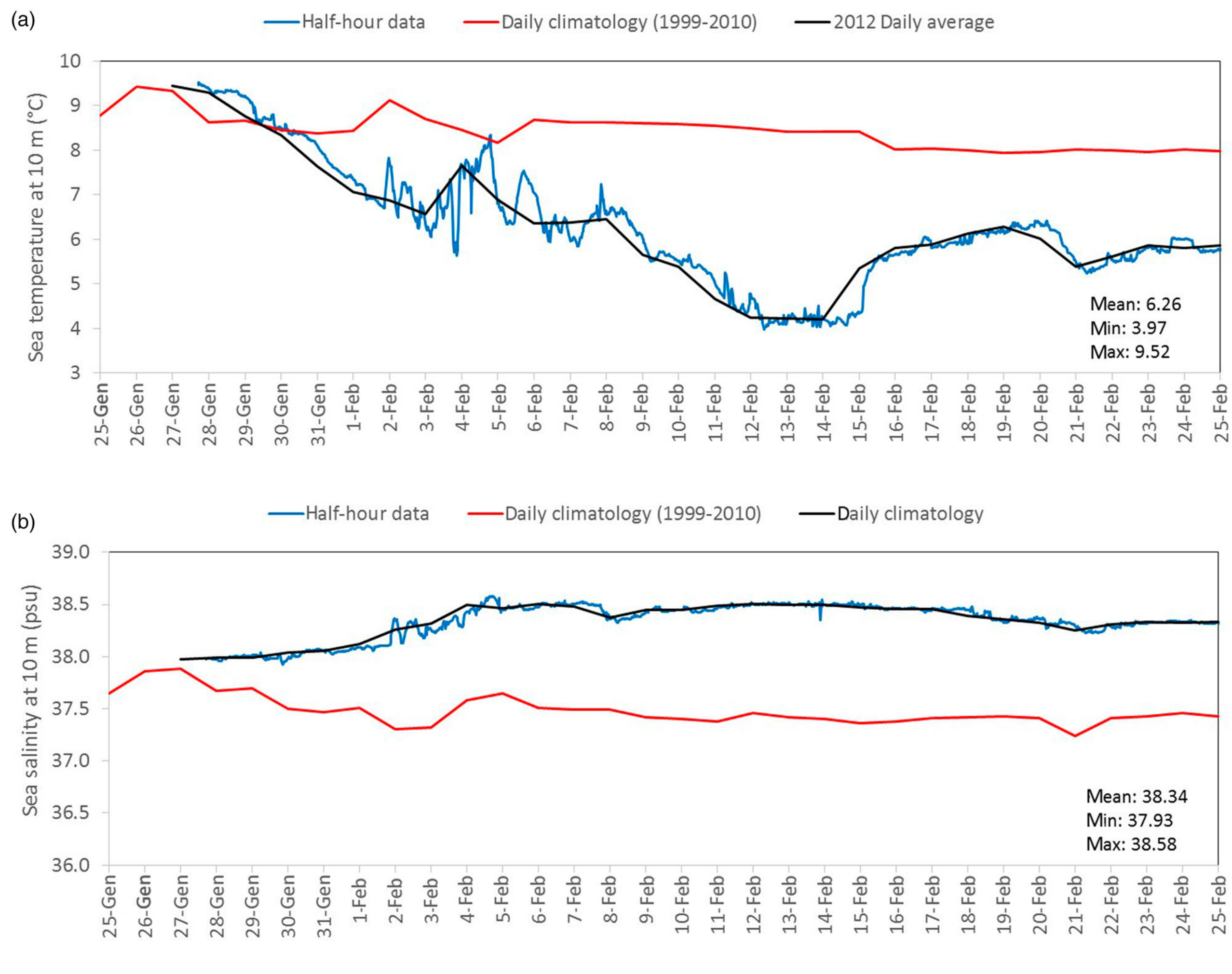

Figure 3. Comparison between continuous (a) sea temperature and (b) salinity data recorded by the MAMBO sensors at 10 m depth in January and February 2012.
Note: The mean, minimum and maximum for the period are indicated in the bottom right corner.

COSMO/ROMS (Consortium for Small-scale Modelling/Regional Ocean Modeling System) models at the grid point nearest to Acqua Alta, documenting the severity of the event (Milhanović et al. 2013).

During the winter 2012 event, the S1 buoy recorded both meteorological and oceanographic data (Figure 5), while the E1 buoy was partially out of service and recorded incomplete data (the dotted line in Figure 5) due to a power system problem the presence of snow during the bad weather. From 28 and 29 January through to 12 February, the data recorded by the S1 show a wind regime of variable intensity (maximum value 13.67 ms^{-1} registered on 4 February) and a NNE main direction, in agreement with Alpers et al. (2009). This northerly wind is often associated with Bora deflection along the Italian coast. The air temperature started to decrease on 28 January, reaching a first minimum (−1.24°C) on 4 February and a second one (−2.29°C) on 11 February. Due to its peculiar position, 6 km offshore of the Po River delta, the S1 site was strongly influenced by the interaction between seawater flowing from the northern Adriatic and fresh water flowing from the Po River. In fact, only the data recorded from 5 to 12 February were representative of the conditions encountered in the north Adriatic basin during the Bora event, with average temperatures in line with the series recorded at PALOMA, MAMBO and Acqua Alta. The water mass was characterised by relatively high salinity (with values over 37) and low temperatures reaching a minimum of 3.75°C on 14 February. The partial dataset acquired by E1 is consistent with the data recorded by S1 (starting from 8 February), with a minimum value of sea temperature of 4.06°C on 18 February.

To study the southward spread of the exceptionally dense water formed in the northern Adriatic (Vilibić & Orlić 2001; Vilibić et al. 2004; Turchetto et al. 2007; Rubino et al. 2012), data from the stations located in the central and southern Adriatic were analysed, together

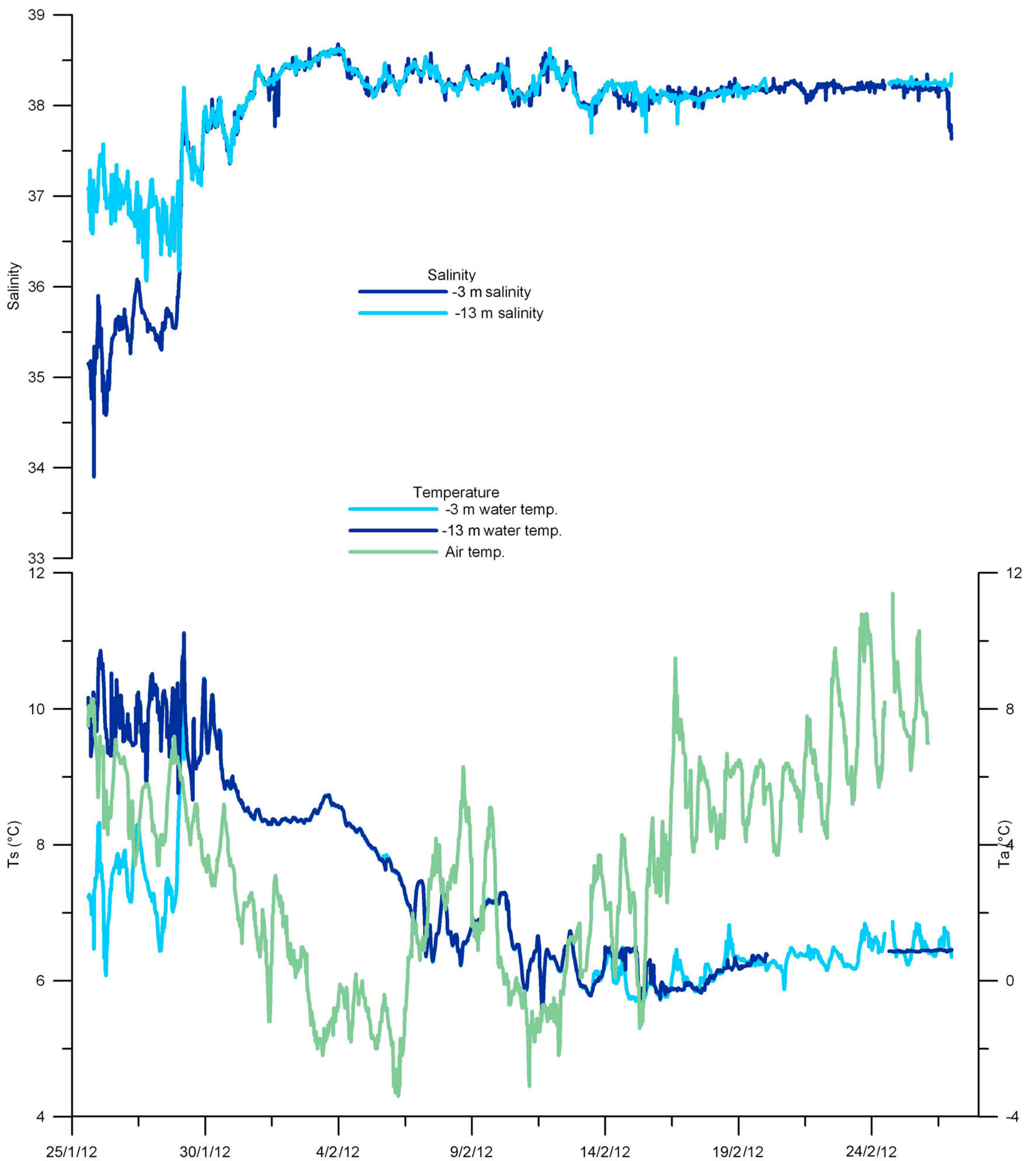

Figure 4. Time-series of surface (3 m) and bottom (13 m) air, potential water temperature and practical salinity for January and February 2012 at the Acqua Alta station.

with CTD casts coming from the section from Senigallia (the Tele–Senigallia pylon) to Susak Island. The time-series of atmospheric parameters at Tele–Senigallia (Figure 6(a)) shows a period of wind ranging from 45 deg to 90 deg N, followed by a significant drop off in temperature (more than 5°C on 9 February).

The temperature and density distribution along the Senigallia–Susak transect, collected onboard the R/V Dallaporta (CNR, National Research Council of Italy) on 27 March, are shown in Figure 6(b). Low temperatures (<10.5°C) and high densities (>29.8 kgm^{-3}) were measured at the bottom of stations 4 and 5 at a depth of 40 m. This water mass corresponded to the NAdDW formed in the northern Adriatic that, flowing southwards along the Italian coasts, partly spread along the bottom of the Meso-Adriatic Depression, progressively filling the three deeps from west to east (Vilibić 2003; Vilibić & Supić 2005; Marini et al. 2006; Campanelli et al. 2011).

A similar situation was registered in the southern Adriatic by the BB and DD moorings, where, starting from 12 to 13 February, the salinity and temperature abruptly dropped, with strong high-frequency oscillations (Figure 7). The negative shift in temperature was an average of 0.60°C and 0.35°C for BB and DD,

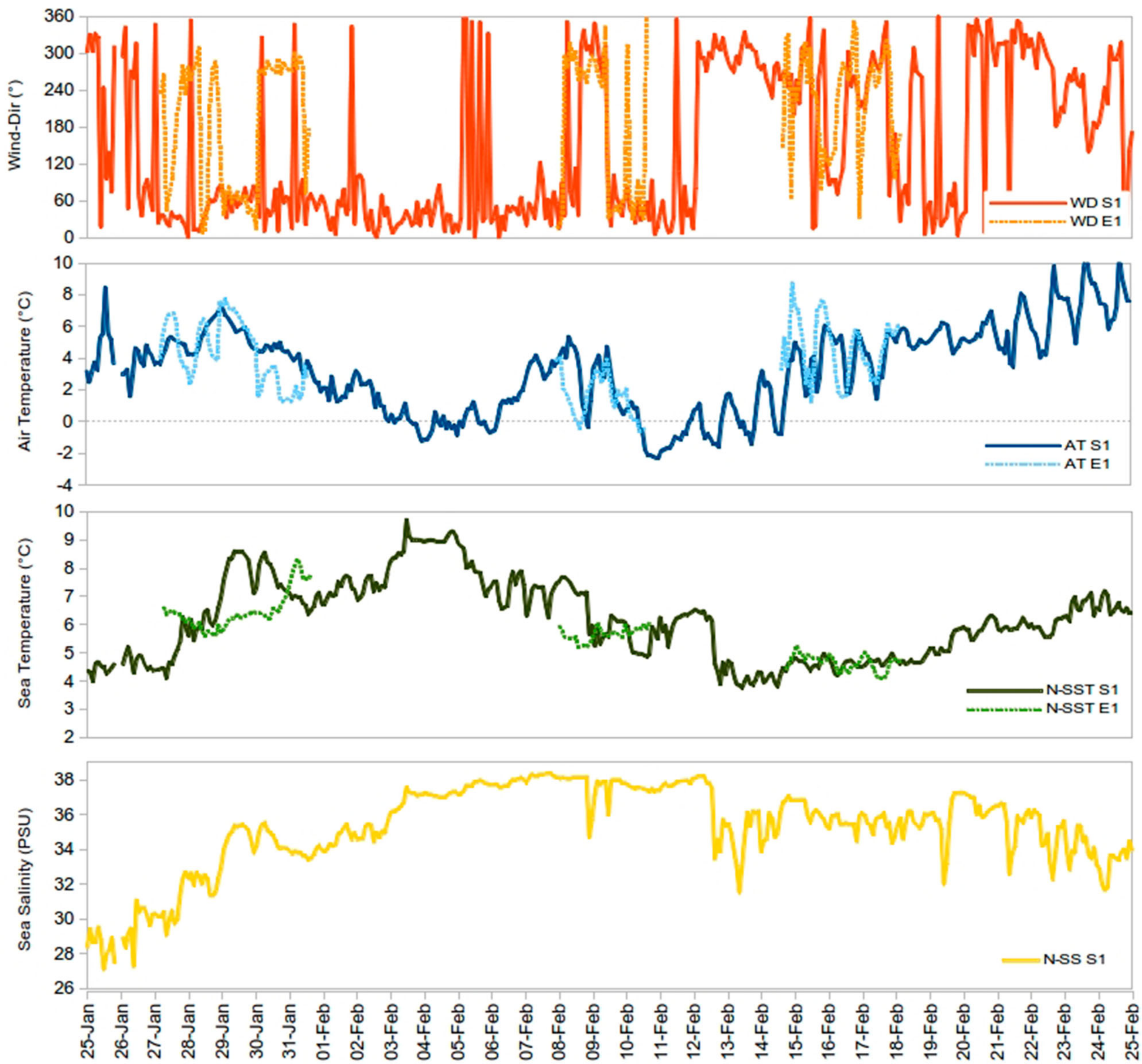

Figure 5. Time-series of wind speed (WS), wind direction (WD), air temperature (T), sea temperature (ST), and surface salinity (SS) measured at sites S1 and E1 (dotted line) from 25 January to 25 February 2012.

respectively. The first minimum was reached on 21 February at 12.27°C and 12.81°C in the canyon and the sediment wave station, respectively (Langone et al. 2015).

In the southernmost station (DD), the variability was more limited, with small-amplitude and broad fluctuations. The highest velocities of the near-bottom currents were recorded in late March to early April 2012, which ranged between 48 cms^{-1} at DD and 73 cms^{-1} at BB, suggesting that a strong cascading process was triggered, impacting the whole deep Adriatic basin (Langone et al. 2015).

Peaks of current speed occurred on 11 to 13 February, 20 to 21 February and 9 to 11 March. While the high current speed and the low temperatures recorded in March can be ascribed to the 'usual' arrival of NAdDW (Vilibić & Supić 2005), the signals of dense water cascading observed in February occurred only around 10 days after the maximum heat losses calculated in the northern Adriatic (3 and 11 February); (Mihanović et al. 2013; Raicich et al. 2013).

This finding implies a rapid transfer of newly-formed NAdDW from the formation area to the southern Adriatic during the early phase, which was also modelled by Benetazzo et al. (2014) and Janeković et al. (2014) and which probably originated in a closer area with respect to the northernmost part of the Adriatic Sea (along the Croatian coast, according to Mihanović et al. 2013, or offshore of Ancona, according to Benetazzo et al. 2014).

Also at E2M3A, a sudden decrease in temperature (from ~13.07°C to ~12.92°C) and salinity (from

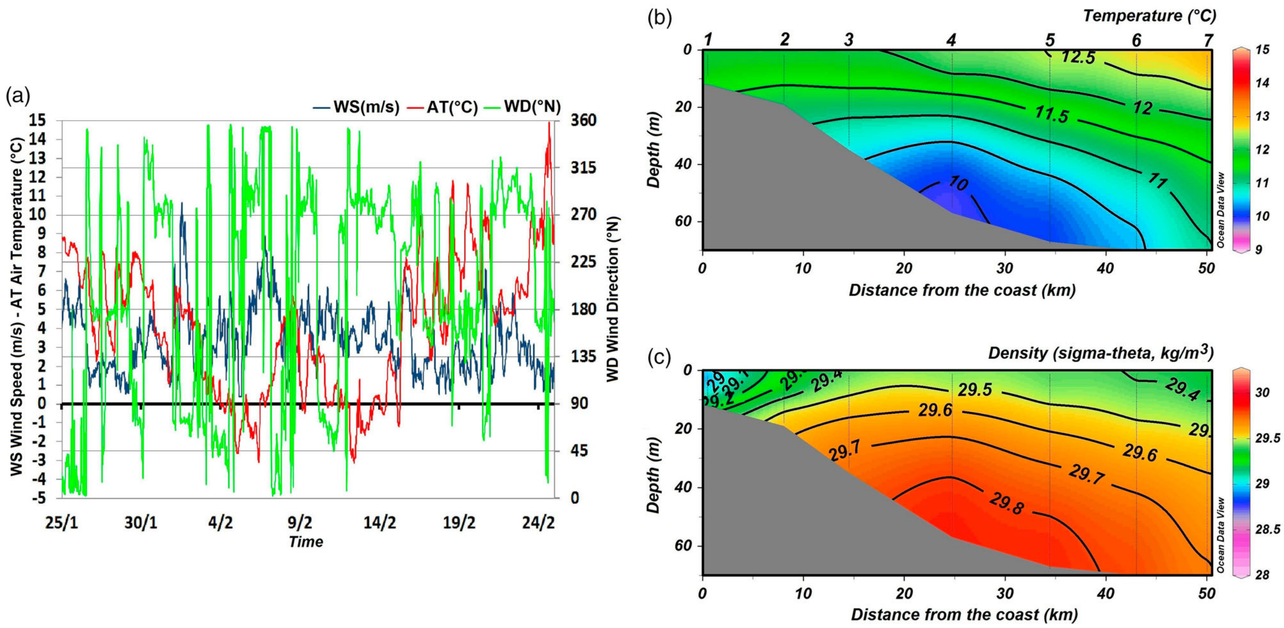

Figure 6. (a) Hourly time series of wind speed (WS, blue line), wind direction (WD, green line) and air temperature (AT, red line) recorded at Tele–Senigallia from 25 January to 25 February 2012 and (b) vertical distribution of sea temperature (ST) and density (D) along the Senigallia–Susak transect on 27 March.

~38.735 to ~38.72) was observed close to the sea bottom after 10 March (Figure 8). This resulted in a density increase of ~0.02 kgm^{-3}. This signal can be ascribed to the arrival of NAdDW in the abyssal part of the southern Adriatic (as evidenced by Marini et al. 2015), which has not been so evidently observed in previous years (Bensi et al. 2013, 2014). Finally, positive trends in temperature and salinity started again after winter 2012 (Figure 8), revealing a 'saw-tooth' pattern which deserves further investigation; the alternation of long-lasting linear increases (the mixing phase) and sudden decreases (the dense water intrusion phase) of temperature and salinity.

Data coming from the IFON helped to determine that the Tyrrhenian basin was also affected by the 2012 cold event.

Onshore, along the north-Tyrrhenian coasts, a minimum down to −10°C was observed in the period of 4 to 11 February. The Mediterranean coast of France was covered in deep snow by the end of January and Corsica was buried under 40 cm of snow, too.

Data collected at the W1M3A in the Ligurian basin showed a drop in the hourly average of air temperature of 3.62°C (from 15.14°C down to 11.52°C) on 25 January. The air temperature at the W1M3A site remained lower than 5°C from 31 January until 14 February, reaching a

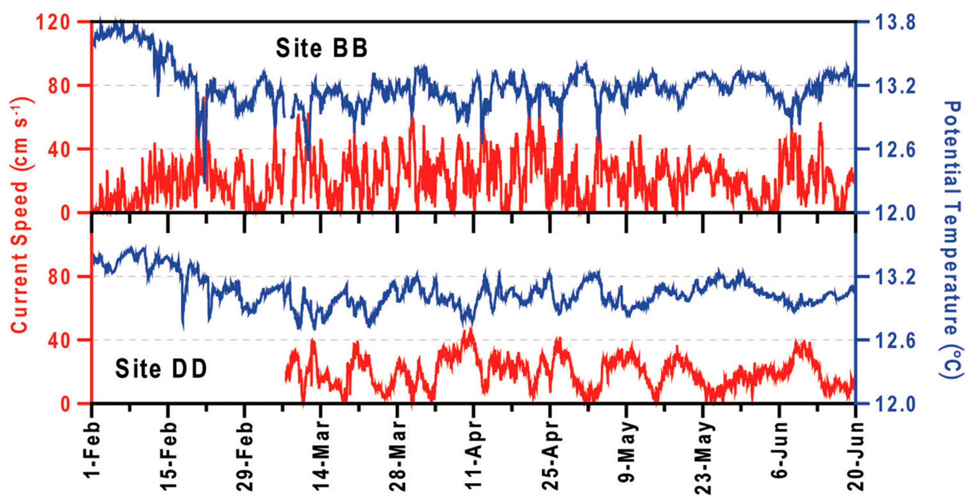

Figure 7. Time-series 1 February to 20 June 2012 of potential temperatures and current speeds measured near the bottom at the BB and DD moorings.

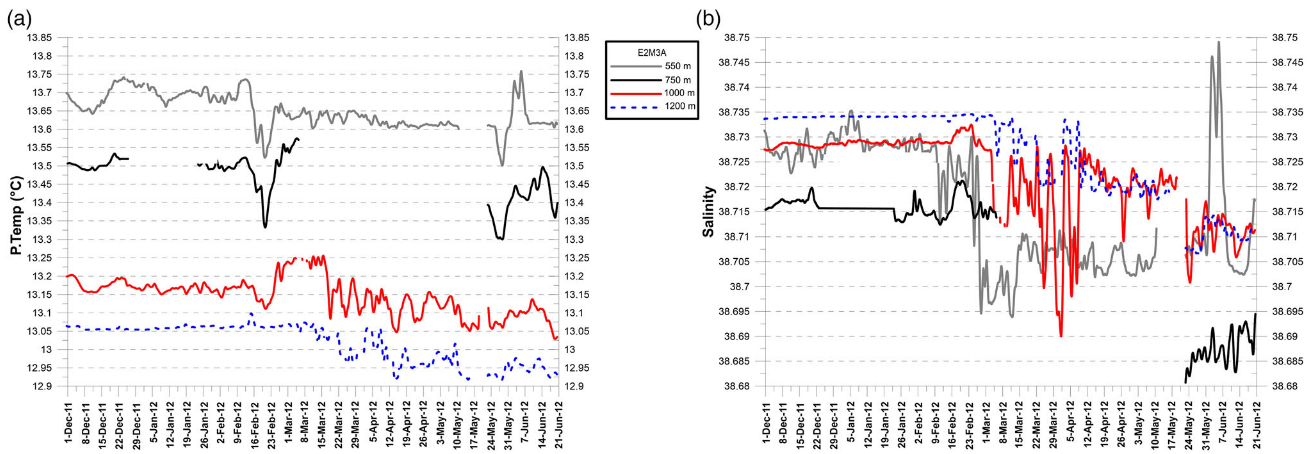

Figure 8. Time-series 1 December 2011 to 21 June 2012 of (a) potential temperatures and (b) salinities recorded by the CT and CTD sensors installed at E2M3A. Note: Data were despiked and filtered with a 33-h Hamming filter.

minimum of 1.6°C on 1 February, with the exception of few hours between 7 and 9 February.

Among the resulting effects, the Ligurian basin experienced very large energy losses, mostly related to the intense cold winds blowing in from northern sectors. Sensible and latent heat fluxes into the ocean showed a simultaneous decrease and the gap between air and sea surface temperature reached the exceptional value of about −11°C compared to the 13 years of corresponding climatology data collected by the W1M3A observatory (Figure 9(a)).

The abrupt decrease in air temperature can be ascribed to the persistence from late January up to mid-February of strong winds coming from the north with gusts often greater than 20 ms^{-1} (Figure 9(b)).

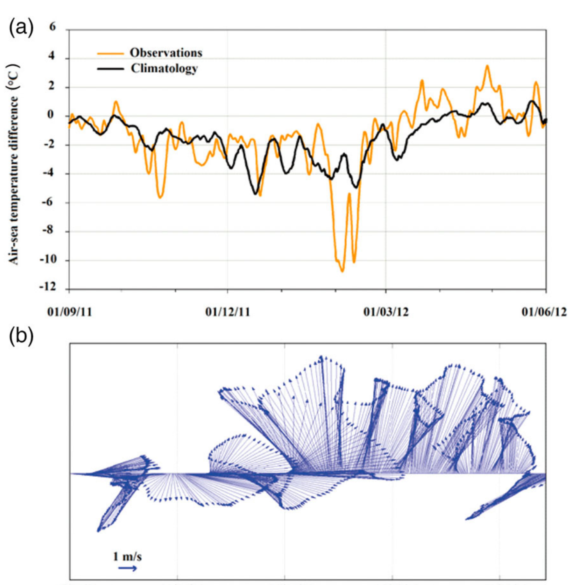

Figure 9. (a) Time-series of air-sea temperature difference collected by the W1M3A observatory in the period September 2011 to June 2012 and the 13-year period of 2000 to 2013 for the climatology of the site and (b) stick diagram of the wind field for the period 15 January to 15 February 2012 corresponding to the largest anomaly between the observed and climatic air-sea temperature difference.

It is noteworthy that the influence of the cold wave in the atmosphere had a limited impact on the water column, affecting only the surface layer. In fact, the overall time-series of sea temperature acquired by the W1M3A evidenced a sharp decrease of about 2°C in the first 6 m of the water column during late January and early February 2012, with respect to data acquired on December 2011, with a consequent average increase of about 0.5 kgm^{-3} in water density. On the other hand, the time-series of sea temperature from a depth of 10 m down to 40 m from January to February 2012 showed an absolute anomaly of about 0.5°C with respect to the climatology obtained from the data acquired for the same period during the previous 13 years.

Conclusions and future developments

The comparison between datasets from the different IFON sites allowed us to better characterise the cold spell of winter 2012 at a basin scale (Adriatic Sea) and to make also some comparisons with the Tyrrhenian basin. The main results are as follows:

- In the atmosphere, the cold event was almost synchronous in the sites of the north Adriatic. The air temperature started to decrease on 30 January, reaching the lowest values on 4 to 5 and 11 February (data from PALOMA, MAMBO, Acqua Alta, S1, E1 and Tele-Senigallia sites). The cold event was characterised, both in the Adriatic and in the Ligurian basin, by very large energy losses, mostly related to the intense cold winds blowing in from northern sectors. A temperature decrease was also recorded in the Ligurian basin (W1M3A site).

- At sea the most important consequence of the cold spell, registered in the northern Adriatic basin, was an intense seawater cooling with values around 3.7–4.0°C at the coastal sites (PALOMA, MAMBO, S1 and E1 systems) and a minimum value of 5.6°C at the more offshore site (Acqua Alta) between 12 and 15 February. The water cooling and the concomitant higher salinities triggered the production of exceptionally dense NAdDW.
- Newly-formed bottom dense waters propagated southwards, filling the bottom layer of both the central and southern Adriatic basins, partially mixing with the ambient seawater and gradually losing their original signature.
- The integrated dataset from the southernmost sites (the BB and DD moorings and the E2M3A site) allowed the highlighting of the presence of an early arrival of NAdDW about 10 days after the cold spell, followed by the 'usual' arrival after about one and a half months.
- In the Ligurian basin, the influence of the cold wave in the atmosphere had a limited impact on the water column, affecting only the surface layer.

This inter-site case study points out the usefulness of a network of sites for integrated environmental monitoring even in the case of extreme events, which can be, in future, even more frequent.

A key objective of the RITMARE SP5-WP3 is to make IFON a multidisciplinary and sustainable observing system with a common, validated database. Given the scale of the Italian seas and the costs and logistical demands associated with making observations, we need to select those parameters that will provide us with the information needed to detect, track and attribute change in the physical, biogeochemical and biological systems of the sea.

Moreover, the nodes of the network are implemented in order to ensure high-quality real-time observation of the selected variables, also applying standardised QC and QA procedures.

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