Data resulting from hydrodynamic model (and wave) to integrate the environmental database

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Authors	Michol Ghezzo (CNR-ISMAR), William Mckiver (CNR-ISMAR), Christian Ferrarin (CNR-ISMAR),
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Summary

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Abstract

This report describes the forecast system adopted in the project to estimate the evolution of temperature and salinity variables in the North Adriatic area. It describes the flow of data between the WPs and users and the quality check system for the data. Finally, it describes the data format and offers some examples of the provided data and of their analysis

1 Introduction

A crucial information in the underwater sound propagation is the sound speed assessment. It is strongly dependent from the water density, and this means that temperature and salinity distribution influence the propagation properties of the sound in the water column.

Generally, the recording system deployment is accomplished with a CTD measurement. This offers the estimation of the instantaneous sound speed, but this record can be considered as reliable only for a couple of days after the deployment.

Anyway, with the aim to record continuously the underwater noise and to simulate the underwater noise propagation during a whole year it is the evaluation of sound speed is needed more frequently.

The use of numerical models to estimate of the circulation, water temperature and salinity dynamic is often applied in the most updated sound propagation models.

The advantage of this practice is obvious: a continuous detailed spatially distribution information on water column movement and structure and consequently the detailed assessment of the sound speed.

In this report we compare also the temperature and salinity data produced in the Adriatic Sea by different forecasting systems: Tiresias forecasting system and THE COPERNICUS OCEAN product named MEDSEA ANALYSIS FORECAST PHY 006 013 EAS5

2 The SHYFEM application in Tiresias

SHYFEM is a 3D hydrodynamic finite element model solving the primitive equations, vertically integrated over each layer considering tidal, atmospheric and density-driven forces. It is open-source model and is freely available athttp://www.ismar.cnr.it/shyfem and https://github.com/SHYFEM-model. Several applications of the SHYFEM model have been performed in Mediterranean Sea (Cucco et al. 2012;

Ferrarin et al. 2013), in the Adriatic Sea (Ferrarin et al. 2017), and in several coastal systems (Ghezzo et al 2019, Umgiesser et al 2014, and references therein).

The state variables are discretized in the horizontal using the finite element method, with the subdivision of the numerical domain in triangles varying in form and size. The model discretizes vertically using Z layers with varying thickness. A more detailed description of the model equations and of the discretization method is given in Umgiesseret al. (2004) and Ferrarin et al. (2017).

The numerical computation is performed on a spatial domains representing the Adriatic Sea, the lagoon of Marano-Grado, the lagoon of Venice and the Po River Delta (including the Scardovari and Goro Lagoons) using an unstructured grid (Figure 1). The numerical domain includes all Po River branches starting downstream from the Po di Goro diversion (40 km upstream) with 9 river mouths. To resolve the river-sea continuum, the unstructured grid also includes the lower part of the other major rivers flowing into the Adriatic Sea.

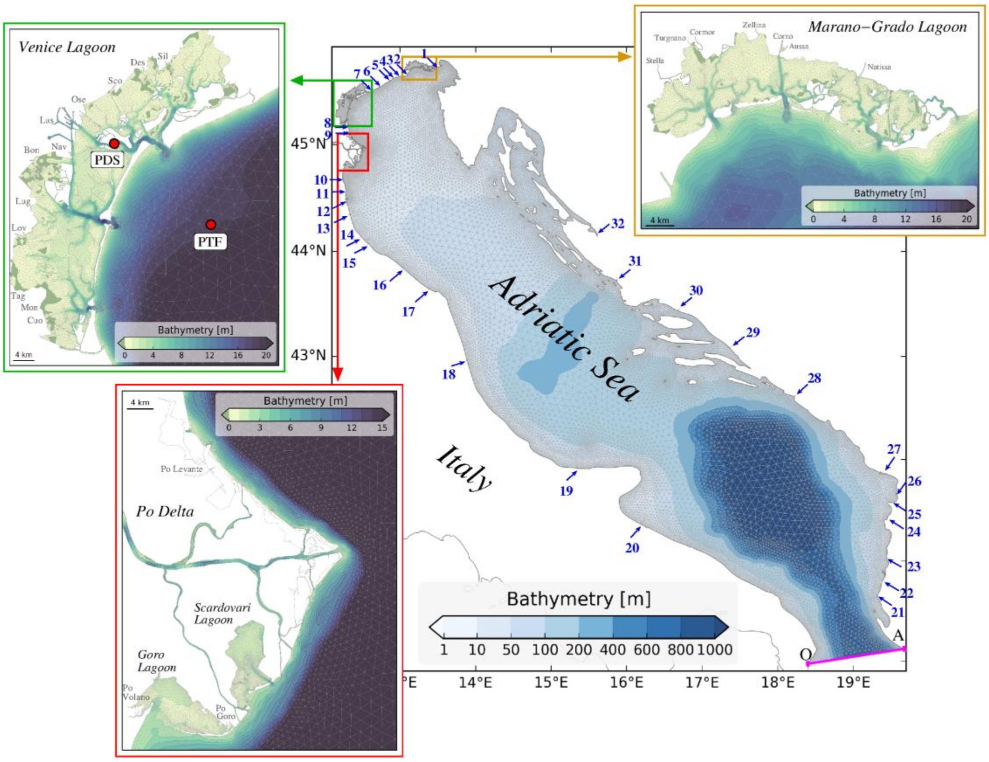

Figure 1 Adriatic Sea, numerical grid and bathymetry, river inputs location and zoom on lagoons and Po river delta included in the Tiresias forecasting system

Elements of variable sizes are used in order to suit the complicated geometry of the basin, the rapidly varying topographic features, and the complex bathymetry of the lagoon systems. The numerical grid of the Adriatic Sea with the lagoons uses approximately 110,000 triangular elements with a resolution ranging from 7 km in the open sea to a few hundred meters along the coast and tens of meters in the inner lagoon channels. The model uses a wetting and drying feature, which is needed in the shallow lagoons, where some areas consist of salt marshes that are intermittently dry and wet, and in the Po River floodplains. The bathymetry of the Adriatic and the lagoons was obtained by merging several datasets, having different spatial resolution and obtained using different measurement approaches, but the same reference datum (Genoa 1942 - IGM42). The resulting bathymetry, interpolated and superimposed on the triangular mesh, is shown in Figure 1.

For this model application, the water column is discretized into 34 vertical layers with variable thickness ranging from 1m, in the topmost 10m, to 100m for the deepest layer of the Adriatic Sea. The higher vertical discretization near the surface layers allows one to describe the tidal propagation over the shallow tidal flats and the vertical structure of the tidal flow in the tidal channel network.

To compute the water temperature, the air-sea heat fluxes are parameterised by the COARE (Coupled Ocean-Atmosphere Response Experiment) 3.0 bulk algorithm. This algorithm is also used to compute the drag coefficient for the momentum transfer of wind in the hydrodynamic model formulae.

Accurate forcing and boundary conditions are crucial to correctly forecast the circulation in the Adriatic Sea, which is strongly influenced by high temporal and spatial variability of the atmospheric conditions and river runoff.

The weather in the Adriatic region is strongly influenced by local orography and small-scale processes. Therefore, in order to obtain a realistic oceanographic prediction an appropriate spatial resolution of the meteorological fields is required. The use of high-resolution meteorological models is essential to capture the temporal and spatial inhomogeneity of north-easterly Bora winds, characterised by topographically controlled high-speed wind jets along the eastern shore.

In Tiresias, the meteorological forcing is supplied by the MOLOCH limited-area, high-resolution model developed and implemented at CNR-ISAC (National Research Council of Italy - Institute of Atmospheric Sciences and Climate) with a daily operational chain (http://www.isac.cnr.it/dinamica/projects/forecasts). The forecast framework comprises the hydrostatic model BOLAM (implemented over the Euro-Mediterranean region) and the non-hydrostatic model MOLOCH (implemented over Italy), nested in BOLAM (Figure 2). The initial and boundary conditions for the BOLAM model are derived from the analyses (00 UTC) and forecasts of the GFS (NOAA/NCEP, USA) global model (http://www.emc.ncep.noaa.gov/GFS).

MOLOCH is a non-hydrostatic, fully compressible, convection-permitting model. The state variables pressure, air temperature, specific humidity, horizontal and vertical wind velocity components, turbulent kinetic energy and five water species, are represented on a latitude-longitude rotated Arakawa C-grid. A hybrid terrain-following coordinate system is used, which relaxes to horizontal surfaces at higher elevation from the ground. A time-split scheme is used for time integration with an implicit treatment of the vertical propagation of sound waves and a forward-backward scheme for the horizontal propagation of gravity and sound waves. Advection is computed using a second order implementation of the Godunov method, which is particularly suited for the conservation of scalar quantities during time integration. This scheme is a total variation diminishing one, and therefore prevents the occurrence of spurious oscillations. See Malguzziet al.(2006), and Davolio et al. (2017) for further details about the MOLOCH model physics and numerics.

The MOLOCH model uses a horizontal grid spacing of 0.0113 degrees, equivalent to 1.25 km, and with 60 atmospheric levels and 7 soil levels. This model chain has already been successfully validated over the Adriatic Sea (Davolio et al.2017).

MOLOCH forecasts are provided daily at an hourly resolution for up to 2 days. The hourly atmospheric forcing fields used from MOLOCH are: 2m air temperature and relative humidity, total cloud cover, mean sea level atmospheric pressure, meridional and zonal 10m wind components, total precipitation rate, and the downward short-wave radiation flux. The atmospheric forcing fields are horizontally interpolated at each ocean grid node using a bilinear technique.

Freshwater discharged into the Adriatic Sea comes mostly from rivers along the northern and north-western coasts. Due to the abundant freshwater inputs, the Adriatic Sea is considered a dilution basin, exporting a relatively freshwater to the adjacent Ionian Sea. The Po River represents the major buoyancy input with a mean discharge rate of 1500m3 s−1, accounting for about one third of the total riverine freshwater input into the Adriatic Sea.

Even if most of the existing oceanographic forecasting systems for the Adriatic Sea adopt climatological values for the river boundaries (in example Federico et al. 2017), it is well known that freshwater discharges are generally characterised by high-frequency variations. As freshwater strongly influences the Adriatic Sea circulation, realistic forecasts should be supplied by consistent river discharge values. To improve the representation of the coastal freshwater discharge, in Tiresias the lower part of major rivers are included in the unstructured numerical mesh. To consider the importance of land-sea interactions in coastal forecasting in this study much effort has been devoted to choosing the most accurate available river discharge conditions over the Adriatic Sea. Where available, daily update driver discharge values are derived from automatic hydrometric stations nearest to river mouths, through calibrated stage-discharge relationships. Thisis the case for the rivers Isonzo, Aussa, Corno, Zellina, Cormor, Turgnano, Stella, Lemene, Livenza, Piave, Brenta-Bacchiglione-Gorzone,Adige, Po, Reno, Lamone, Fiumi Uniti, Savio, Uso, Marecchia, Metauro, Esino and Tronto. The updated hydrographic levels are retrieved daily from the Civil Protection of Friuli Venezia Giulia and the Regional Environmental Protection Agencies of Veneto, Emilia-Romagna and Marche.

For the other rivers considered in this study (Tagliamento, Natissa, CanaledeiLovi, Sile, the tributaries of the Venice Lagoon, Po di Levante, Po di Volano, Fortore, Ofanto, Vijuse, Seman, Shkumbi, Erzen, Ishm, Mat, Bojana, Ombla, Neretva, Cetina, Krka, Zrmanja) discharges are prescribed using monthly or annual mean climatological values .

Due to a lack of available observations, river inflow surface salinity is fixed to a constant value of 0.1 at the river boundaries. This value is lower than the ones (15–17) used by other and is justified by the fact that in Tiresias, by resolving the river-sea continuum, freshwater mixes with seawater before reaching the coast. Water temperature at the river boundaries adapts to the environmental value inside the basin.

While the model has to resolve the appropriate coastal scales, for the open sea boundary conditions, the coastal model needs an upscaling effort to the basin scale. In this case the boundary conditions can be supplied by a model at a larger scale. The use of an unique numerical mesh limits the open sea boundaries to the Strait of Otranto at the southern end of the Adriatic Sea. Each node of the Otranto open boundary is treated by defining water level, current velocity, salinity and water temperature.

The sea level and the current velocity conditions were obtained by summing the hourly tidal signal derived from the FES2012 global tidal model and the daily water level and baroclinic velocity predicted by the Mediterranean Forecast System (MFS), available via the Copernicus Marine Environmental Monitoring Service (http://marine.copernicus.eu/). The total water levels are imposed on the boundary nodes, while the total current velocity is nudged using a relaxation time of 3600 s. Water temperature and salinity boundary conditions are computed using the oceanographic fields of MFS.

One of the reasons to adopt the TIRESIAS forecasting system is that the unstructured grid permits to enhance the spatial resolution in coastal areas, representing in more detail local processes. In addition the system includes the main rivers and lagoons in the numerical domain.

McKiver et al. (2016) showed that non-hydrostatic processes are not important for the northern Adriatic Sea. However, non-hydrostatic processes can play a role in accurately capturing dense water cascading events in the deep Pit in the Southern Adriatic (Bellafiore et al. 2018) also if they have an high numerical cost making it impractical for operational forecasts. Despite the lack of non-hydrostatic processes, the implementation with more numerous and up-to-date river discharges improves the capability to simulate the salinity distribution in a coastal area and shallow parts of the Adriatic sea. Finally, Ferrarin et al. (2017) showed that the inclusion of the lagoons in the simulation improved the capability of the model in reproducing tidal currents in the whole northern Adriatic Sea.

3 The Tiresias forecasting system configuration

The operational system chain consists of a daily cycle of numerical integrations. Every day a two-day forecast is produced, with the initial conditions from a hot start based on the Tiresias forecast of the previous day. A 2.5 day-long simulation is performed with the first 12 h as a spin-up time (the time interval in the past with respect to the target initial forecast day), allowing the model state to adjust to the updated river discharges and MFS fields.

The model is forced by the atmospheric and open sea boundary data from the MOLOCH forecasts and the MFS analysis and forecasts, respectively, for the whole simulation duration. Tiresias uses the last available river discharge data, keeping this value constant throughout the two-day forecast.

Since Tiresias in not assimilating observations, MFS 3D fields of sea temperature and salinity are nudged during the simulation. MFS runs on a structured grid having horizontal resolution of $1/24^{\circ}$ and is operatively assimilating, using the 3DVAR scheme, satellite sea level anomaly, satellite sea surface temperature and vertical temperature and salinity profiles from Argo floats. Nudging data are given for all nodes of the unstructured grid. The value of the relaxation coefficient is spatially varying over the model domain (as a function of the grid resolution) from 2 days in the open sea and increasing, thus diminishing the restoration contribution, toward the coast. The nudging allows the model state to be reconciled with the assimilated MFS data in the open sea – limiting error growth in the forecast chain – and fully compute the hydrodynamics along the coast and in the lagoons

Tiresias runs operationally since September 2014. A two months-long simulation (July–August 2014), initialised with the MFS sea temperature and salinity fields, was performed to define the conditions for the starting state of the operational forecasting system. A similar spin-up time was used by McKiver et al. (2016) for simulating the Adriatic Sea hydrodynamics. The spin-up time is longer than the water renewal time in the north Adriatic lagoons (Umgiesser et al. 2014), and therefore allowed these systems to dynamically adjust after initialisation from the interpolation of coarser MFS fields.

Tiresias runs on a Linux operating system. Its core is composed of a set of scripts, activated as soon as the MOLOCH atmospheric forcing is available, which prepare and launch each forecast simulation.

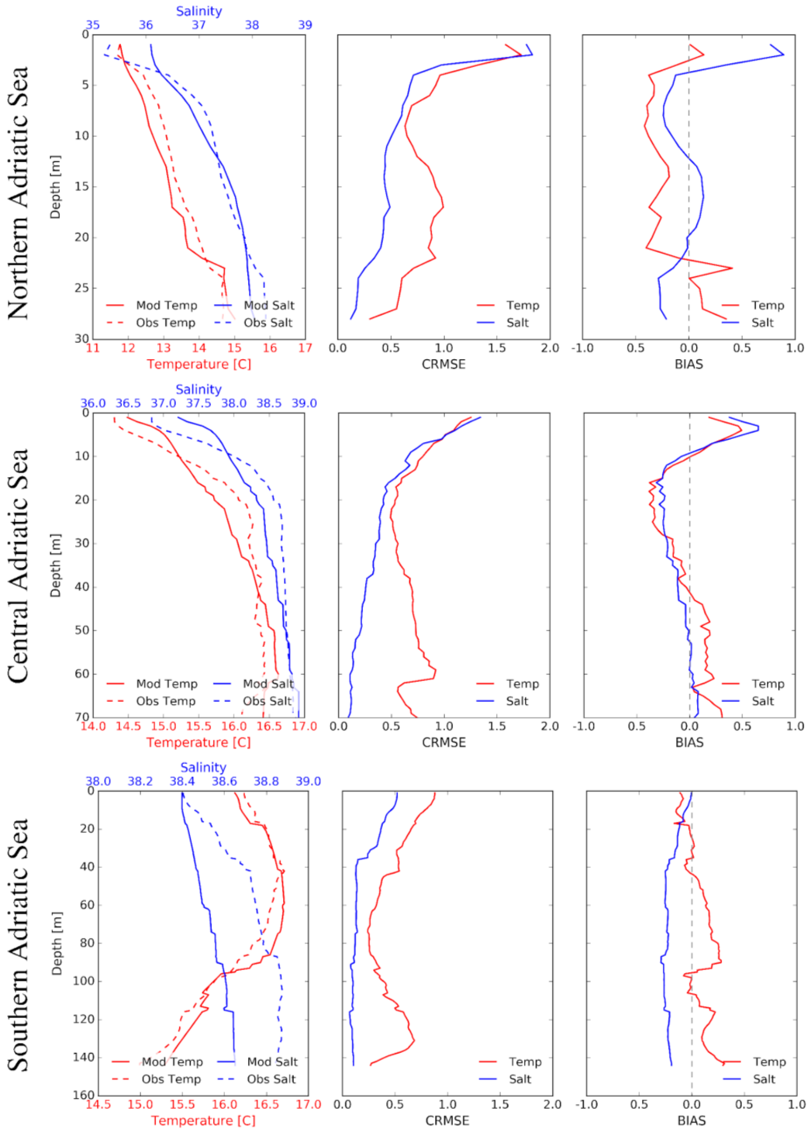

Figure 2 Comparison of Tiresias temperature and salinity profiles with observations.

The system was validated by comparison of CTD field data and modeled temperature and salinity profiles. An example is given in Figure 2. Other tests on the model capability to reproduce coastal processes are reported in Ferrarin et al. 2019.

4 Automatic sharing procedure

An automatic procedure was implemented to check and elaborate the data produced by the Tiresias forecast system and to make them available for the project purpose.

The first day of forecast is averaged daily and resampled on a regular grid of 100m and transferred in netcdf format in the SOUNDSCAPE server at the folder:

/home/mghezzo/ISMAR_shyfem_data/

At the same time the wind components used to force the forecast are transferred in the same folder.

The name of the files has regular pattern ismat_Tiresias_TS_yyyymmgg.nc and isac_bolam_wind_yyymmgg.nc, respectively.

The QUONOPS model can access directly to this folder.

5 Data quality check

An data quality check for the temperature and salinity outputs was implemented.

First a script extracts the vertical profile of temperature and salinity, corresponding to the 9 recording stations. For each point the vertical plot of Tiresias data is draw together with the corresponding CTD profile, if available, and with the COPERNICUS profile. The figure 3, 4 and 5 shown an example of this procedure in the 9 measurement points at the deployment date 09/04/2020, when only the data in MS1 Acqua Alta platform were available.

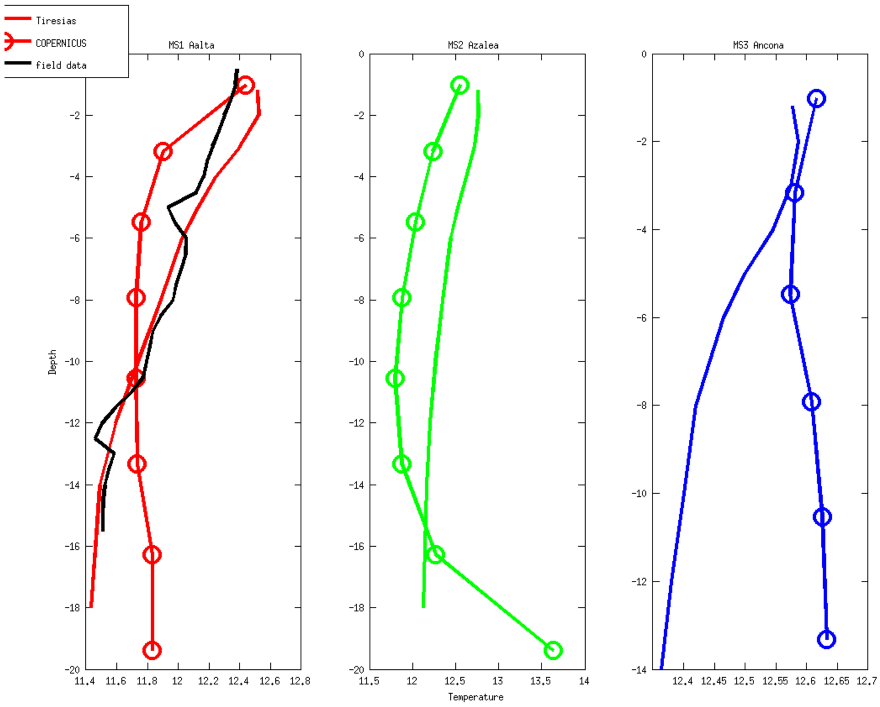

Figure 3 Temperature profiles comparison in stations MS1, MS2 and MS3. Field data (black), Tiresias(line) and COPERNICUS (circles).

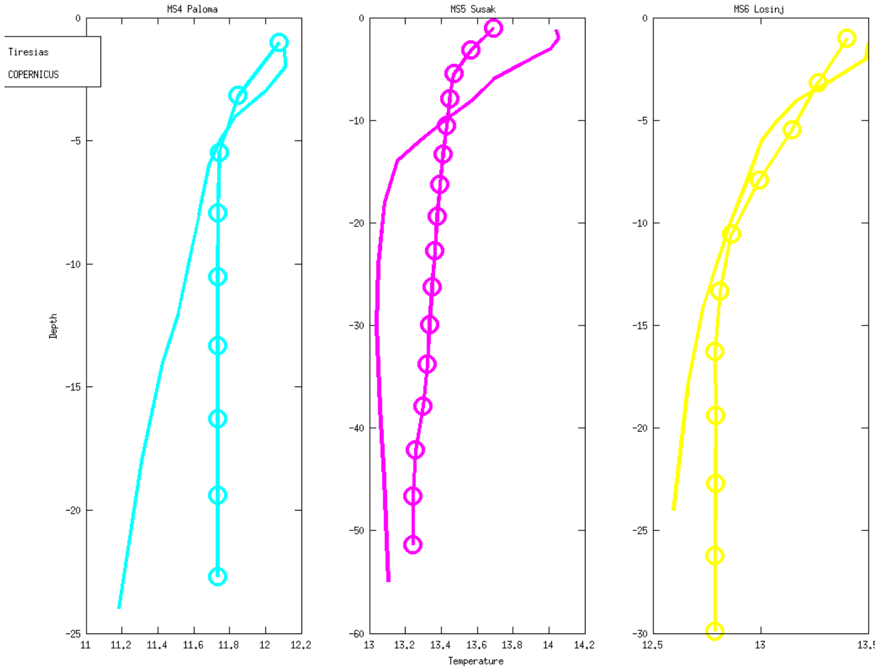

Figure 4 Temperature profiles comparison in stations MS4, MS5 and MS6. Field data (black), Tiresias(line) and COPERNICUS (circles).

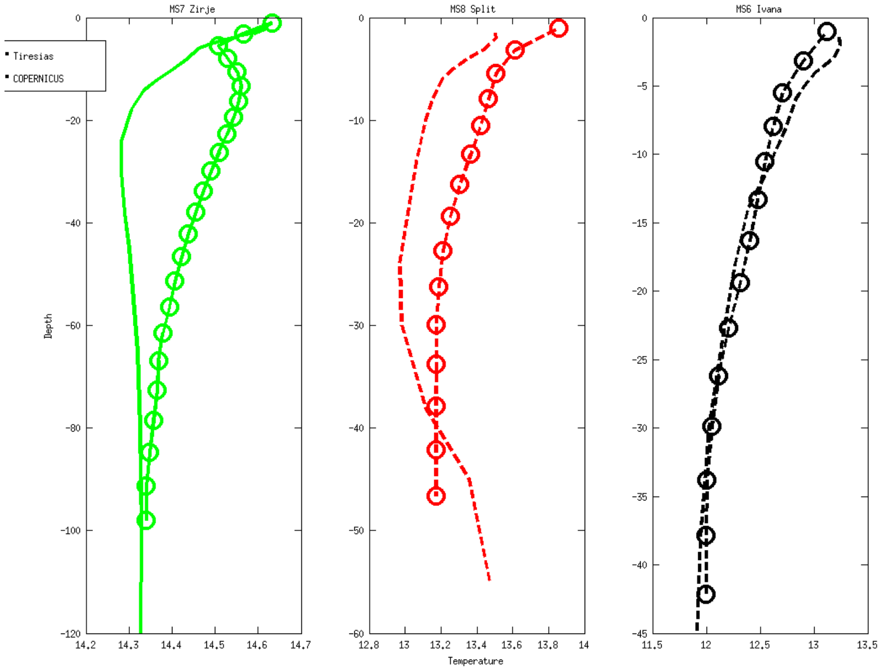

Figure 5 Temperature profiles comparison in stations MS7, MS8 and MS9. Field data (black), Tiresias(line) and COPERNICUS (circles).

The figures shown only the comparison between profiles. It is possible also to estimate the goodness of the fit the CTD data interpolated in correspondence of the Tiresias vertical levels. In this case the correlation coefficient (r2) and the root mean square error (RMSE) are calculated.

The comparison with field data and salinity profiles in Tiresias and in COPERNICUS indicates a difference between models around 0.5-1.5 PSU. The difference between field data and Tiresias is around 1.5 at the surface until to 0.5 in the bottom. In the follow the equivalent figure for salinity as in figure 4, 5 and 6.

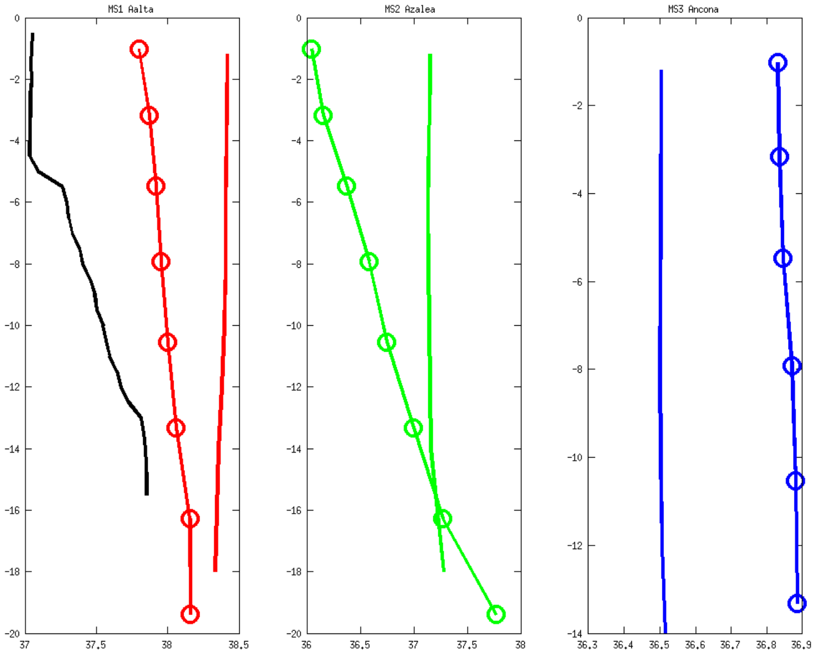

Figure 6 Salinity profiles comparison in stations MS1, MS2 and MS3. Field data (black), Tiresias(line) and COPERNICUS (circles).

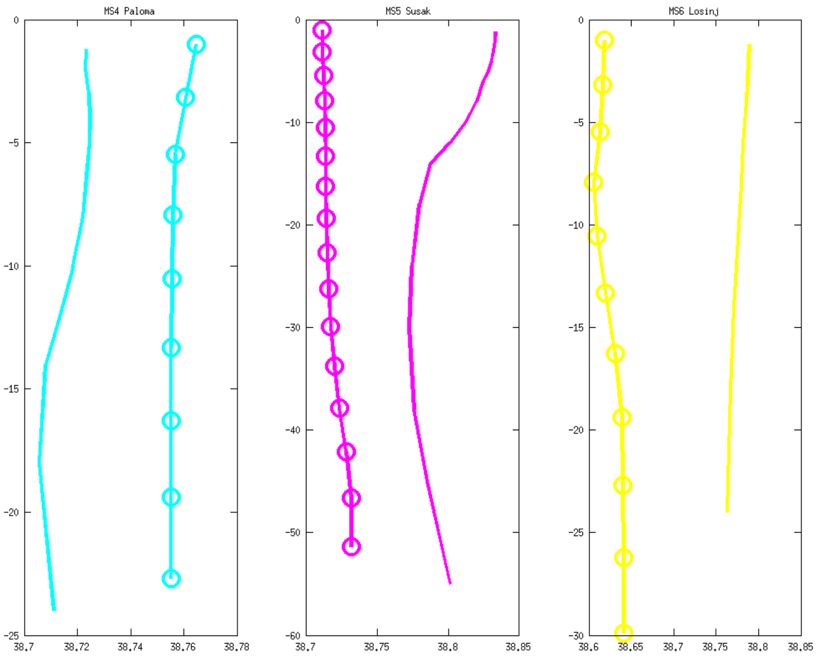

Figure 7Salinty profiles comparison in stations MS4, MS5 and MS6. Field data (black), Tiresias(line) and COPERNICUS (circles).

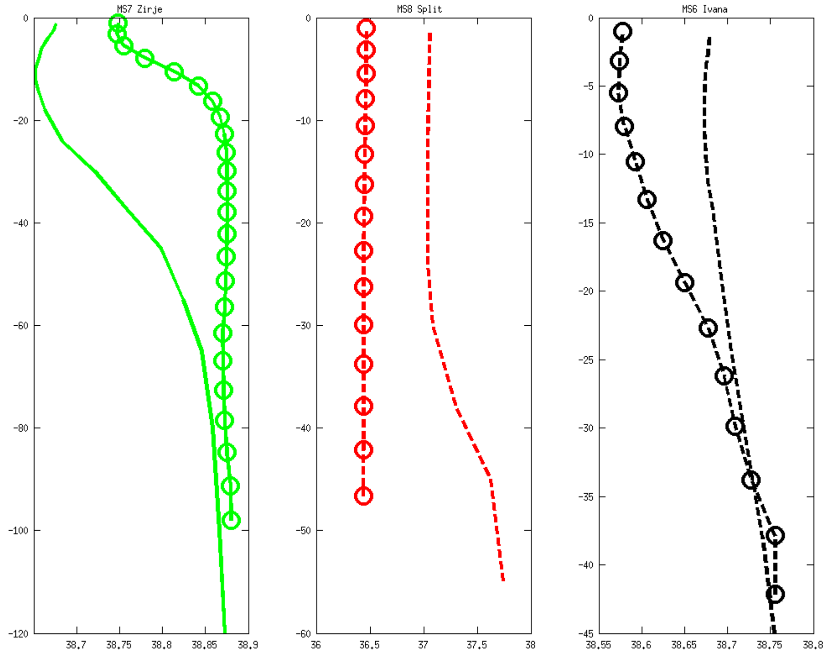

Figure 8Salinity profiles comparison in stations MS7, MS8 and MS9. Field data (black), Tiresias(line) and COPERNICUS (circles).

If no other data as field data or data produced by different numerical models, are available an intercomparison check is performed between the stations. Figure 6 and 7 shown the profiles calculated by Tiresias system at 09/04/2020 in the 9 stations for temperature (a) and salinity (b). This tests that the calculated profiles are qualitatively reasonable.

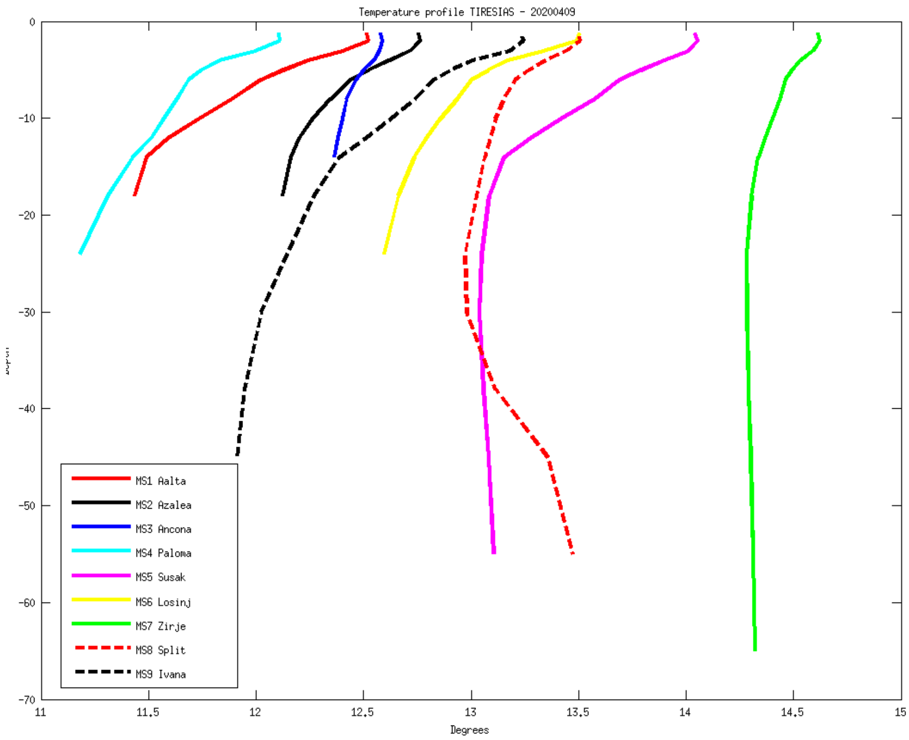

Figure 9 temperature profiles calculated by Tiresias in the 9 stations at 09/04/2020

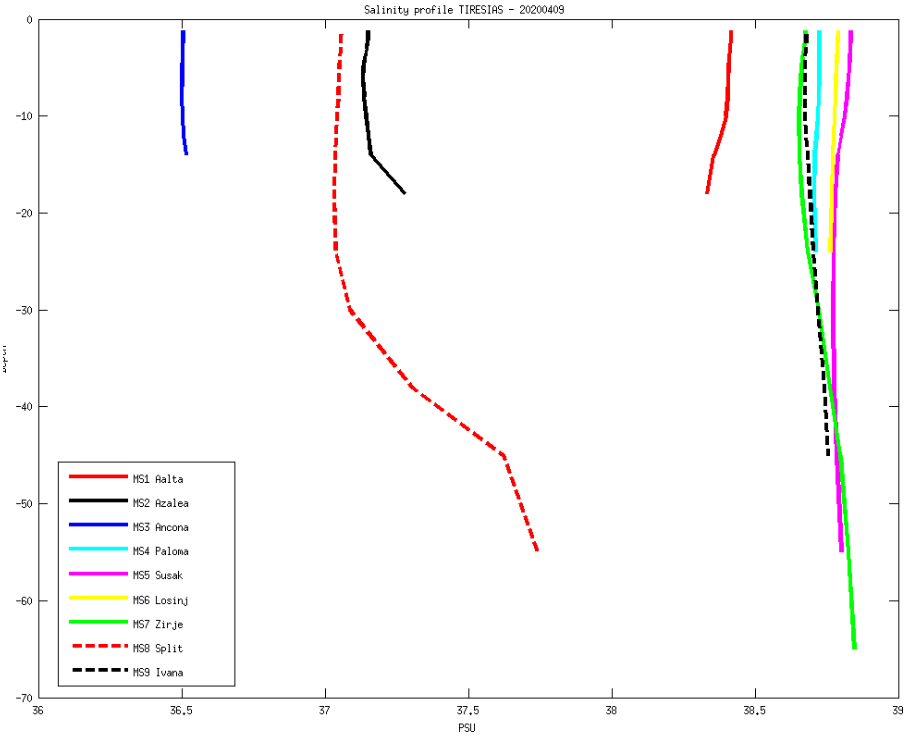

Figure 10 Salinity profiles calculated by Tiresias in the 9 stations at 09/04/2020

Second a check in outliers is performed for each daily Tiresias map in temperature and salinity and the daily maps of superficial values are produced. In Figure 8 are reported the maps of daily averaged temperature and salinity in the top layer of the Tiresias forecasting system at the 09/04/2020.

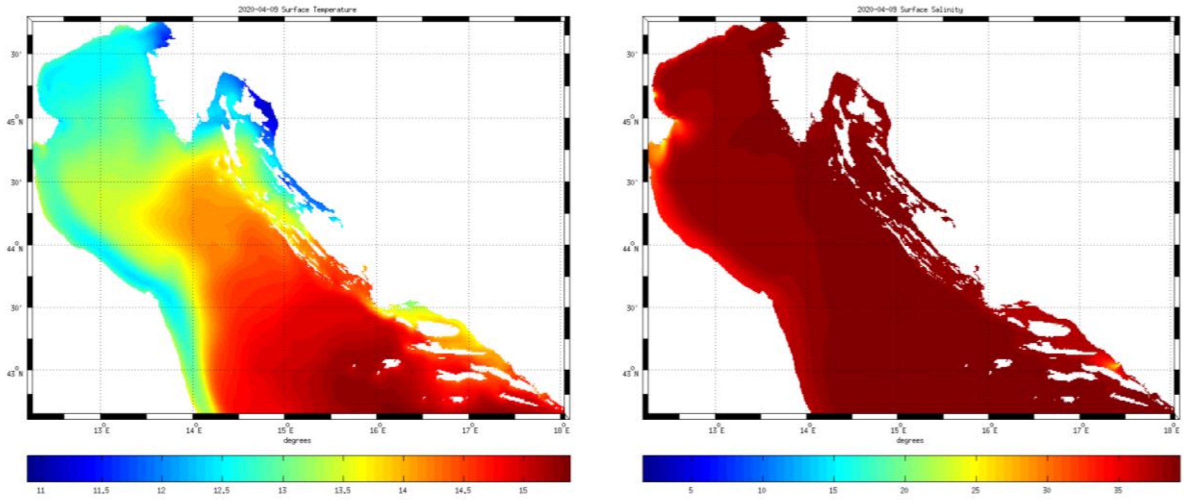

Figure 11 Daily average of surface temperature (left) and salinity (right) calculated by Tiresias forecasting system

The script check for each layer the range of value and the presence of outliers and on demande produce the daily maps.

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