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Hindcasting the Adriatic Sea surface temperature and salinity: A recent modeling experience

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Oceanographic model simulations of the Adriatic temperature and salinity fields for the year 2008 were compared against coastal Conductivity Temperature Depth (CTD) observations and satellite detected Sea Surface Temperature (SST) in order to evaluate the model hindcasting skills. To that end, the Regional Ocean Modeling System (ROMS) configured with horizontal resolution of 2 km and forced with 8 km resolution output from the atmospheric model ALADIN (Aire Limitée Adaptation Dynamique développement InterNational), was applied to the Adriatic Sea.

Temperature and salinity CTD measurements collected along the eastern Adriatic coast, within the framework of the Adriatic Sea Monitoring Program, exhibits correlation with model in the temperature field between 0.75 and 0.95, depending on the season/cruise, while for salinity those values are between 0.32 and 0.78. Comparison of the modeled and daily derived satellite SST for the whole 2008 year was made on each data pixel. Results show that the hindcasts are characterized with small model-to-data RMSE, namely with values in the North Adriatic 0.90 °C, in the Middle Adriatic 0.79 °C and in the South Adriatic 0.80 °C. There is a high correlation between modeled and satellite SST data with values in a range of 0.44 to 0.92, depending on month and region, with a value of 0.99 for all time records and in any of three regions.

Keywords: Adriatic Sea, Sea Surface Temperature, ROMS, in situ data

1. Introduction

Within the framework of the Adriatic Sea Monitoring Program – ASMP (Andročec et al., 2009), numerical modeling of the whole Adriatic Sea was initiated in order to provide the boundary conditions for the smaller domains hydrodynamic, biological and chemical models. Hindcasts were conducted for the period 15 November 2007 until 15 November 2008.

Temperature and salinity Conductivity Temperature Depth (CTD) measurements were made along the eastern Adriatic coast with the primary aim to improve the smaller-domain ecological models. The same data, grouped into coastal regions, were used in this study to assess the hindcast modeling skill. In addition to CTD measurements, remotely sensed Sea Surface Temperature (SST) data, for the whole 2008 at 2 km resolution, provided appropriate spatial and temporal resolution to address the hindcast error for the entire Adriatic Sea. Those daily Level 4 (L4) SST products were made available within Medspiration project.

In this paper, we evaluate the skill of the temperature and salinity hindcasts generated for the ASMP using both mentioned data sources. To that end, a primitive equation Regional Ocean Modeling System (ROMS) forced with winds and other meteorological fields from the ALADIN (Aire Limitée Adaptation Dynamique développement InterNational) model output and configured for the Adriatic region was used to generate the hindcasts.

A recent study (Chiggiato and Oddo, 2008) with similar model-to-data comparison for three different operational systems, one being the AdriaROMS, provides an additional source of data for comparison for this study. They utilized in-situ and remote sensing data collected from the Advanced Very High Resolution Radiometer – AVHRR and a collection of CTD data confined to the western Adriatic to evaluate the mentioned forecasting systems. In that respect, the present study with data-biased on the eastern side, complements the work reported in Chiggiato and Oddo (2008). It should be pointed out that in this study, in a similar manner as the authors before, we used results from a larger model to define open boundary conditions located at the Otranto Strait (Oddo et al., 2006). In addition, assimilation capabilities of the ROMS model were not utilized, as usually done in operational forecasting (e.g. Powell et al., 2008).

The rest of the paper is organized as followed. The study area, model setup and forcing are described in section 2. The data used in assessment are briefly presented in section 3. We examine the results of simulation comparison to CTD and satellite-derived data in section 4. Conclusions are drawn in the final section.

2. Study area, model setup and forcing

The study area encompasses the whole Adriatic Sea, a narrow epicontinental marginal basin, communicating with only one open boundary at the south with the Ionian Sea (Figure 1). Its complex topography, many narrow channels, and islands of various sizes make it a challenging modeling problem. The bathymetry varies over three orders of magnitude with a mean depth of 35 m on the shallow north end, and a depth about 1200 m in the South Adriatic Pit. Figure 1 shows the intermediate structures of Jabuka Pit and Palagruža Sill, but one should bear in mind the bathymetry between islands can be of similar depth. This complex bathymetry as well as orography that surrounds the basin contribute to the rich dynamics of the Adriatic Sea in which

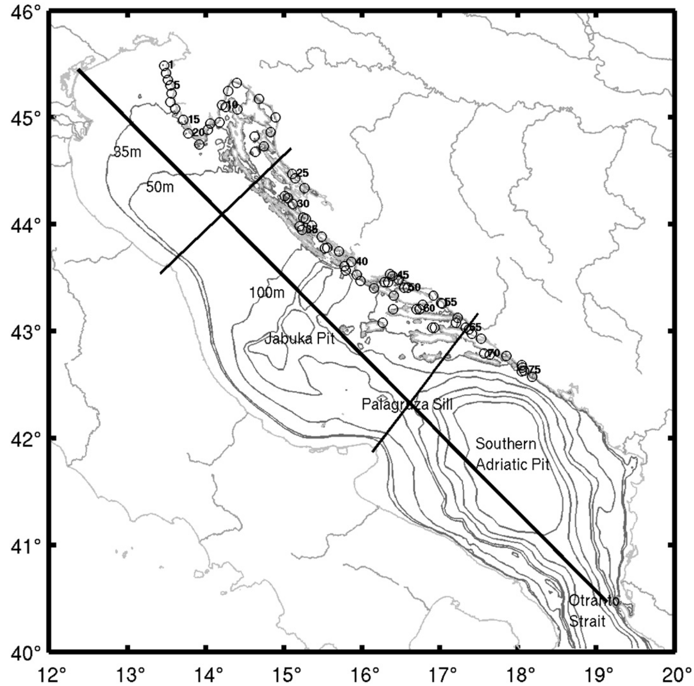

Figure 1. Bathymetry of the Adriatic Sea with CTD stations sorted from North to South along Eastern coast, marked with "o" and corresponding numbers. Across basin lines define northern, middle and southern Adriatic regions used in model to data SST comparison.

air-sea exchange, riverine inflows, and exchange at the Otranto Strait each play a role. These processes, as well as the Adriatic physical oceanography features in general, are reviewed extensively in Cushman-Roisin et al. (2001).

For modeling the Adriatic Sea, we use ROMS version 3.3 (Shchepetkin and McWilliams, 2005). It is a finite difference, free surface model that solves the primitive equations in curvilinear grids by using the Boussinesq and hydrostatic approximations. A major problem of this class of models is the treatment of free surface modes which impose a strong constraint on the time stepping. In the case of ROMS, the solution to the problem is the use of the operator splitting method, by applying a much shorter time step for free surface and barotropic momentum than for temperature, salinity and baroclinic momentum. The advection scheme for temperature and salinity used in the study is multidimensional positive definite advection transport algorithm (Smolarkiewicz and Margolin, 1998), which is a conservative and positive definite scheme. For baroclinic momentum, we used the upwind 3rd order scheme. Sigma coordinates are used for the vertical discretization, and the implied errors in the horizontal pressure gradient are minimized using the spline method (Shchepetkin and McWilliams, 2003). A comparison of turbulent closure parameterizations (Warner et al, 2005) demonstrated that general length scale methods are better than the Mellor Yamada 2.5 formulation, with no significant difference between *k-ε*, *k-ω,* and *gen.* schemes. Therefore, we used the general length scale parameterization *gen.* with the parameter values given in of Warner et al. (2005) and the background vertical viscosity of 10^{-6} m^2/s (Li and Boicourt, 2005). The bottom friction is of quadratic form with a coefficient computed from the logarithmic profile. For bulk fluxes of surface heat exchange and momentum, we used Fairall et al. (1996) while equivalent salt exchange is computed from the evaporation within ROMS, and rainfall rates were prescribed from ALADIN model. At the open boundary of our model (located at the Otranto Strait), we used tidal forcing with Chapman and Flather boundary conditions (Chapman, 1985; Flather, 1976) for free surface and barotropic velocities. Tidal variability of free surface and currents for the major 7 tidal constituents (Janeković and Kuzmić, 2005) is added to the boundary values of daily average Adriatic REGional model (AREG) outputs (Oddo et. al., 2005). For temperature and salinity fields, we used AREG values along with radiation type conditions imposed at the open boundary.

The curvilinear grid used in the study has a spatial horizontal resolution of 2 km. It has been chosen so that the numerous islands and straits of the Adriatic Sea are reproduced as faithfully as possible, while still providing annual and/or near-real time simulations in a timely fashion on available hardware. The available bathymetry with a spatial resolution of 7.5 sec is averaged on the 2 km grid. In order to make the necessary bathymetry smoothing and reproduce as much as possible the real features of the basin, we used the linear programming method (Dutour Sikirić et al., 2009). In the vertical, we used 20 sigma levels with a nonlinear transformation to ensure that the near-surface layer is adequately resolved (Figure 2).

Numerical simulations were performed from 15 August 2007 till 15 November 2008, starting 3 months before the start of the project. The temperature, salinity, free surface and velocity fields of the initial state were obtained from the AREG model. The initial values for turbulent kinetic energy and turbulent length scale were problematic; they are governed by the two-equation model of the GLS. Spin up periods of turbulence models are rarely considered, but in our case, the vertical viscosity reached at some grid cells a value bigger than 100 m^2/s. Those excessively high values lead to destruction of the vertical T/S profiles at those respective cells. To remedy this problem, we used a three-day spinup period in which the effect of vertical viscosity on temperature and salinity was limited to 0.01 m^2/s.

At the surface, the model was forced with atmospheric data originated from the ALADIN atmospheric model, with 8 km spatial resolution and temporal resolution of 3 hours. The model provided shortwave radiation, 2 m temperature, relative humidity, 10 m wind, mean sea level pressure, total cloud cover and precipitation. Longwave radiation was computed from cloud cover fraction, and air/sea temperatures using the Berliand formula (Berliand and

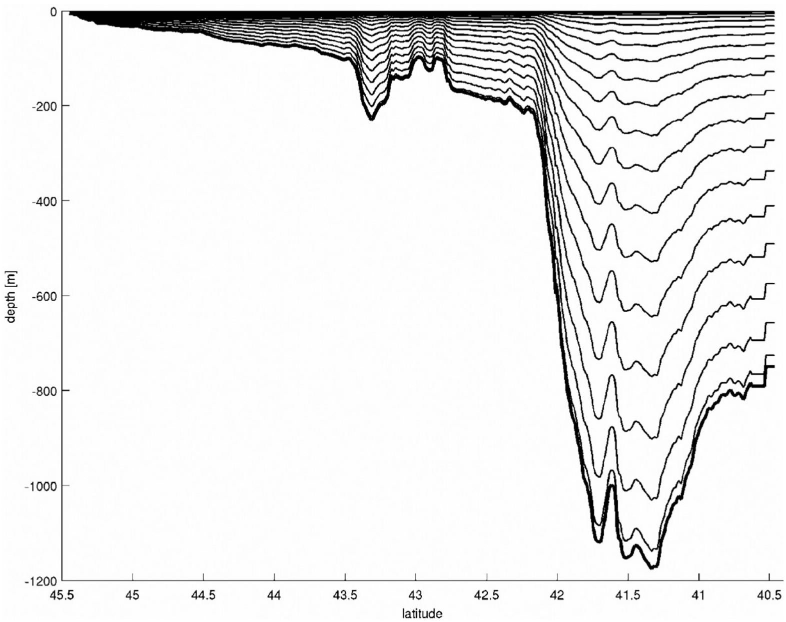

Figure 2. Vertical model levels along the longitudinal transect marked in Figure 1.

Berliand, 1952). It should be noted that we use rain fall rate (P) from the ALADIN model, but evaporation (E) was computed inside the ROMS model from the bulk flux formulation. This could introduce imbalance in the fresh water flux at the air-sea interface. In our case, it means that evaporation could be slightly underestimated and that the resulting E-P is sometimes negative, while it is expected to be positive over the whole year (Maggiore et al., 1998). Coupling ocean and atmosphere models could solve the problem but only if both models use the same boundary layer formulation, which is not usually the case. When interpolating ALADIN values onto the ROMS grid, we first computed the coefficients of linear interpolation and discarded the cells that are located on the land. If all points were discarded, we took the values at the nearest point of the atmospheric model over the sea in order to avoid contamination of ocean forcing fields by using meteo values over the land. The shortwave heating of the water column is modeled by exponential decay parameters (Paulson and Simpson, 1977) obtained by assuming that the sea waters are of Jerlov type I.B (Jerlov, 1976). More accurate description of near-surface conditions in space and time were not available. Fresh water inflow was taken into account by applying 48 fresh water sources around the basin according to Raicich (1994) climatology and modified with real time measurements of temperature and river flux for the Po and Neretva rivers. In addition to the two major fresh water sources we had access to real time data for small rivers on the eastern side of the Adriatic Sea: Ombla, Jadro, Krka, Zrmanja, Cetina, Rječina, Dubračina and Raša which we used during the simulation. For rivers Mirna, Dragonja, Timav, Drnica, Badaševica, Rižana and Soča, we used recently published climatological values (Malačič and Petelin, 2009). For the rest of the rivers located at the western side of the Adriatic Sea, we scaled their climatological flux values with respect to the measured Po river flux. The scaling factor as function of time was computed as the ratio between measured Po river fluxes and climatological values for Po river in that particular time. On the other hand, for fresh water springs located predominantly in the Velebit Channel and Rijeka Bay, we used scaled climatological values with respect to the Neretva river, computed in the same manner as for the Po river. This approach assumed that if there is a dry or rainy period at the western side of the Adriatic Sea (according to the Po river flux) then it is propagated into all other fresh water sources on the side for that period. A similar situation holds for the eastern side of the Adriatic coast and rivers where we had no observations. This can seem wrong for certain episodes, but generally, we think this improves the crude climatological values for the rivers and springs without available measurements.

3. Data

The complex topography and the size of the Adriatic Sea, as seen on Figure 1, will always result in undersampling of 3D variables needed for model initialization or comparison. During the project, CTD data were collected in the proximity of Croatian coast (1 Nm off the coast) and were designed to be used in local small domain models and not for direct comparison with the ROMS 2 km model. Still, we found the data valuable for estimating the error of our model near the coast. Therefore, one has to bear in mind that this is the very first wet grid cell in the model where lateral boundary conditions play an important role, and physical processes are still not fully developed. Nevertheless, we used the CTD data observations in four different periods, one at the beginning of the project – November 2007, then in March 2008, following with May – June 2008 and July 2008. Data were sampled at 77 CTD stations along the Croatian coast (Figure 1) making an overall large number (13629 = 4 casts * 77 stations * depths every 1 m) of available data for model comparison. Mismatch between model and CTD depths were more pronounced at the southern part of the stations, hence we decided to use only the CTD data at depths that are presented within our model so that no vertical extrapolation was made from the model to CTD data.

The second type of data used in model skill estimation is produced by the European Space Agency's Medspiration project (http://www.medspiration.org). We used the daily L4 high resolution SST product retrieved from Jan to Sep 2008 at 2 km resolution. These are merged SST data, derived from both infrared and microwave sensors, into a single daily product that provides the best estimate of foundation SST, i.e. the SST free of diurnal warming influence and

Table 1. Statistical parameters for model to CTD data comparison. The columns represent in order mean cruise date, number of CTD stations used for comparison, temperature and salinity RMSE, ME and Correlation coefficient.

Mean Cruise date	N	Temperature (°C)			Salinity (psu)		
		RMSE	ME	Correlation	RMSE	ME	Correlation
01-11-2007	75	1.18	0.84	0.75	0.47	–0.17	0.32
20-03-2008	78	0.61	0.33	0.92	0.69	–0.30	0.64
01-06-2008	77	0.92	–0.21	0.92	0.92	–0.44	0.76
01-07-2008	77	1.38	–0.37	0.95	0.79	–0.41	0.78

cool skin effect. SST skin or sub-skin data from different sensors are first converted to foundation SST by applying skin layer and diurnal thermocline structure parameterization. Afterwards, the optimal interpolation technique is used to merge the converted data. Since foundation temperature represents the temperature of the upper mixed layer, this temperature should correspond to the surface layer of the ocean model and therefore is adequate for comparison with model data. However, one problem that arises in the winter months for the Adriatic Sea, specifically the northern part, is the lack of observational data over the Adriatic Sea; higher resolution infrared sensors cannot provide any observation for prolonged periods of time due to the prevailing cloud coverage, while microwave sensors, unaffected by clouds, have near-land SST contamination of around 75 km with a rather coarse sensor resolution (1/4 deg). In absence of available high resolution observation, analyzed SST fields are sometimes overly smoothed. When producing L4 SST analysis, each single sensor measurement contributes its own error statistic to the value of each pixel, and the overall L4 absolute error is targeted to be less than 0.4 °C (Donlon et al., 2005).

When compared to the CTD data, the SST L4 data, are limited only to the surface layer and have a significantly higher observation error. Nevertheless, they are available over the entire domain on a daily basis, which makes them extremely useful for assessing model SST skill.

4. Results and discussion

As noted in Greenberg et al. (2007), comparing model with data has an intrinsic difficulty: numerical schemes, and thus models, have good error estimates in the middle of the domain but are inaccurate on the boundaries, where measurements are performed. This makes it quite hard to evaluate the quality of oceanographic modeling; especially in our study, since the reliable water column oceanographic data sets we have are CTD data near the coast and SST data on the surface. Within the study, we performed simulations using the previously described setup without any data assimilation techniques. Comparison of measurements with model results was done by interpolating in space and time from model hourly outputs into observation data space.

4.1 Model to CTD data comparison

Model-to-data comparison was done for CTD data sampled during four cruises (November 2007, March, May and July 2008) by applying 3D interpolation of observed CTD data to model depths. We found some inconsistencies between the depth measured by CTD and the existing bathymetry in the model, mainly due to the fact that bathymetry of the model grid is the average of observed bathymetry over 2 km x 2 km grid cells. Nevertheless, for stations 23, 27, 44, 47, 74 and 77 the differences are more than 20 m, which leads us to suspect that some of bathymetry measurements used in the model grid are incorrect.

Comparisons for temperature in November 2007 yield relatively large RMSE at all depths with a mean value of 1.18 °C. We believe that the large model-to-data discrepancy reflects the fact that the model was still in spinup phase from the AREG fields, which were warmer than CTD observations at the end of year 2007; this is evident in the high value for ME of 0.84 °C (presents bias of the model with respect to the observations). The situation is much better for salinity; the overall RMSE is 0.47 PSU, with its highest value at the surface of 0.56 PSU (from surface till 20 m depth), as opposed to 0.15 PSU for deeper ones (20 m till bottom). The overall ME for salinity is –0.21 PSU for the shallow part and –0.09 PSU for the deeper part of the water column with a column mean value of –0.17 PSU. The correlation coefficient, with a confidence level of 95 %, between model and CTD data for all depths is 0.75 and 0.32 for temperature and salinity, respectively.

After winter, when the water column in the shallow coastal region has cooled all the way from surface to bottom, one can expect that the sea state has reset, and a new cycle of heating process begins. The ability of the model to develop vertical structures can now be evaluated, it will reflect the capability of our model to correctly represent turbulence and vertical heat transfer between the atmosphere and the ocean. For temperatures in March 2008, the results are much better from a statistical point of view. RMSE equals to 0.60 °C and ME is 0.33 °C, showing that the model-to-CTD data bias is quite small. There is still mismatch between model and CTD data at stations close to river inlets, where the model is too fresh and too cold at the surface; this is true for the most CTD casts during the project (Figure 3, stations 4, 31, 53 and 69 near Rječina, Zrmanja, Cetina and Neretva). One should note that those CTD stations fall in the very first model grid where we have imposed point source river forcing. On the other hand, station 22, at the southern tip of Istria, is not adequately resolved because it is near a group of small islands that are not reproduced in the model grid. Station 58, near island Brač, exhibits the similar issue. Another problem that we noticed were narrow straits, for

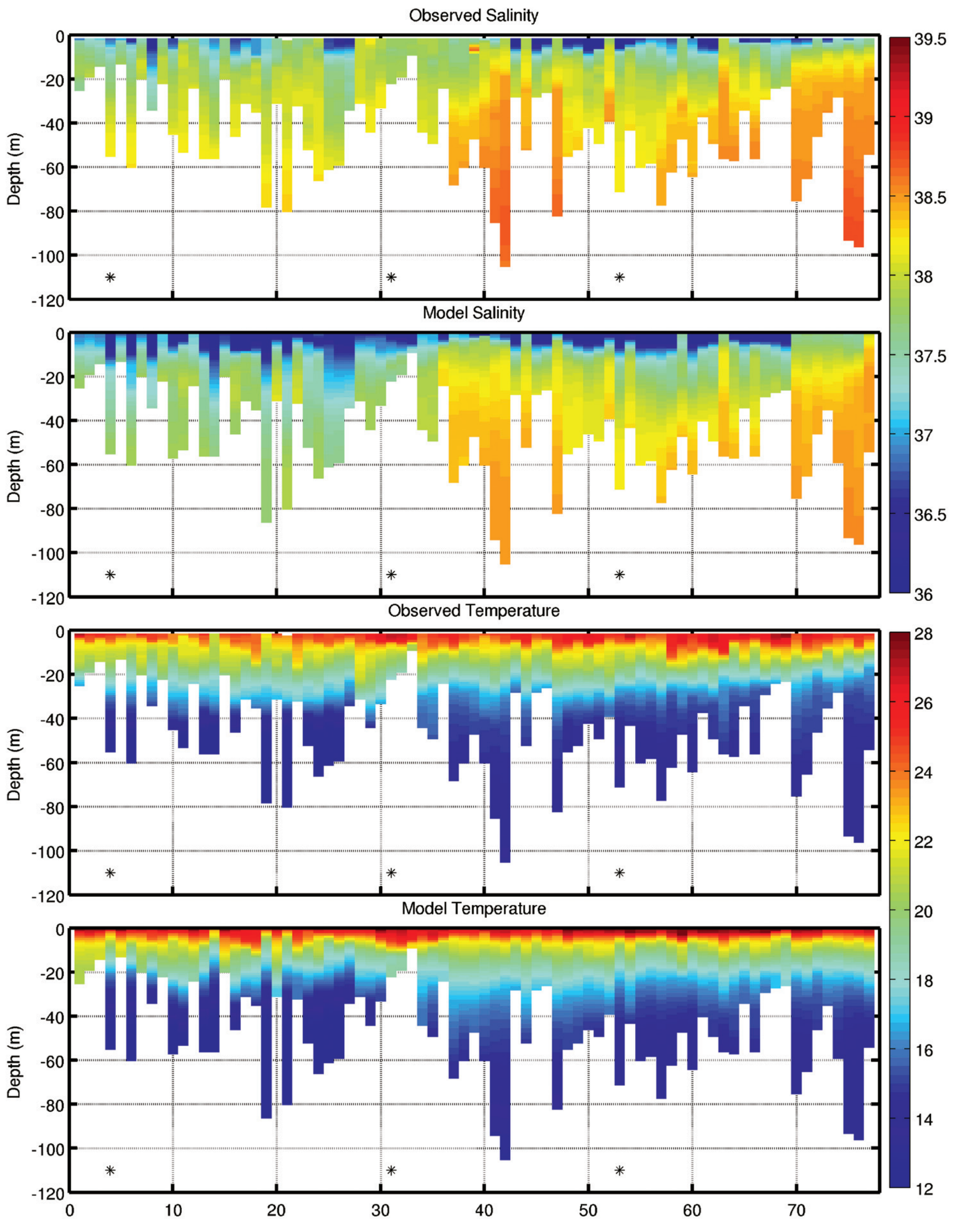

Figure 3. Temperature and salinity data for July 2008 cruise based on CTD observations and model prediction. The stations are at x-axis and numbers correspond to one at Figure 1 (sorted from North – station 1 to South – station 77). Observations 4, 31 and 53 with star are near rivers Rječina, Zrmanja and Cetina.

example the one between the island Pag and Krk, which are important for circulation but almost impossible to reproduce adequately within numerical model grid. Stations 8 and 28 are flawed for this reason. For the most of the CTD data, the model is too fresh with the exception at the south (Figure 3) where we have the opposite situation, the model is slightly saltier than observations, probably because we had poor representation of the Albanian rivers inside our model.

In May–June–July, the thermocline develops, and it is apparent from Figure 3 and transect plots (not shown) that the model represents this development well. The model predicted thermocline in the majority of the stations at correct depths, with somewhat a bit shallower thermocline for southern stations (Figure 3). Therefore, this gives us confidence in the turbulence closure scheme used in the model, at least in comparison with available CTD data.

In the Southern part of the Adriatic Sea, observed CTD values are well represented within the model throughout all casts, with correct values for temperature and salinity and a relatively small error overall. All of these results indicate that exchange between Adriatic and Ionian Sea waters are well modeled by the AREG model and thus, by the ROMS model as well. However, the quality of results for stations strongly influenced by topography or in the proximity of rivers was worse.

Recently, Chiggiato and Oddo (2008) made inter-model – CTD comparisons for the Adriatic Sea using a setup similar to ours. The results of their study provides us with valuable information of model-to-data misfit that one could expect for three different models (AdriaROMS, AREG – both local models for the Adriatic Sea with spatial resolutions of 3–10 km and 5 km, respectively, and MFS, also known as Mediterranean Ocean Forecasting system, with a resolution of 7 km). In their work, they compare model to CTD temperature data misfits in winter, when the water column is not characterized by pronounced stratification, along the western side of the Adriatic Sea (January 2005). Similar to our approach, they split their comparison into two groups: shallow water 0–20 m and deep water 20–50 m. AdriaROMS had a RMSE close to 1 °C with a ME close to 0 °C, the AREG RMSE was close to 1.5 °C with a ME in the range –1 to 0 °C and MFS RMSE was in the range of 1.5 to 2.0 °C with a ME in a range of –1.1 to 0.7 °C. Unfortunately, we cannot directly compare our results with theirs because our CTD observations are made at different locations and times, but the comparison can give us an idea of our model skill in the Adriatic Sea. In particular, a comparison of our March 2008 cruise CTD data on the eastern side of the Adriatic Sea in shallow water and still winter time conditions, gives a smaller model to data of RMSE (0.60 °C).

4.2 Model to satellite SST data comparison

Medspiration L4 SST data products, used in model to data comparison, were available from January till the end of 2008 on a daily basis, with some gaps in April and May. We used daily fields from the individual scenes and compared them against model values at 3 UTC time. In that sense, model temperature values were not affected by diurnal heating and thus were equivalent to foundation temperature.

To further investigate and locate the regions that contribute the most to the model mismatch, we divided the Adriatic Sea into three subdomains; northern, middle and southern Adriatic regions (see Figure 1 for the regions). For each of the regions, we performed statistical analysis using the same method, we interpolated the model results onto satellite grid. We had a total number of 8372 pixels for the northern, 13488 for the middle and 14372 for the southern region on a daily basis. Using the values, we computed the ME, Correlation Coefficient (CORR) and RMSE as measure of model-to-data skill. In general, similar performance is found for the whole Adriatic Sea (Figure 4, Table 2), with subtle differences in each region whether affected by lateral forcing, rivers or open boundary. When using numerical models based on sigma vertical coordinate it is difficult to reproduce the thermocline adequately in deep waters. The top sigma layer should not be too deep, and the number of levels should be sufficient in order to constrain the vertical temperature structure well. In order to resolve that, we used proper boundary conditions from AREG model, as well as new, nonlinear vertical, sigma transformation characterized with denser and thinner layers in the surface region. The slightly larger error found during June in the Northern Adriatic can be attributed partly to the problem of river forcing that is difficult for the model to resolve fully and adequately. Moreover, when looked closer to the source of the discrepancy at the specific days in June, we found that for certain scenes there were no AVHRR data available, meaning that the Medspiration data were obtained solely from coarse resolution microwave data. The same holds for some days in July demonstrating that we should use the data with additional caution.

Transect plots (not shown) and previous CTD plots indicate that the ROMS model reproduces the thermocline in shallow water regions well since the surface is adequately resolved. The ME (Figure 4, C) remains low over the whole period but the correlation (Figure 4, D) is lower for August until October, probably due to the more important subgrid scale processes at the surface.

If we calculate ME for all available data and for all pixels in the Northern Adriatic with respect to the satellite SST, there is a small model bias of –0.03 °C with a RMSE equal to 0.90 °C. The Middle Adriatic overall ME for SST is –0.12 °C with a RMSE equal to 0.79 °C, while for the Southern Adriatic the numbers are –0.03 °C and 0.80 °C, respectively. The correlation coefficient has a value in the Northern Adriatic between 0.70 and 0.89, in the Middle between 0.44 and 0.92 and in the Southern Adriatic between 0.50 and 0.91. However, if we take all available data in time for the model and the satellite and then compute statistics in the same way, we got correlation coefficient of 0.99 for any of the three regions in the Adriatic Sea.

Note that during model to data comparison, we discarded the data in April, since only 3 days of analyzed SST was available due to technical issues, as well May, since we did not have any satellite data to compare with.

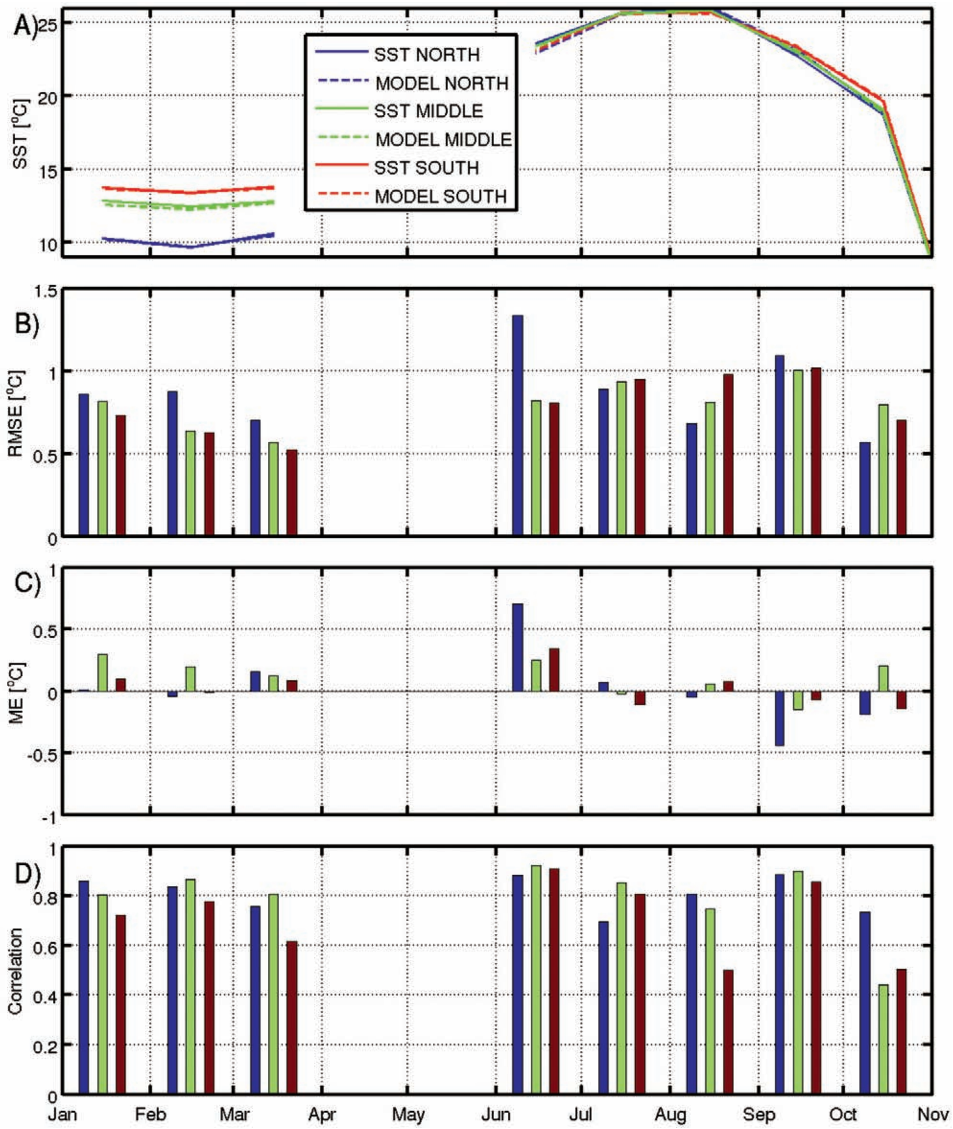

Figure 4. Statistical analysis for the Northern (blue), Middle (green) and Southern (red) regions of the Adriatic Sea. Monthly means for SST from satellite (full line) and model (dashed line) at the three regions (A), RMSE (B), Mean Error (C) and Correlation (D).

Table 2. Statistical parameters for model and remotely sensed SST monthly mean fields in 2008 year at different regions.

		ME		
MONTH	NORTH	MIDDLE	SOUTH	WHOLE
January	–0.00	–0.29	–0.10	–0.15
February	0.05	–0.20	0.01	–0.06
March	–0.15	–0.12	–0.08	–0.11
Jun	–0.71	–0.26	–0.34	–0.39
July	–0.08	0.02	0.11	0.04
August	0.05	–0.06	–0.08	–0.04
September	0.44	0.15	0.07	0.19
October	0.19	–0.21	0.14	0.02
Whole period	–0.03	–0.12	–0.03	–0.06
		RMSE		
MONTH	NORTH	MIDDLE	SOUTH	WHOLE
January	0.86	0.82	0.73	0.79
February	0.87	0.63	0.63	0.69
March	0.70	0.57	0.52	0.58
Jun	1.33	0.82	0.80	0.96
July	0.89	0.93	0.95	0.93
August	0.68	0.81	0.98	0.85
September	1.09	1.00	1.02	1.03
October	0.57	0.79	0.70	0.71
Whole period	0.90	0.79	0.80	0.82
		CORRELATION		
MONTH	NORTH	MIDDLE	SOUTH	WHOLE
January	0.86	0.80	0.72	0.90
February	0.84	0.87	0.78	0.93
March	0.76	0.81	0.62	0.93
Jun	0.88	0.92	0.91	0.90
July	0.70	0.85	0.81	0.81
August	0.81	0.75	0.50	0.68
September	0.89	0.90	0.86	0.88
October	0.74	0.44	0.50	0.63
Whole period	0.99	0.99	0.99	0.99

5. Conclusions

In this study, we have addressed the skill of the Adriatic Sea temperature and salinity hindcasts obtained with the implementation of the ROMS model. The hindcast error estimate was obtained by comparing the ROMS model results with CTD observations in the coastal zone, collected during four cruises at 77 stations, as well as with the remotely sensed SST produced by the Medspiration project. The comparison has shown that the model hindcasts are capable of reproducing the near coastal fields of temperature and salinity (Table 1) with accuracy agreeable, or better, to operational model predictions reported in Chiggiato and Oddo (2008). The period of renewed, spring heating proved to be a rather demanding test for the turbulent closure schemes, but the model successfully reproduced the formation of the seasonal thermocline, in terms of magnitudes and depths. Comparison with previous results (Chiggiato and Oddo, 2008) indicate that the present hindcast has a smaller RMSE, although direct comparison is not strictly valid (observations are made in different time and at different locations). The overall model-to-CTD data hindcast RMSE for 2008 was 1.02 °C for temperature and 0.72 PSU for salinity. The lack of complete river discharge data and exact positions and fluxes of the bottom springs seems to be a considerable problem. The major part of the model to CTD data mismatch is found in the surface layers where river effect is dominant. Climatological values for river runoff are usually limited to the mean values providing low frequency signals that can become problematic for coastal regions due to large variability in time. Comparison with the remotely sensed SST data during the period January 2008 – September 2008 revealed that the ME is similar in the whole Adriatic; in the northern part it is –0.03 °C, middle –0.12 °C and in the southern –0.03 °C. Overall RMSE during the simulation is less than 0.90 °C in all regions. However, we would expect that in sigma based models, where vertical layers have different thickness, more problems would appear in the deeper regions of the model domain (in our case in the Southern Adriatic). In that sense, it is difficult to reproduce seasonal thermocline variability in deeper waters simply by using sparse and thick sigma levels at the surface. In order to minimize the effect, we used a new nonlinear vertical sigma stretching formulation, recently available in ROMS model rev. 322, to provide us far more surface levels in the problematic deep region. Another problem that contributed to the error was the influence of the boundary condition and initial state; we initially used simple radiation boundary conditions along with climatological initial fields, but using AREG initial fields and daily boundary values from the same model proved to be more successful. It is worth mentioning that the ocean model used to generate hindcasts used 2 km spatial resolution whereas the atmospheric forcing was provided at 8 km spatial resolution. The complex eastern side of the Adriatic Sea is characterized by many narrow channels and islands in Croatian waters, suggesting that model solutions could still benefit from higher and better balanced atmospheric and marine model resolution. Another cause of concern is the inaccurate bathymetry measurements in the available bathymetry database. Improvements along any of the mentioned lines are likely to improve the skill of the hindcasts; some of which are already under way.

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SAŽETAK

Predikcija površinske temperature i slanosti Jadranskog mora: novije iskustvo u modeliranju

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Modelske simulacije jadranske temperature i saliniteta u 2008 godini uspoređene su s priobalnim CTD mjerenjima i satelitski detektiranim površinskim temperaturama mora u cilju vrednovanja prediktivnih sposobnosti modela u priobalnom moru. S tim ciljem je Regional Ocean Modeling System (ROMS), forsiran atmosferskim modelom ALADIN (Aire Limitée Adaptation Dynamique développement InterNational) uz razlučivanje od 8 km, primijenjen na Jadransko more uz horizontalno razlučivanje od 2 km.

Mjerenja temperature i saliniteta pomoću CTD sonde, obavljena u istočno-jadranskom priobalju u okviru Programa monitoringa Jadranskog mora, imaju visoku korelaciju s modelom u temperaturnom polju s vrijednostima između 0.75 i 0.95, ovisno o godišnjem dobu/krstarenju, dok za polje saliniteta vrijednosti su između 0.32 i 0.78. Usporedba s daljinski detektiranim podacima o površinskoj temperaturi mora (SST), za cijelu 2008. godinu, napravljena je za svaki pojedinačni pixel s podacima. Rezultati usporedbi pokazuju da aposteriorne simulacije (hindcasts) za cijelu 2008 godinu imaju malu RMS pogrešku, u sjevernom Jadranu 0.90 °C, u području srednjeg Jadrana 0.79 °C, te južnog Jadrana 0.80 °C. Koeficijent korelacije između modeliranih i satelitski dobivenih površinskih temperatura mora ima vrijednosti između 0.44 i 0.92, ovisno o mjesecu i području Jadrana, dok za sve vrijednosti u vremenu iznosi 0.99 za bilo koje područje.

Ključne riječi: Jadransko more, površinska temperatura mora, ROMS, in situ podaci

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