INTERCOMPARISON OF SURFACE HEAT AND WATER FLUXES FOR THE ADRIATIC SEA BETWEEN ECMWF RE-ANALYSIS (ERA-40) AND CLIMATOLOGICAL DATA SETS

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Abstract. Using monthly means for the period 1957-1987, the ERA-40 pseudo-climatological heat and water fluxes have been assessed for the Adriatic Sea basin and have been compared with climatological data sets. It is shown that the shortwave and latent heat fluxes of the ERA-40 are underestimated compared to the climatological ones. This results in overestimation of the annually averaged total heat fluxes. The ERA-40 precipitation and evaporation are underestimated, also. The analysis shows that the ERA-40 heat and water fluxes can not be used in their original form to force a general circulation model for the Adriatic Sea. A simple correction procedure is applied in order to compensate the deviation of the ERA-40 surface fluxes from the climatological ones.

Key words: ocean/atmosphere interactions, weather analysis, Adriatic Sea.

Introduction

The European Centre for Medium-range Weather Forecasts (ECMWF) 40-year reanalysis (ERA-40) project provides a very high quality reference atmospheric state for quite a long period – from September 1957 to August 2002. In addition to analysis of the basic atmospheric variables such as pressure, temperature, wind and humidity, ERA-40 also provides estimates of many diagnostic variables, such as precipitation, energy and momentum fluxes. Due to insufficient observational coverage of many atmospheric variables, researchers in meteorology and oceanography often use re-analysis data as pseudo-observations for validation, verification, initialization, or for the forcing of regional models.

Although largely successful and widely used, several problems were detected in the ECMWF re-analysis data. Mainly, they concern the ERA-40 hydrological cycle and surface energy budget (Betts et al., 2003, Hangemann et al., 2005). The most significant deficiency of the ERA-40 hydrological cycle is the overestimation of tropical precipitation over the oceans (Hangemann et al., 2005). Further deficiencies comprise an overestimation of evaporation and underestimation of precipitation over many river catchments (e.g. Danube, Mississippi etc.), which result in a dry bias over wide land areas. Comparisons of the ERA-40 radiation model with observations (Morcrette, 2002) show that radiation budget fields suffer from deficiencies in the radiative properties of the clouds, and are not recommended for use in studies where accurate heat fluxes are required.

There are two methods to solve a problem with mentioned ERA-40 deficiencies. The first one is to correct the ERA-40 fields, using observational data. This approach is used to correct the excessive precipitation in the tropical regions (Troccoli and Kålberg, 2004). The second one is to recalculate the heat and water fluxes, treating some of the ERA-40 fields as error-free and substituting most problematic fields with analogous, taken from other reliable sources (Maggiore et al., 1998). Unfortunately, the computation of ocean surface fluxes strongly depends on bulk algorithms used, and the use of inadequate bulk formulae can introduce considerable errors (Castellari et al., 1998, Supić and Orlić, 1999).

The aim of present study is to compute climatological surface energy and water budgets derived from the ECMWF ERA-40 re-analysis data and compare them with the available information about the climatological characteristics of the Adriatic Sea surface fluxes. The final purpose of this study is to obtain corrected surface fluxes, using the method of Troccoli and Kålberg (2004), which to be used as boundary conditions in a general circulation model of the Adriatic Sea.

The second section gives some information about the used data sets. The next section focuses on the comparison of the ERA-40 climatology with the observational data. Summary and conclusions are given in the last Section.

The ECMWF ERA-40 fields

The ERA-40 re-analysis system uses a resent version of the model physics (Integrated Forecast System, cycle 23r4) and a 3-D variational assimilation system. The spatial resolution of ERA-40 products is about 110 km in the horizontal and 60 levels in the vertical. The temporal resolution is 6 hours throughout the period September 1957 – August 2002. More details for the ERA-40 re-analysis system and the data quality can be found at http://www.ecmwf.int/research/era/. Unfortunately, free of charge products of ERA-40 are available only with grid-spacing of $2.5^{o}x2.5^{o}$. Therefore, in the present paper this coarse grid resolution data are used.

The ERA-40 time period 1957-2002 can be divided into three consecutive parts: the pre-satellite period 1957-1972 when no satellite data were available, the transition period 1973-1988 when the amount of satellite data increases with time, and satellite period 1989-2002 (Hangemann et al., 2005). In present study, data for the first two periods are used due to two major reasons: First, evaluation shows excessive amount of precipitation over oceans during the last period of ERA-40 (Troccoli and Kålberg, 2004). This has been found to be related to an erroneous bias correction in the assimilation of satellite data (humidity and radiances) from two new satellites launched during the period 1987-1991

(Hangemann et al., 2005). Second, most of the available observational data (May, 1986, Legates and Willmott, 1990, Raicich, 1996, Supić and Orlić, 1999) cover approximately the same period as the first two parts of the ERA-40 (i.e. 1957-1988). Therefore, the ERA-40 monthly data are averaged over a 30 years interval starting from September 1957, to form the ERA-40 climatology.

The ERA-40 surface data utilized in this study are: downward (incoming) solar radiation (Q_{sd}), latent heat fluxes (Q_l), thermal (longwave) radiation (Q_b), sensible heat fluxes (Q_h), evaporation (E), and total precipitation (P) (see the catalogue of ECMWF products, http://www.ecmwf.int/products/catalogue). Monthly mean fields are retrieved at 2.5^ox2.5^o grid, after that they are averaged over the 30 years period to obtain mean monthly annual cycle of each field under consideration, and finally, are interpolated to the 5.3 km grid using the EMOS software (see http://www.ecmwf.int/products/data/software /interpolation.html).

The ERA-40 downward (incoming) solar radiation (Q_{sd}) is used in this work instead of net surface solar radiation (incoming minus reflected), because two problems have been found with ERA-40 albedo. First, the ERA-40 model uses the monthly mean surface albedo and does a linear interpolation between successive months, which gives an inaccurate estimation of the surface albedo annual cycle. The study of Betts et al. (2003) shows that the ERA-40 albedo in summer is 15% for Mississippi basin, which is much greater than the observed albedo of 9%. Second, due to the coarse ERA-40 grid, the grid cells in the Northern Adriatic Sea cover large land area and small sea ones, so the estimated surface albedo is unrealistically high, reaching values of 14% in summer and 20% in winter. Therefore, the net surface solar radiation (Q_s) in the present study is calculated from Q_{sd} assuming a constant sea surface albedo of 5%.

Climatological data

Climatological surface heat fluxes components are taken from the May data-set (May, 1986). May used ship observations made from 1945 to 1984 to calculate the monthly heat fluxes in 1^ox1^o grid. May (1986) first computed the heat fluxes from each individual observation and subsequently calculated the spatial and time averages. This data-set is used frequently as a representative of the Adriatic Sea climatological heat fluxes (Artegiani et al., 1997, Maggiore et al., 1998). Latent heat fluxes (Q_l) are used to determine total evaporation by means of the following equation (Raicich, 1996)

$$E = Q_l / L_T \,, \tag{1}$$

where L_T is the latent heat of evaporation.

Two precipitation data sets are frequently used in climatological studies (Raicich, 1996, Hangemann et al., 2005). The first one is developed by Legates and Willmott (1990) and consists of monthly grids with 0.5^ox0.5^o resolution. Station records (including ocean stations) of precipitation used to produce the first version of this data set cover the period of 40 years, starting from 1950. Annual average of the precipitation over the Adriatic Sea for the first version of this data set is 1.02 m year^{-1} (Raicich, 1996). The corresponding value for the second version of the Legates and Willmott (1990) data set is 0.86 m year^{-1}. The difference between two values is due to the improved spatial interpolation and extension of the period of observations (1950-1996) for the second version.

The Global Precipitation Climatology Center (GPCC) provides monthly gridded precipitation data for the normal period 1961-1990, with 1^{o}x1^{o} grid resolution (http://gpcc.dwd.de). The annual precipitation over the Adriatic Sea is estimated to 0.99 m year^{-1}. This value and the value of the first version of Legates and Willmott (1990) data set are likely to be overestimated because of the lack of observations in the open sea (Raicich, 1996), and the inaccuracy of the interpolation/extrapolation methods used. Therefore, the second version of the Legates and Willmott (1990) data is used in the present study.

Supić and Orlić (1999) estimated the surface heat and water fluxes at three stations in the northern Adriatic. They used observational data taken between 1966 and 1992 to study spatial seasonal and interannual variability of the northern Adriatic surface fluxes. In order to estimate the heat flux components Supić and Orlić (1999) used three different formulae previously used in the Mediterranean and showed that the latent and longwave fluxes were most sensitive to the different methods of computation. Finally, the authors assessed the error due to the use of coastal data in order to compute offshore fluxes and introduced a simple regression formula to estimate the total heat fluxes offshore of the three stations of consideration. These estimates are used in the present paper to verify the ERA-40 heat fluxes in the northern Adriatic.

Results and discussion

Fig. 1 presents the annually averaged surface solar radiation (Q_s^M) and latent heat fluxes (Q_l^M) from May (1986) climatological data set. The Q_s^M field (Fig. 1a) is characterized by well defined meridional gradients in the northern and southern Adriatic and increase of Q_s^M from north-west to south-east in the central Adriatic. The difference between Q_s^M in the southern and northern parts of the sea reaches maximum of 45 W m^{-2} in August, while in February it decreases to 25 W m^{-2}. The basin average of the annual mean Q_s^M is 172 W m^{-2} (Table 1). The Q_l^M field shows significant space variability (Fig. 1b). There are two areas with maximal latent heat losses located in the northeastern and southeastern part of the sea. The Q_l^M minimal losses are in the northwestern and central Adriatic. Strong zonal gradient exists in the northern Adriatic during the whole year due to the blowing of the Bora wind and to the advection of warm water masses by the northern Adriatic current (Artegiani et al., 1997).

Table 1. Annual averages of the surface heat flux components from May (1986), ECMWF ERA-40 and corrected ERA-40 data (ERA_{NEW}). Units are in W m^{-2}.

	Q_s	Q_b	Q_h	Q_l	Q_t
May (1986)	172	-68	-18	-108	-22
ERA-40	145	-71	-14	-69	-9
ERA_{NEW}	172	-69	-16	-95	-8

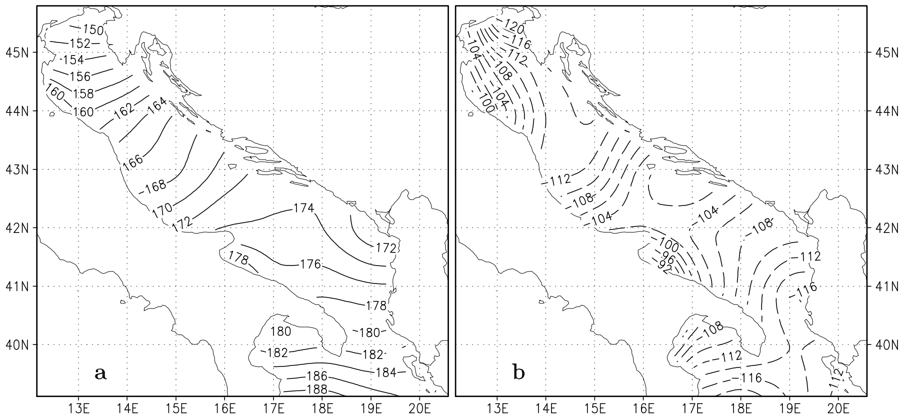

Fig. 1. Maps of annually averaged surface heat flux components from May (1986): a) solar radiation (Q_s); b) latent heat fluxes (Q_l). Units are in W m^{-2}.

Fig. 2a presents the surface solar radiation (Q_s^E) for the ERA-40. Comparison with Fig. 1a shows that Q_s^E is qualitative similar to Q_s^M only in the part of the northern Adriatic, while the Q_s^E is almost uniform in the northernmost, central and southern Adriatic. There are considerable differences in annual values of Q_s, also, which are about 30 W m^{-2} lower for the ERA-40 climatology (Table 1). Most significant differences are between fields of latent heat fluxes (Fig.1b and Fig. 2b). The ERA-40 field (Q_l^E) is characterized by increase of the latent heat losses from the north towards the south. The area with maximal latent heat losses in the northern Adriatic in Fig. 1b is completely missing in the ERA-40 Q_l^E field (Fig. 2b) during the whole year and the magnitude of the annual value of Q_l^E in the northernmost Adriatic is about 2 times lower than the one in the May (1986) data set. The ratio Q_l^M/Q_l^E reaches its maximal value of 3 in November. Probably, this is connected with the coarse grid of the ERA-40 modeling system, which leads to the impossibility to simulate properly the effects of Bora winds, prevailing during winter and autumn.

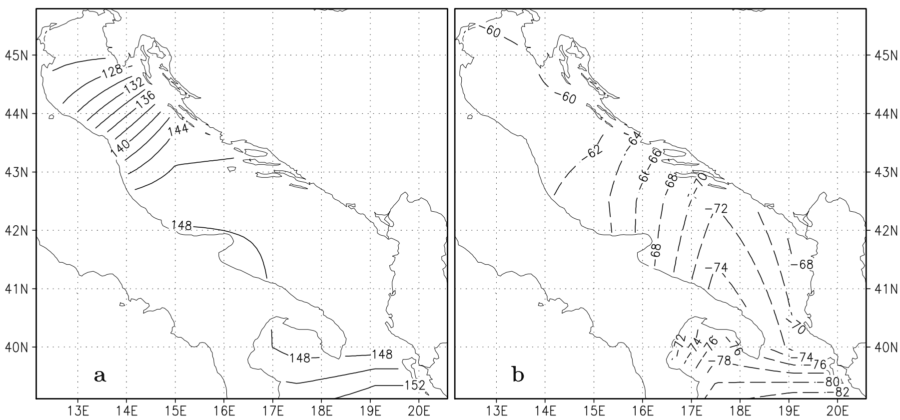

Fig. 2. Maps of annually averaged surface heat flux components from ECMWF ERA-40: a) solar radiation (Q_s); b) latent heat fluxes (Q_l). Units are in W m^{-2}.

The annual averages of the rest two components of the heat budget (sensible fluxes and longwave radiation) are almost the same in both data sets under consideration (Table 1). Some differences exist in the spatial distribution of the sensible fluxes between ERA-40 field (Q_h^E) and May (1986) field (Q_h^M). The Q_h^M field is characterized by well defined maximum losses in the northern Adriatic during the cold part of the year, while this maximum is badly pronounced in the Q_h^E field and the ratio Q_h^M/Q_h^E reaches value of 2 during the winter. In spring and summer both fields Q_h^M and Q_h^E are characterized by small horizontal gradients and approximately the same values. Only the longwave radiation flux of the ERA-40 (Q_b^E) shows significant meridional variability and bigger magnitude than May (1986) data (Q_b^M). The annual mean lose of Q_b^E has maximum in the central Adriatic and rapidly decreases toward the north, while the Q_b^M field is almost uniform. One possible explanation of the decrease of the Q_b^E in the northern Adriatic consists in the inaccuracy of the ERA-40 cloud parameterization, which overestimates the cloudiness over the northern Adriatic and this reflects to the decrease of the longwave radiation losses and surface solar radiation, also.

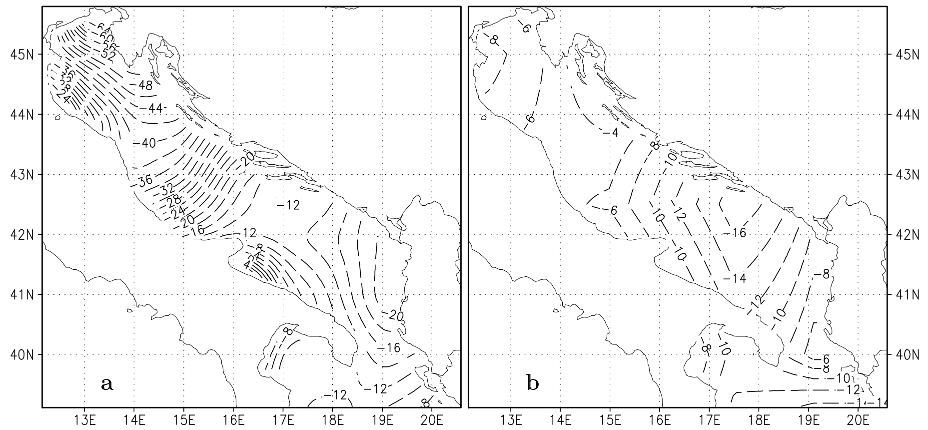

Fig. 3. Annually averaged surface total heat flux for a) May (1986) data set and b) ERA-40.

Maps of the annual heat total fluxes are presented in Fig. 3 for both ERA-40 (Q_t^E) and May (1986) data sets (Q_t^M). Comparison between Fig. 3a and Fig. 3b shows considerable quantitative and qualitative differences. The Q_t^M is characterized by minimal value in northeastern Adriatic, while the Q_t^E has minimum in the northeastern part of the southern Adriatic. The ratio Q_t^M/Q_t^E ranges between 10 in the northernmost part of the sea and 0.8 in the northeastern part of the southern Adriatic. The area averages of Q_t^M and Q_t^E are -22 W m^{-2} and -9 W m^{-2}, correspondingly (Table 1). The comparison between Fig. 3 and Fig. 1 and Fig. 2 shows that the Q_t patterns are very similar to these of dominant heat losses component, which is Q_l. The spatial variability of Q_t^M is influenced by the spatial distribution of the Q_h^M field, while the Q_t^E field is affected by the Q_b^E variations, also. Obviously, the most significant differences between the Q_t^M and Q_t^E and their components are observed in the northern Adriatic. Therefore, the ERA-40 and May (1986) surface heat fluxes will be compared with estimations of Supić and Orlić (1999) based on the observational data collected at three stations in the northern Adriatic.

Significant discrepancy exists in annual evaporation (*E*) and precipitation (*P*) patterns between the ERA-40 and climatological data sets (Fig. 4). Obviously, the ERA-40 fields are smoother and both evaporation and precipitation are underestimated. The spatial distribution of the annual evaporation is the same as that of the annual latent heat flux, therefore the differences between values of the *E* will be noted. The basin averaged annual evaporation of ERA-40 (E^E) is 0.83 m year^{-1}, while the corresponding value determined by means of the equation (1) is 1.34 m year^{-1} (Table 2). The value of E^E is somewhat lower then the minimal climatological value of 1.08 m year^{-1} reported by Raicich (1996), while the value of E^M is the maximal one estimated by the same author.

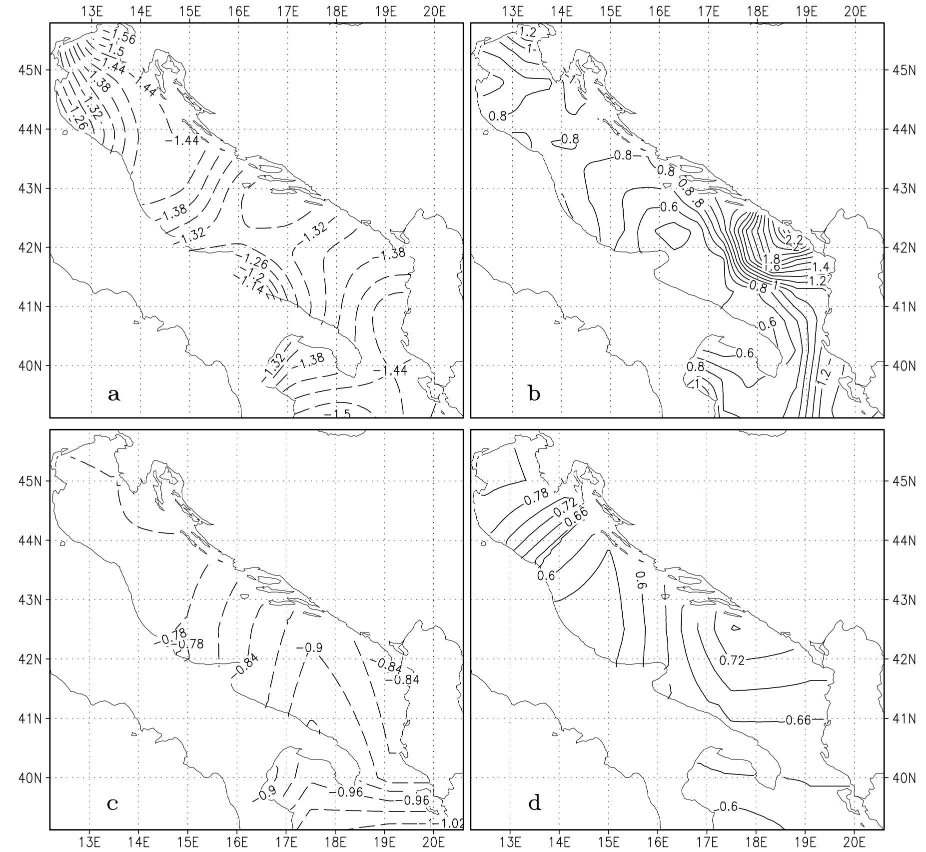

Fig. 4. Maps of annual evaporation (a and c) and precipitation (b and d) for: a) May (1986) data set; b) Legates and Willmott (1990) data set; c) and d) ECMWF ERA-40. Units are in meters.

The ERA-40 annual precipitation is almost uniformly distributed over the basin (Fig. 4d) and the values of the P^E range within the interval 0.57 - 0.81 m year^{-1}. The spatial variability of the annual precipitation of Legates and Willmott (1990) data set (P^L) is well pronounced and the values range from 0.5 m year^{-1} in the central Adriatic to 2.3 m year^{-1} close to the eastern coast of the southern Adriatic. Comparison between P^E and P^L values in the central Adriatic (open sea) with the value of 0.7 m year^{-1} deduced from the observations made at island stations in the same region (Raicich, 1996) reveals that probably the P^E is underestimated, while P^L is overestimated in the open sea. The same conclusion can be made comparing the annual precipitation of 1.0 m year^{-1} measured at station Trieste with values of P^E= 0.8 m year^{-1} and P^L= 1.2 m year^{-1}. The total precipitation for the Adriatic Sea is 0.86 m year^{-1} for the Legates and Willmott (1990) data set and 0.66 m year^{-1} for the ERA-40 (Table 2).

Table 2. Annual averages of the evaporation (*E*), precipitations (*P*) and freshwater budget (*P*+*R*-*E*) of climatological, ECMWF ERA-40 and corrected ERA-40 data (ERA_{NEW}). Units are in meters. The runoff (*R*) value is taken from Raicich (1994b, 1996).

	E	*P*	*P*+*R*-*E*
Climatology	-1.34	0.86	0.69
ERA-40	-0.83	0.66	1.0
ERA_{NEW}	-1.17	0.76	0.76

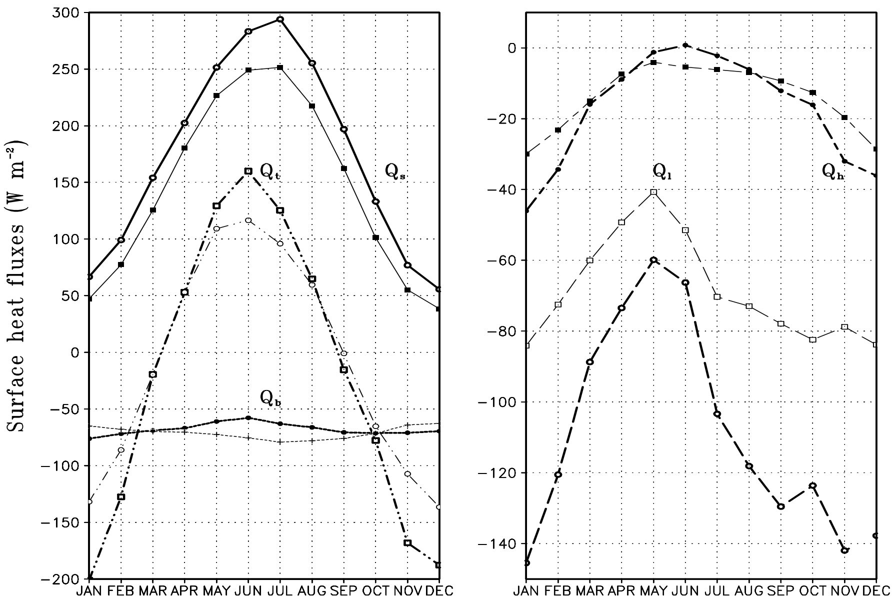

Fig. 5. Area averaged heat fluxes annual cycle. The total heat fluxes (Q_t), longwave and shortwave fluxes are presented on left panel, and latent and sensible fluxes are plotted on right panel. Thin lines present ERA-40 data and thick lines – May (1986) climatological data.

Fig. 5 presents the area averaged heat fluxes annual cycle for the both data sets under consideration. It is clear, that the ERA-40 shortwave radiation is underestimated during the whole year, with maximal difference of about 40 W m^{-2} in June. Annual cycles of Q_h^M and Q_h^E are similar, but the absolute values of Q_h^E are lower during the cold part of the year. The variations of Q_b^E are relatively small during the year with maximal difference between the two data sets of 15 W m^{-2} in June. The most significant difference is found between annual cycles of Q_l^M and Q_l^E reaching a value of 65 W m^{-2} in January. As a result the annual amplitude of Q_t^E is smaller than that of Q_t^M with about 90 W m^{-2}. Analogously, the amplitudes of annual cycles of evaporation and precipitation are smaller for the ERA-

40, compared to the climatological ones (Fig. 6). The same is valid and for the sum *P+E*, which is important in specifying the buoyancy forcing in ocean models. Probably, above mentioned disagreements between annual cycles of heat and water fluxes are connected mainly with the inaccuracy of the cloud parameterization and a coarse grid of the ERA-40 modeling system.

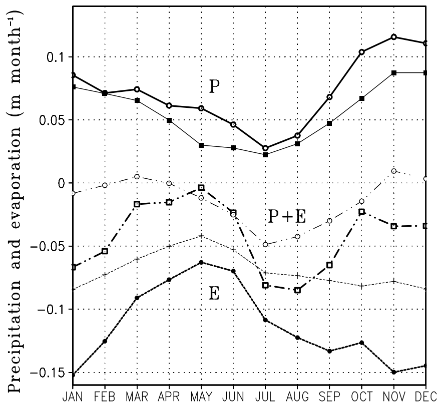

Fig. 6. Area averaged precipitation (P) and evaporation (E) annual cycles. Thin lines present ERA-40 data and thick lines – climatological data

The analyses show that there are significant differences between the ERA-40 heat and water fluxes and climatological ones. The use of the ERA-40 heat fluxes to force an ocean model for the Adriatic Sea for a long period will result in inadequate simulations of the sea circulation and temperature. For instance, the correct sea surface temperature can't be reached using the underestimated Q_t^E in summer, and the winter convection can't be simulated with the weak cooling of the ERA-40. That is why, an attempt to correct the ERA-40 fluxes is made here on the base of the observations available.

Heat flux components of the ERA-40 and May (1986) are compared with the estimates of Supić and Orlić (1999) (hereafter SO) at three stations in the northern Adriatic. Fig. 7 shows the results at the station Mali Losinj with coordinates $\lambda = 14.46$E, $\varphi = 44.53$N and at the nearest ERA-40 grid node $\lambda = 14.4$E, $\varphi = 44.5$N. It is worth to notice, that the annual cycle and the averaged values of the shortwave, sensible and longwave fluxes of May (1986) are very close to these of SO (Q_s^{SO}, Q_h^{SO}, Q_b^{SO}). Annual cycles of all heat flux components of ERA-40 have smaller amplitudes than SO ones, and even the annual cycle of Q_b^E is inverted compared with this of Q_b^M and Q_b^{SO}. Heat losses due to the sensible and latent heat fluxes of SO are systematically smaller than these of May (1986) data set and are bigger than Q_h^E and Q_l^E during the warm part of the year, only. The Q_s^E is underestimated during the whole year, again. Probably, these differences are due to the land influence, since the meteorological station at Mali Losinj is located at island at 51 m height above the sea level and the ERA-40 grid sell covers some area of the Balkan Peninsula.

Supić and Orlić (1999) introduced a correction for Q_t^{SO} due to the use of coastal data in order to compute offshore heat fluxes. Their corrected results for Q_t^{SO} are presented in Fig. 8 (filled squares) together with Q_t^M and Q_t^E. Monthly averages of Q_t^{SO} are higher than Q_t^M in all months, except in October. The amplitude of the annual cycle of Q_t^E is significantly smaller than that of Q_t^{SO} and the total heat lose/gain of the ERA-40 is underestimated during winter/summer, compared with Q_t^{SO}. Annually averaged values of Q_t are -15, -7, and -56 W m^{-2} for the SO, ERA-40 and May (1986) data set, correspondingly.

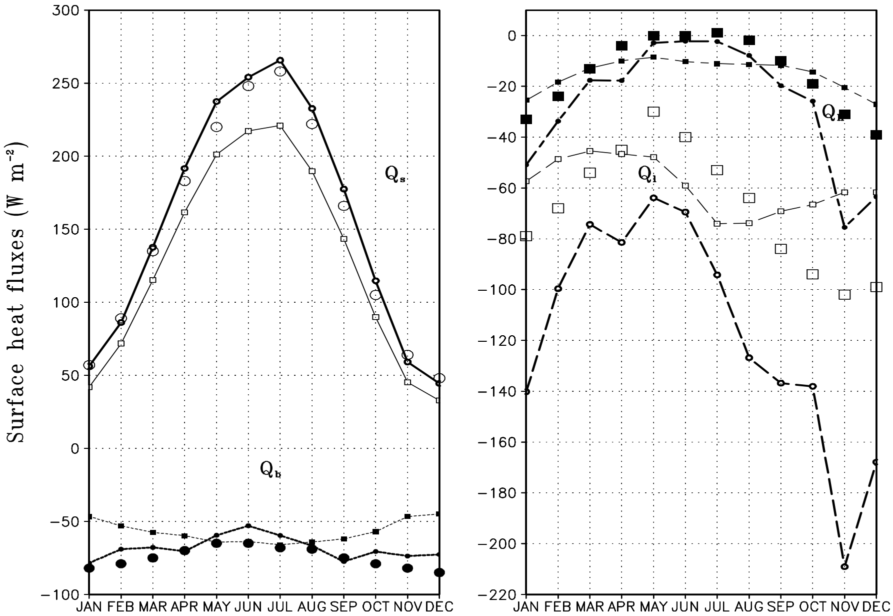

Fig. 7. Annual cycle of heat flux components at location (14.4E, 44.5N), northern Adriatic. Thin lines present ERA-40 data and thick lines – May (1986) climatological data. Big marks present the data of Supic and Orlic (1999) for the station Mali Losinj (14.46E, 44.53N).

On the base of this comparison, the ERA-40 and May (1986) data have been combined to fit better Supić and Orlić (1999) values for the northern Adriatic. The simple linear formula is used

$$Q^{EN} = (\alpha Q^E + \beta Q^M)/(\alpha + \beta) \qquad (2)$$

where α and β are integers, Q^E and Q^M are heat flux components (Q_l, Q_s, Q_b or Q_h) for ERA-40 and May (1986) data set, correspondingly, and Q^{EN} is the corrected heat flux of the ERA_{NEW} data set. Values of α and β are as follows: $\alpha = 0$, $\beta = 1$ for Q_s, $\alpha = 1$, $\beta = 2$ for Q_l and Q_b, $\alpha = 2$, $\beta = 1$ for Q_b. The corrected annual cycle (ERA_{NEW}) of the total heat fluxes at location (14.4E, 44.5N) is presented in Fig. 8 (dashed line). It is evident, that the ERA_{NEW} total heat fluxes almost coincide with the Supić and Orlić (1999) corrected data during the period September – March. A small deviation of Q_t^{EN} from Q_t^{SO} exists during the period April – August, when monthly values of Q_t^{EN} are underestimated. This deviation is smaller at stations Trieste (13.7E, 45.6N) and Rovini (13.6E, 45.1N), where annual cycles of Q_t^{EN} and Q_t^{SO} are closer. After the correction the annually averaged value of Q_t^{EN} at location (14.4E, 44.5N) is -20 W m^{-2}.

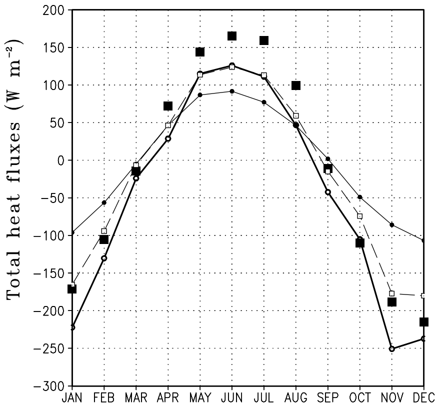

Fig. 8. Annual cycle of the total heat fluxes at location (14.4E, 44.5N) (Mali Losinj). The thin line presents ERA-40 data, the thick line - May (1986) data, filled squares – Supic and Orlic (1999) corrected data, and dashed line - ERA-40 corrected data (ERA_{NEW}).

The total heat flux of ERA_{NEW} is presented in Fig. 9a. Comparison between Q_t^{EN} and Q_t^{M} (Fig. 3a) shows, that both fields are very similar, but horizontal gradients of Q_t^{EN} are somewhat reduced. The biggest differences are in the northern Adriatic, where absolute values of Q_t^{EN} are more than two times smaller than Q_t^{M}, but remain few times bigger than Q_t^{E}. Taking into consideration and the well pronounced zonal gradient of Q_t^{EN} in the northern Adriatic, it can be concluded that Q_t^{EN} represents the effects of Bora wind better than Q_t^{E} (Fig. 3b).

The horizontal gradient of Q_t in the central Adriatic is preserved, but its value is about 2 times smaller/bigger than this of Q_t^{M}/Q_t^{E}. Total heat flux changes in the southern Adriatic are smaller, reaching maximal difference of 16 W m^{-2} between Q_t^{M} and Q_t^{EN} in the southernmost part of the basin. In any case, the ERA_{NEW} heat fluxes (Fig. 9a) match better the observational data than the original ERA-40 data. The area averaged value of Q_t^{EN} is -8 W m^{-2} (Table 1) and is very close to the value used by Zavatarelli and Pinardi (2003) to force the general circulation model for the Adriatic Sea.

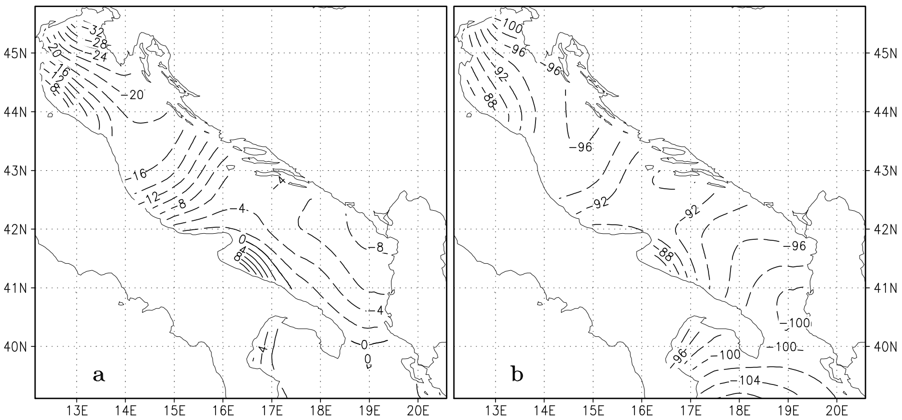

Fig. 9. Annual a) heat budget and b) latent fluxes for the ERA_{NEW} data.

Fig. 9b shows the annual field of the ERA_{NEW} latent heat flux, which is the most problematic heat flux component. The Q_l^{EN} and Q_l^M (Fig. 1b) are qualitatively similar, but horizontal gradients of Q_l^{EN} are weaker. The comparison between area averaged value of Q_l^{EN} and Q_l^E and Q_l^M (Table 1) shows that the ERA_{NEW} latent heat losses are with 13 W m^{-2} lower than Q_l^M, and are with 26 W m^{-2} higher than Q_l^E. The maximal differences are in the northern Adriatic.

The analogous correction is applied to the precipitation and evaporation monthly fields ($\alpha = 1$, $\beta = 1$ for the precipitation and $\alpha = 1$, $\beta = 2$ for the evaporation). The choice of the α and β for the precipitation is based on Supić and Orlić (1999) data, which give values of 1.0 m year^{-1}, 0.84 m year^{-1} and 0.93 m year^{-1} at Trieste, Rovini and Mali Losinj, correspondingly. The values of the ERA-40 (Fig. 4d) are underestimated, while these of Legates and Willmott (1990) are overestimated (Fig. 4b) at locations mentioned. The ERA_{NEW} precipitation field is presented in Fig. 10b from where it is visible that the corrected precipitation in the northern Adriatic is very close to Supić and Orlić (1999) data. In the central Adriatic, the annual precipitation of the ERA_{NEW} coincides with estimates of Raicich (1996) who gives an average value of 0.7 m year^{-1}. The precipitation maximum is located in the southern Adriatic close to the eastern coast (Fig. 10b), but now it is twice smaller than in Legates and Willmott (1990) data (Fig. 4b). This maximum is due mainly to the orography and it seems that it is overestimated in the Legates and Willmott (1990) data, because of the use of coastal stations data to estimate the precipitation in open sea and the spatial interpolation procedure used.

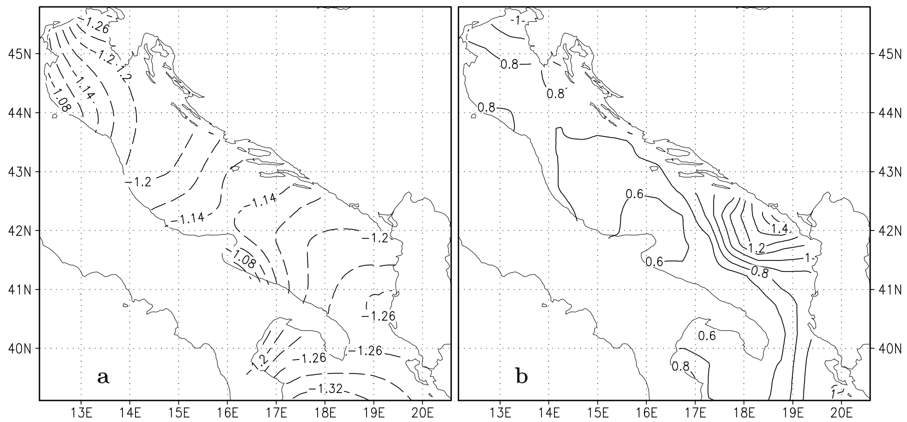

Fig. 10. Maps of annual evaporation (a) and precipitation (b) for the ERA_{NEW} data. Units are in meters.

Spatial patterns of the ERA_{NEW} and May (1986) evaporation fields are very similar, but there are differences in the absolute values (Fig. 10a). For the ERA_{NEW} the total precipitation for the Adriatic Sea is 0.76 m year^{-1} and the annual evaporation is 1.17 m year^{-1}. These values are very close to estimates of Raicich (1996) (Table 2). It is worth to notice, that shapes of annual cycles of precipitation and evaporation for ERA_{NEW} are closer to the observed ones than the original ERA-40 cycles.

The annual fresh water budget (P+R-E) for the Adriatic Sea can be estimated using for the river runoff the value $R = 1.17$ m year^{-1} given by Raicich (1996) (Table 2). The calculated freshwater budget for ERA_{NEW} is 0.76 m $year^{-1}$ and is consistent with previous estimates (0.65 – 0.84 m $year^{-1}$) of Raicich (1996) made on the base of the climatological data. The water budget of ERA-40 is overestimated due to the lower evaporation losses (Table 2).

Conclusions

This work is done in order to check the possibility ERA-40 data to be used to force the numerical ocean model of the Adriatic Sea. The comparison of the ERA-40 data with climatological ones suggests, that the original ERA-40 data can not be used directly to force the ocean model for long periods. Analyses show that magnitudes of the shortwave and latent heat fluxes are significantly underestimated in the ERA-40, compared with climatological ones. This results in significant differences in spatial patterns and annual values of the total heat flux between both data sets. The biggest difference is in the northern Adriatic, where the ratio Q_t^M/Q_t^E reaches value of 10. Annual cycles of all ERA-40 heat flux components are smoother than the climatological ones. There are considerable differences between climatological and the ERA-40 precipitation and evaporation fields, also.

A simple linear correction procedure is applied to the heat and water flux components in order to reduce the inaccuracy of ERA-40 data. Comparisons with observational data show a considerable improvement of the ERA_{NEW} fields. Annual cycles, spatial patterns and area averaged values of ERA_{NEW} fields coincide better with observations. This ensure that the heat and water budgets are specified correctly and modified ERA-40 (ERA_{NEW}) data can be used to force a general circulation model of the Adriatic Sea for a long period. The idea is to substitute monthly mean values of ERA-40 heat and water fluxes with these of ERA_{NEW}. Thus the high frequency variability of the ERA-40 data will be preserved and the closure of heat and water budgets will be guaranteed.

Acknowledgements. N. Rachev acknowledges the ICTP Programme for Training and Research in Italian Laboratories, Trieste, Italy and the ISMAR-CNR (section Trieste) for the support. This study has been partially supported by the Project “ANOCSIA” of MIUR, Italy. The meteorological data used in this work were provided by the ECMWF ERA-40 project.

References

Artegiani, A., D. Bregant, E. Paschini, N. Pinardi, F. Raicich, and A. Russo, 1997. The Adriatic Sea general circulation. Part I: Air-Sea interactions and water mass structure, *J. Phys. Oceanogr.*, **27**, 1492-1532.

Betts, A., J. H. Ball, M. Bolovich, P. Viterbo, Y. Zhang, and W. B. Rossow, 2003. Intercomparison of water and energy budgets for five Mississippi sub-basins between ECMWF re-analysis

(ERA-40) and NASA-DAO fvGCM for 1990-1999, *ERA-40 Project Report Series*, N 7, 19 pp.

Castellari, S., N. Pinardi, and K. Leaman, 1998. A model study of air-sea interactions in the Mediterranean Sea, *J. Mar. Sys*., **18**, 89-114.

Hangemann, S., K. Arpe, and L. Bengtsson, 2005. Validation of the hydrological cycle of ERA-40, *ERA-40 Project Report Series*, N 24, 42 pp.

Legates, D. R. and C. J. Willmott, 1990. Mean seasonal and spatial variability in gauge-corrected global precipitation, *Int. J. of Climatology*, **10**, 111-127.

Maggiore, A., M. Zavatarelli, M. G. Angelucci, and N. Pinardi, 1998. Surface heat and water fluxes in the Adriatic Sea: Seasonal and interannual variability, *Phys. Chem. Earth*, **23**, 561-567.

May, P. W., 1986. A brief explanation of Mediterranean heat and momentum flux calculations, *Tech*. *Rep*., NORDA Code 322, NSTL, MS.

Morcrette, Jean-Jacques, 2002. Assessment of the ECMWF model cloudness and surface radiation fields for the ARM SGP site, *Mon. Wea. Rev*.,**130**, 257-277.

Raicich, F., 1994a. Note on the precipitation on the Adriatic coast, *Tech*. *Rep*., *RF 03/94*, 6 pp., CNR, Ist. Sperim. Talassogr.

Raicich, F., 1994b. Note on the flow rates of the Adriatic rivers, *Tech*. *Rep*., *RF 02/94*, 8 pp., CNR, Ist. Sperim. Talassogr.

Raicich, F., 1996. On the fresh water balance of the Adriatic Sea, *J. Marine Systems*, **9**, 305-319.

Supić, N. and M. Orlić, 1999. Seasonal and interannual variability of the northern Adriatic surface fluxes, *J. Marine Systems*, **20**, 205-229.

Troccoli, A. and P. Kalberg, 2004. Precipitation correction in the ERA-40 reanalysis, *ERA-40 Project Report Series*, N 13, 6 pp.

Zavatarelli, M. and N. Pinardi, 2003. The Adriatic Sea modeling system: A nested approach, *Ann. Geophys.*, **21**, 345-368.

Сравнение на потоците топлина и влага на повърхността на Адриатическо море между данни от реанализи на ECMWF (ЕРА-40) и климатични данни

Н. Рачев

Резюме: Обработени са данни от атмосферни реанализи на ECMWF ERA-40 за месечните полета на повърхностните потоци топлина и влага за периода 1957-1987 год.. Пресметнати са псевдоклиматичните потоци топлина и влага на ERA-40 за района на Адриатическо море и са сравнени с данни от измервания. Показано е, че късовълновата радиация и потока топлина при фазовите преходи на водата на ERA-40 са занижени в сравнение с климатичните норми. По-ниски от климатичните са и годишните суми на валежите и изпарението на ERA-40. Това прави данните за потоците топлина и влага на ERA-40 непригодни за продължително форсиране на морски модел за Адриатическо море. Предложена е процедура за коригиране на данните на ERA-40 намаляваща до значителна степен отклонението им от климатичните норми.