S1 Introduction

In order to analyse the differences between the results of the four simulations several additional analyses were performed. The presented supplementary material (Fig. S1 to S5 and text) complements the results of the article titled “Multi-model analysis of the Adriatic dense water dynamics”. In particular, supplementary results include (a) spatial distributions of minimum bottom temperature and maximum bottom salinity and the corresponding timing of the extremes, (b) time series of daily bottom temperature and salinity in four subdomains and (c) daily volume transport along selected transects.

S2 Results

S2.1 Analysis of the extremes

Spatial distributions of minimum bottom temperature and the corresponding timing of the minimums for the four simulations are shown on Fig. S1. In general, lowest temperatures are reproduced in the northern Adriatic down to 5 °C, along the western coast and in Kvarner Bay, while highest minimums are found in shallower parts of southern Adriatic up to 15 °C.

MEDSEA minimums mostly occurred in winter, in the western part of middle Adriatic during spring, whereas in Jabuka Pit minimum temperatures were reproduced in autumn 2014 (Fig. S1a and b). For ROMS hind, the main difference is in the Jabuka Pit where the minimums occurred in summer (Fig. S1c and d). ROMS full minimums mostly happened in winter but also in spring in a part of Kvarner Bay and in the middle Adriatic (Fig. S1e and f). It can be seen that ROMS full reproduced lowest temperatures in a patch in the northern Adriatic. For AdriSC ROMS, temperature minimums are also present mostly in winter while in parts of the middle Adriatic including Jabuka Pit they occurred in spring (Fig. S1g and h). In the SAP, minimums are mostly reproduced in autumn and partly in winter and spring by all models.

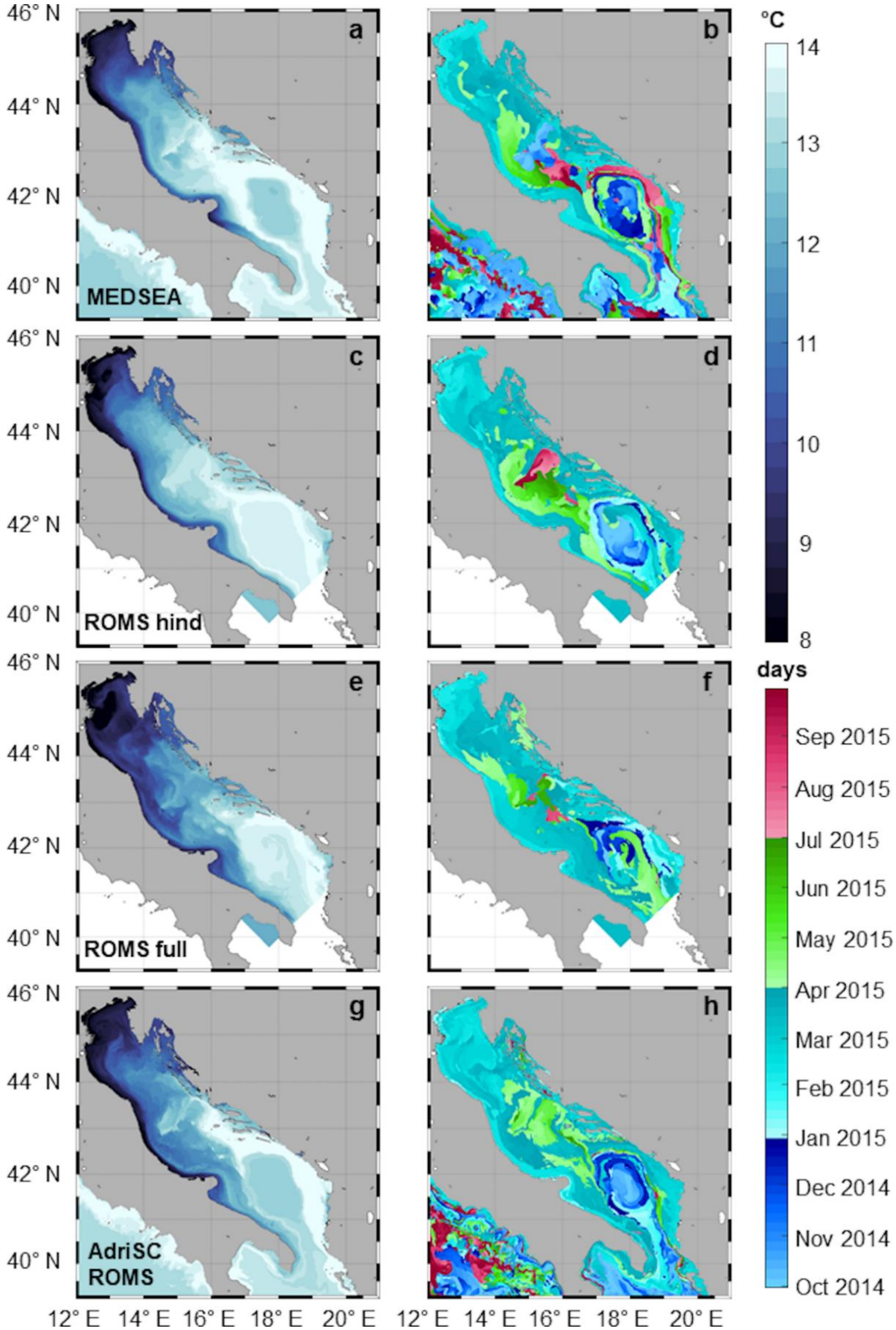

Figure S1. Spatial distribution of minimum bottom temperature and corresponding time of the minimums for (a, b) MEDSEA, (c, d) ROMS hind, (e, f) ROMS full and (g, h) AdriSC ROMS.

Fig. S2 shows the spatial distributions of maximum bottom salinity with the corresponding timing of the maximums for all simulations. Lowest maximum salinities are obtained in the northern Adriatic, in Kvarner Bay and along the western coast with values reaching down to 38.2, while the highest salinities are reproduced in the southern Adriatic up to 39.2. MEDSEA results are characterized by the largest contrast between these areas. Maximums occurred in summer mainly in the coastal areas whereas in the middle Adriatic they happened mostly in autumn (Fig. S2a and b). ROMS hind results resemble MEDSEA results but with slightly lower maximums in the middle and southern Adriatic. The timing of the maximum salinities is mostly in late autumn and winter as well as in summer in parts of northern Adriatic and some coastal areas (Fig. S2c and d).

Overall, ROMS full reproduced slightly higher maximums than ROMS hind with the biggest differences offshore of Kvarner Bay. Also, maximums are mostly reproduced in winter in the northern Adriatic and Kvarner Bay, in summer along the western coast and in spring in the middle Adriatic (Fig. S2e and f). Lastly, AdriSC ROMS results revealed high maximum salinities (above 38.5) over the whole Adriatic except in very narrow coastal parts. The timing of the maximums is mostly in summer for the northern and north-eastern Adriatic as well as along the eastern coast, whereas the rest of the Adriatic reached maximum salinity in autumn (Fig. S2g and h).

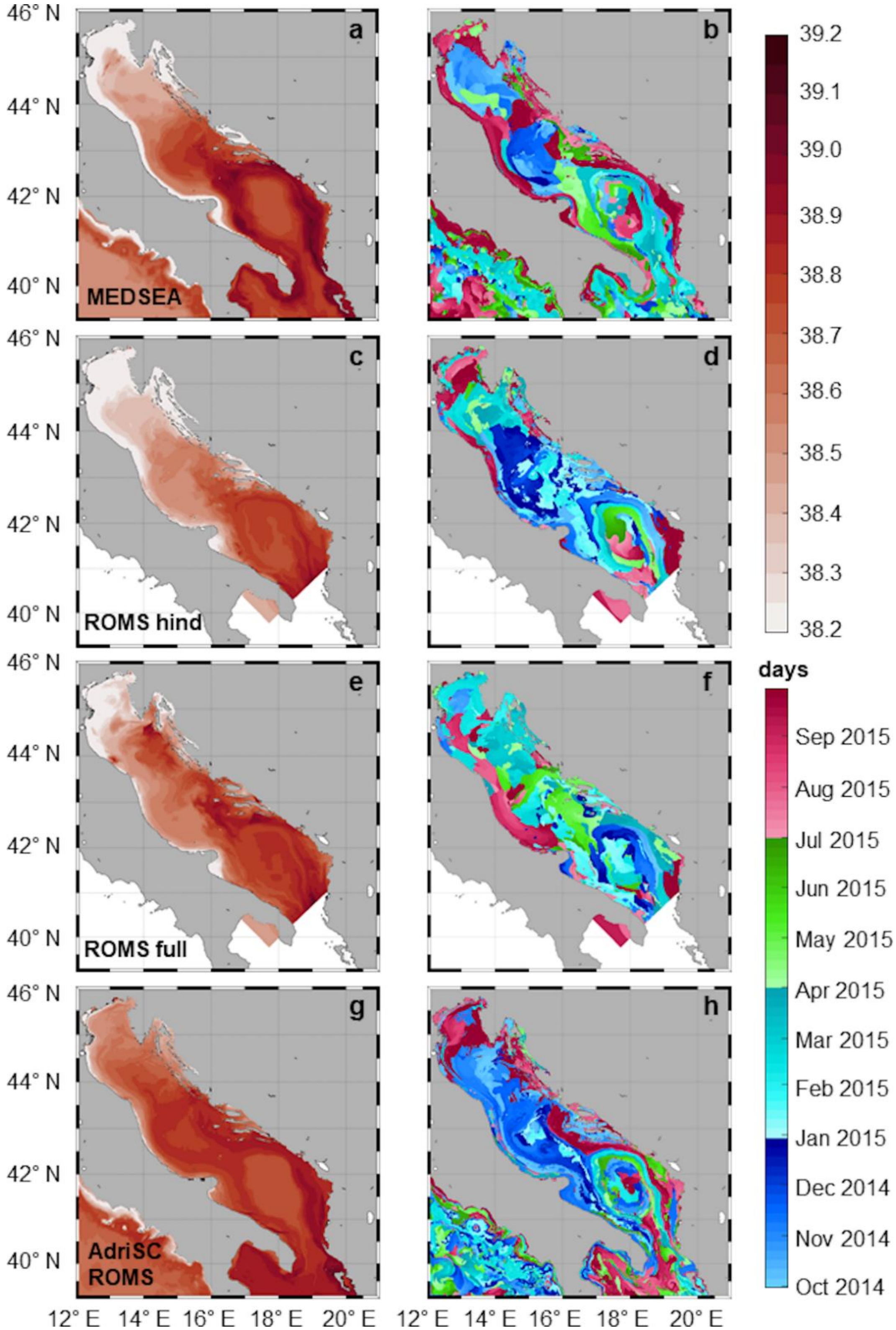

Figure S2. Spatial distribution of maximum bottom salinity and corresponding time of the maximums for (a, b) MEDSEA, (c, d) ROMS hind, (e, f) ROMS full and (g, h) AdriSC ROMS.

S2.2 Dense water dynamics

Time series of daily bottom temperature and salinity in four subdomains for all simulations are shown on Fig. S3 and S4, respectively.

First, in the northern Adriatic subdomain (Fig. S3a), the largest differences in modelled temperature occurred in autumn 2014 and summer 2015 when MEDSEA gives the highest mean temperatures reaching 20.8 °C in October and 20.3 °C in September while the other modelled temperatures are around 1-1.5 °C lower. In contrast, winter and spring temperatures have better matching between simulations with smaller differences. The northern Adriatic mean temperature minimum occurs in the end of February and beginning of March for all simulations. However, ROMS full is standing out with uneven temperature curve near the minimum and lowest values. The mean salinity results (Fig. S4a) reveal a large positive bias in AdriSC ROMS results ranging from 0.3 – 1.1 with respect to other simulations.

All models produce maximum mean salinity in summer and minimum values in December 2014 when ROMS full shows a sharp minimum up to 37 while the other models have higher values. ROMS hind and ROMS full mostly differ from March to August with a positive bias around 0.2 for ROMS hind whereas ROMS full shows a sharp minimum in December up to 37. MEDSEA salinity is generally lower than all the other models with a few exceptions.

Second, in the Kvarner Bay subdomain (Fig. S3b), the autumn temperatures are more than 1 °C higher for AdriSC ROMS and MEDSEA than for ROMS hind and ROMS full. ROMS hind temperatures are generally little higher than ROMS full over the whole 2015. During winter all simulations give relatively similar results while the differences become larger in spring and summer. AdriSC ROMS and MEDSEA showed similar temperatures to ROMS full until April when the biases increased by up to 1-2 °C. Regarding the mean salinity (Fig. S4b), as in the previous subdomain, AdriSC ROMS showed a large positive bias up to 0.6 as well as a similar timing of the minimums and maximums for all simulations. In the whole 2015, ROMS full salinities are higher than ROMS hind, particularly during February and March whereas the MEDSEA salinities are mostly very low compared to other models. The obtained salinities in Kvarner Bay are generally higher than in the northern Adriatic, particularly in late autumn and winter.

Third, in the Jabuka Pit subdomain (Fig. S3c), the models reproduce the mean temperature quite differently. AdriSC ROMS gave higher temperatures until March (up to 14.5 °C) after which they decreased to around 12.5 °C in April and then slowly increased. ROMS full and ROMS hind show the same temperatures (around 13.8 °C) by December when ROMS full starts to decrease, reaching a slight peak in February and then continues to decrease almost down to 12 °C. In contrast, ROMS hind increased up to 14 °C until mid-February and then decreased and remained around 13.5 °C throughout the year. MEDSEA results are similar to ROMS hind but lower in autumn. Regarding the mean bottom salinity, AdriSC ROMS gives similar results to MEDSEA but with a month later timing of the minimum. The ROMS full and ROMS hind salinities are lower form the other models by around 2.5 in autumn (Fig. S4c). ROMS full produced an increase in winter, a minimum in March and an increase during spring. ROMS hind slightly decreased throughout the whole 2015 period.

Lastly, in the deep Adriatic subdomain (Fig. S3d), the mean bottom temperature is nearly monotonic for all the simulations. ROMS full and ROMS hind gave the highest values, AdriSC ROMS showed the lowest temperatures with a 0.5 °C difference and MEDSEA results are slightly higher than AdriSC ROMS. Mean salinity is similarly reproduced in the deep Adriatic for all models (Fig. S3d). Higher values are obtained with ROMS full and lowest values with the AdriSC ROMS simulation.

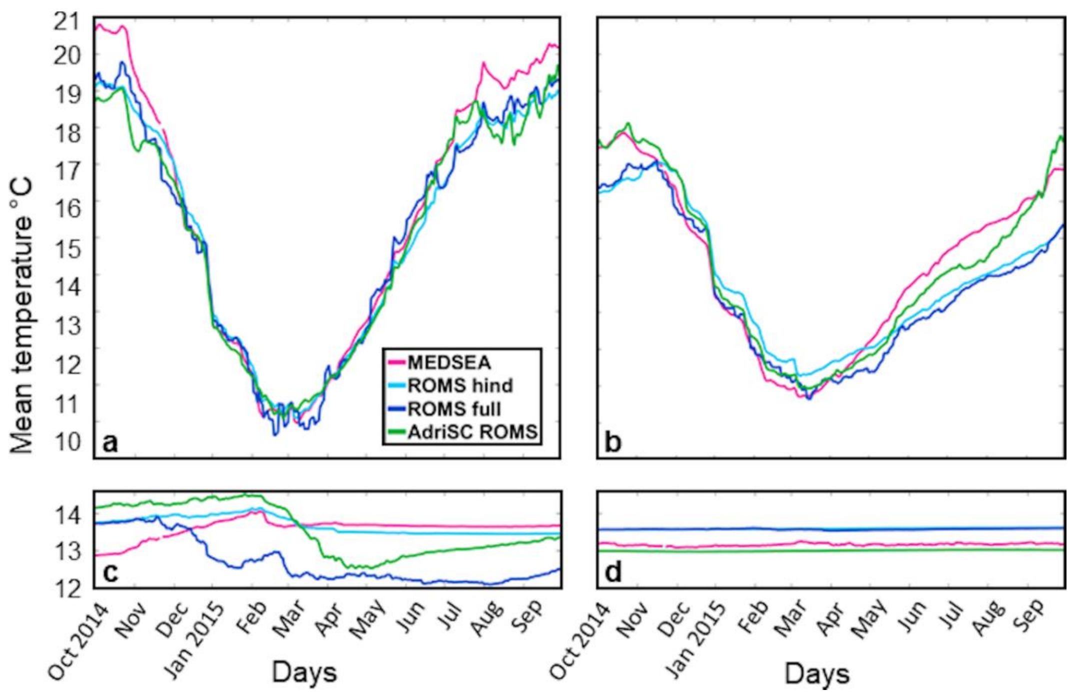

Figure S3. Time series of daily bottom temperature averaged over four subdomains: (a) northern Adriatic, (b) Kvarner Bay, (c) Jabuka Pit and (d) deep Adriatic for the 2014-2015 period and four simulations.

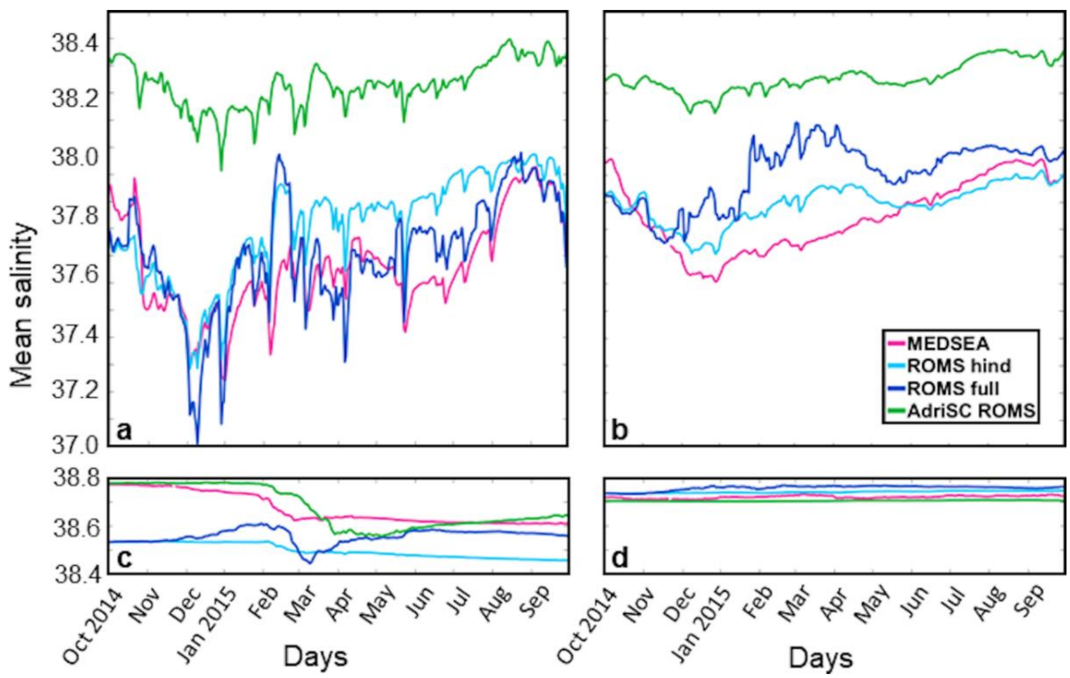

Figure S4. Time series of daily bottom salinity averaged over four subdomains: (a) northern Adriatic, (b) Kvarner Bay, (c) Jabuka Pit and (d) deep Adriatic for the 2014-2015 period and four simulations.

To quantify the dense water outflow across different sections of the northern and middle Adriatic, the volume transports of dense water defined by the PDA threshold of 29.2 kg m^{-3} through four transects (T1 to T4) are presented in Figure S5. The transport is defined as positive towards northwest (transects T1, T3 and T4) or northeast (transect T2). In general, MEDSEA and ROMS hind transports are the lowest for all transects, which is expected as their overall PDA values are found to be the lowest of all simulations. With the same argument, the AdriSC ROMS transport is reproduced as the highest everywhere, except for T4, where the ROMS full transport prevails (Fig. S5d).

The transport produced by MEDSEA at T1 is mostly very low, peaking at -0.03 Sv in February (Fig. S5a). ROMS hind transport varies there between -0.07 Sv and -0.01 Sv in February while the largest absolute values are reproduced during March, reaching -0.30 Sv. ROMS full transports at T1 are similar in magnitude to ROMS hind but the timing is different. In February, the transport reaches down to -0.20 Sv whereas in March the values are smaller reaching only -0.04 Sv. AdriSC ROMS transports at T1 are extremely high from February to April compared to the other simulations. Largest southeastward transports are reproduced in February, with values down to almost -1.00 Sv, while in March and April they reach -0.80 Sv.

For T2, MEDSEA and ROMS hind transports are null or almost null for all days, as they don't reproduce dense waters in the Kvarner Bay with such PDA values (Fig. S5b). ROMS full negative transports are highest in February and in the first half of March, where intense measurements were carried out in the Kvarner Bay, peaking at -0.20 Sv. AdriSC ROMS negative transports are the highest in February and March, peaking at -0.60 Sv, while the values in April reach -0.20 Sv. AdriSC ROMS transports indicate that the ratio between dense water originating from the northern Adriatic and the Kvarner Bay is roughly 60:40, which is similar to the transport ratio derived for the massive dense water generation in winter 2012 (Janeković et al., 2014).

For T3 and T4, both MEDSEA and ROMS hind transports are null throughout the whole period. ROMS full negative transports at T3 vary around -0.05 Sv from the middle of February to the end of May (Fig. S5c), being the highest in the second half of March and reaching -0.20 Sv. Furthermore, the results show some similarities in the behaviour of the ROMS full and AdriSC ROMS transports. Interestingly, the dense water transports at T3 are lagged for about two to three weeks (depending on the simulation) after the transports at T1 and T2, from which an estimate of bottom density current may be computed (approximately 0.10-0.17 m s^{-1}). Lastly, ROMS full transports are extremely high at T4, much higher than in AdriSC ROMS, peaking during March-April with values reaching -0.90 Sv and -0.70 Sv, respectively. For the rest of the time, the transports are relatively low, questioning if these outbursts of dense water are driven by the assimilated data or by an outflow of dense waters with high densities that are reproduced by ROMS full northwest from transect T4, in the Jabuka Pit.

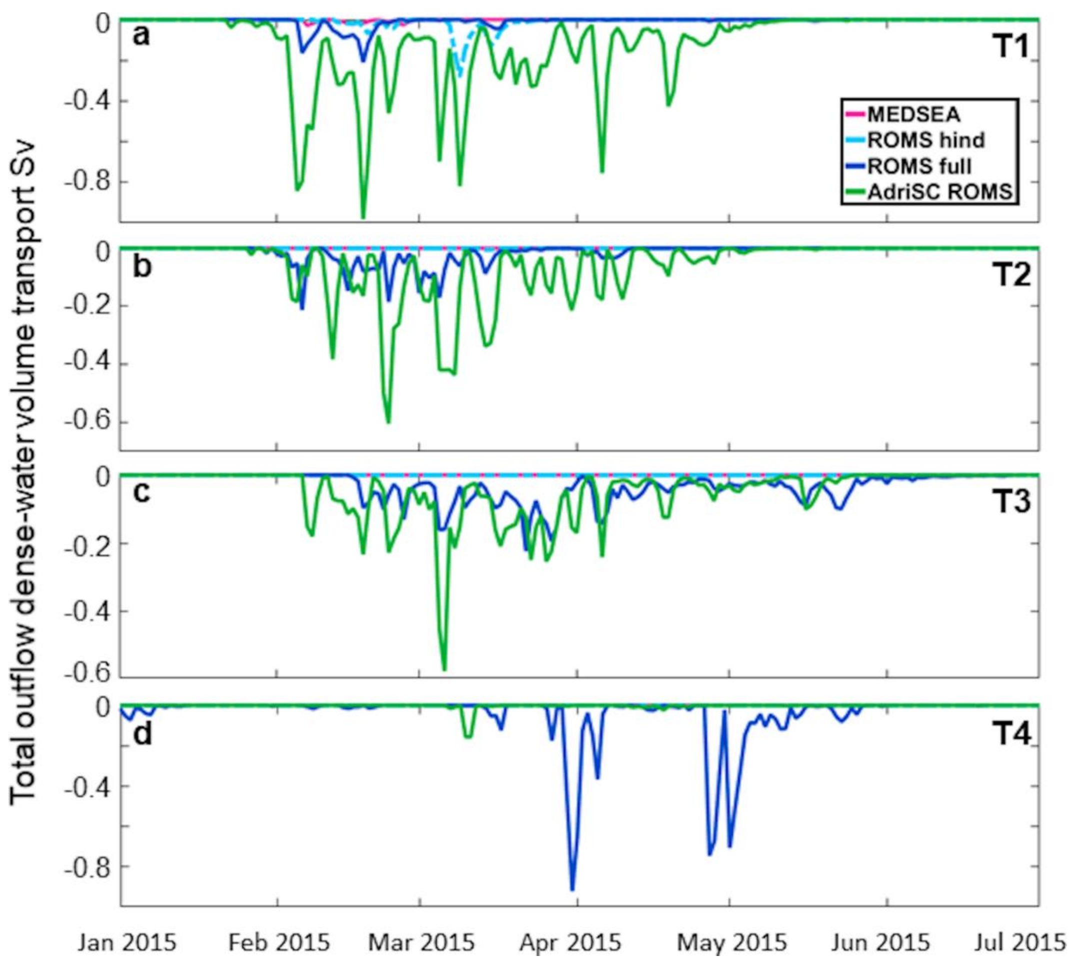

Figure S5: Daily volume transport rates of dense water outflow with PDA higher than 29.2 kg m^{-3} integrated over transect (a) T1, (b) T2, (c) T3 and (d) T4.

References

Janeković, I., Mihanović, H., Vilibić, I., Tudor, M.: Extreme cooling and dense water formation estimates in open and coastal regions of the Adriatic Sea during the winter of 2012, J. Geophys. Res. Oceans, 119, 3200–3218, https://doi.org/10.1002/ 2014JC009865, 2014.