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Upscaling of regional models into basin-wide models

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Abstract. Traditionnally, in order for lower-resolution, global- or basin-scale models to benefit from some of the improvements available in higher-resolution regional or coastal models, two-way nesting has to be used. This implies that the parent and child models have to be run together and there is an online exchange of information between both models. This approach is often impossible in operational systems, where different model codes are run by different institutions, often in different countries. Therefor, in practice, these systems use one-way nesting with data transfer only from the large-scale model to the regional models. In this article, it is examined whether it is possible to replace the missing model feedback by data assimilation, avoiding the need to run the models simultaneously. Selected variables from the high-resolution forecasts will be used as pseudo-observations, and assimilated in the lower-resolution models. The method will be called "upscaling".

A realistic test-case is set up with a model covering the Mediterranean Sea, and a nested model covering its North-Western basin. A simulation using only the basin-scale model is compared with a simulation where both models are run using one-way nesting, and using the upscaling technique on the temperature and salinity variables. It is shown that the representation of some processes, such as the Rhône river plume, are strongly improved in the upscaled model compared to the stand-alone model.

1 Introduction

In the present-day operational oceanography landscape, services are provided at different scales by different expert centers. At the European Union level, the Copernicus Marine Environment Monitoring Service (CMEMS) provides reanalysis and forecasts at global and basin scales. The models for the different basins are run by different institutes and centers. Various regional and coastal oceanographic centers then use the CMEMS products to provide initial and/or boundary conditions to their respective models. These regional and coastal models benefit from the increased experience and specific knowledge of the local teams in their particular area of interest. Furthermore, local models usually run at higher resolution, and may include more accurate data (bathymetry, river discharge data...) and processes of smaller scales, that cannot be easily included into basin-scale models. High resolution observations such as satellite sea surface temperature (SST), and recent ultra-high resolution products (see e.g. Le Traon et al., 2015) have been shown to be best assimilated into nested models, as chances are higher that the observed processes are well represented (Vandenbulcke et al, 2006). This is also true for new high-resolution current observations by high-frequency radars.

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When large-scale and regional or coastal models are run together (meaning, concurrently and on the same computing platform), it is possible to use two-way nesting; the benefits mentioned above of using a regional or coastal model are then transferred back to the basin-scale model. This has been shown numerous times in the literature, e.g. Debreu et al. (2012); Barth et al. (2005). The beneficial impact of the feedback from regional-scale to the basin-scale forecasts is visible even outside the domain of the regional model.

To emulate this nesting feedback, missing in the operational context, in this article it is analyzed whether forecasts from the regional model can be used as pseudo-observations and assimilated in the basin-scale model. Indeed, data assimilation is not limited to the use of (real) observations by measurement devices. Onken et al. (2005) used data assimilation as a substitute for one-way nesting in a cascade of nested models. Alvarez et al. (2000) used a statistical model to predict SST, which was then assimilated as pseudo-observations in a hydrodynamic model (Barth et al., 2006). In the proposed "upscaling" method, the pseudo-observations come from the nested model. From the point of view of the basin-scale forecasting centers, a data assimilation scheme is already implemented in the basin-scale, and all that needs to be done is obtain the high-resolution forecasts and assimilate them (along the real observations) during the analysis phase of the system.

By upscaling the child model into the parent model, the latter is brought closer to the former. In subsequent model runs, the boundary conditions provided to the nested model will thus be more consistent with the interior of the nested model domain; over time, the procedure may benefit the nested model as well. Common problems at the boundary include stratification mismatches, artificial waves, artificial rim currents; and ultimately instabilities and model blow-up. Upscaling may reduce the risk of discrepancies at the open sea boundary.

Upscaling can also be seen as using a regional or coastal model as a "measurement device" that replaces ever-too-sparse (real) observations. Guinehut et al. (2002, 2004) showed that a coverage of the North Atlantic with a 3°-resolution grid of Argo floats allows to effectively represent the large scales. Using a 5° array reduces the precision of the estimated fields two times. Currently, some CMEMS areas are largely undersampled.

Upscaling can be understood as a complement to downscaling (initialization) techniques such as the one presented in Auclair et al. (2000, 2001) and called VIFOP. The point of these methods is to combine interpolated fields coming from the large-scale model (the background or first-guess field) and existing high-resolution fields, so that small-scale structures present in coastal models are not lost whenever it is (re)-initialized by fields interpolated from the basin-scale model, and the obtained fields are physically balanced with respect to the coastal physics. If upscaling is used to improve the basin-scale fields and accord them with the coastal model, the "first guess" will be already much better.

Schulz-Stellenfleth and Stanev (2016) is another recent example showing the benefits of two-way nesting, especially in sophisticated modern-day forecasting systems. It is demonstrated that two-way nesting is critical for correct energy transfer

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between large and small scales (especially in coupled ocean-wave-atmosphere models), for cross-border advection, for the correct use of high-resolution coastal observations that cannot be fed directly into a large-scale model, etc. Ackowledging that operational systems are using only one-way nesting, the authors therefor strongly advocate the research into "upscaling" techniques. The present article tries to develop precisely such a technique.

In this article, the upscaling procedure is tried out in a realistic, nested model configuration covering the Mediterranean Sea and the North-Western basin and simulating the year 2014. The model and data assimilation scheme are described in section 2. Section 3 proposes some metrics to evaluate the system, related to the Rhône river plume, the cross-shelf exchanges, the large-scale current, SST, and the formation of Western Mediterranean Deep Water. Results are given in section 4 and a conclusion in presented in section 5.

2 Model and data assimilation configuration

2.1 Hydrodynamic model

The upscaling technique is tried out in the North-Western Mediterranean Sea, including the Gulf of Lions and the Ligurian Sea. The latter is characterized by large-scale currents (the Northern Current also called Liguro-Provencal Current, created by the junction of the Eastern and Western Corsican Currents), by intense meso-scale activity and by inertial oscillations. Furthermore, the NW-Med is the siege of formation of Western Mediterranean Deep Water (WMDW), important to the circulation in the whole Mediterranean Sea (e.g. Millot, 1999; Bosse et al., 2015).

A realistic, one-way nested configuration was implemented using the NEMO 3.6 model (Madec, 2008) and the AGRIF nesting tool (Debreu et al., 2008), covering respectively the Mediterranean Sea (MED) with a 6 km horizontal resolution, and the North-Western Mediterranean basin (NW-Med). The parent model resolution is similar to the actual CMEMS Mediterranean Sea forecasting system (1/16°). The bathymetry of the nested model (1/80°) is more realistic than the parent model, at the coastline and more importantly, at the different canyons at the Gulf of Lions shelf break.
When implementing the upscaling method, it is expected that after some time, the feedback from the NW-Med model will modify the Northern Current position and intensity in the MED model, which will in turn influence the NW-Med model through its open-sea boundary. The boundary condition provided by the MED model also influences the stratification of the water column, which is important for the pre-conditionning of the convection (S. Somot, private communication).

Both model bathymetries are interpolated from the GEBCO bathymetry. The temperature and salinity initial condition is interpolated from the CMEMS Mediterranean analysis for 01/01/2014. The model starts from rest. Atmospheric fluxes are computed using bulk formula; the atmospheric forcing fields are obtained from ECMWF ERA Interim with a horizontal resolution of 1/8° and a temporal resolution of 3 hours. In the MED model, the flow between the Black Sea and the Mediterranean Sea, through the Marmara Sea and the Dardanelles Strait, is modelized as a river, using climatological flow, temperature and salinity values from the litterature. The salinity of the incoming water has a minimum and maximum of 22.5 psu and 27.5 psu reached in July and March respectively. Five other rivers (Rhône, Po, Ebro, Nile, Drin) are also represented, and monthly climatologic values for the flow and temperature are used, whereas the salinity is put to 5 psu, except for the Drin river where is it put at 2 psu. Using climatologic monthly values is coherent with the operational set-up in the CMEMS Mediterranean system. Daily Rhone river discharge measurements at the Beaucaire station were obtained from the Compagnie du Rhône, in order to be used in the nested NW-Med model. Interestingly, the total annual flow computed from the climatology and from the measured values for 2014-2015 are very similar (1% difference). However seasonal and daily values can be very different (see Fig. 1a). In particular, during the considered period, the climatology underestimates the winter discharge, but overestimates the summer discharge. Hence, depending on the dataset used, it is expected that the modelled river plume will also be significantly different. This is illustrated in Fig 1b, showing the difference in surface salinity obtained with the nested model at the end of January 2014. The plume obtained using real river discharge extends much further offshore, almost completely across the Gulf of Lions, whereas the plume obtained with the climatological river discharge is essentially staying at the coast close to the river mouth. This is consistent with the much larger (almost double) discharge values observed in the real river data during January 2014.

2.2 Upscaling experiment description, Ensemble generation, and Data Assimilation scheme

When assimilating pseudo-observations into the basin-scale models, different setups are possible regarding the choice of the pseudo-observations, the frequency of assimilation, the data assimilation scheme itself, etc. The choices described below are consistent with current-day practices in all the CMEMS operational systems. In particular, none of them currently assimilates velocity fields, and all of them use parameterized model state vector error covariances. Only one system (the Arctic system) currently uses an Ensemble Kalman filter, but the other systems are planning to evolve toward ensemble simulations in the future. The following settings were chosen for the current experiment: assimilation will be performed with an Ensemble Kalman filter; it will be performed daily; only temperature and salinity will be used as pseudo-observations, but the whole 3D fields will be used; these pseudo-observations coming from the nested model are considered independent, i.e. their error covariance matrix is diagonal. The multi-variate model state vector will comprise also only temperature and salinity;the model itself will update the other prognostic variables.

The members of the ensemble have perturbed initial conditions, atmospheric forcing fields and Rhône river discharge, similar to Auclair et al. (2003).

The initial condition is the randomly weighted sum of the real initial condition (01/01/2014), and 6 other initial conditions (1 year, 20 days and 10 days earlier, and 10 days, 20 days and 1 year later). The weight of the real initial condition is a random-normal number chosen in the Gaussian distribution with mean 0.5 and standard deviation 0.2; if necessary, the randon number is then limited back into [0.2 0.8], whereas the 6 remaining weights are random numbers chosen uniformly in [0 1], and normalized so that the sum of all 7 weights is 1. This procedure ensures that the stability of each member is not modified (for example, the linear combination of 7 stable water columns is still a stable water column).

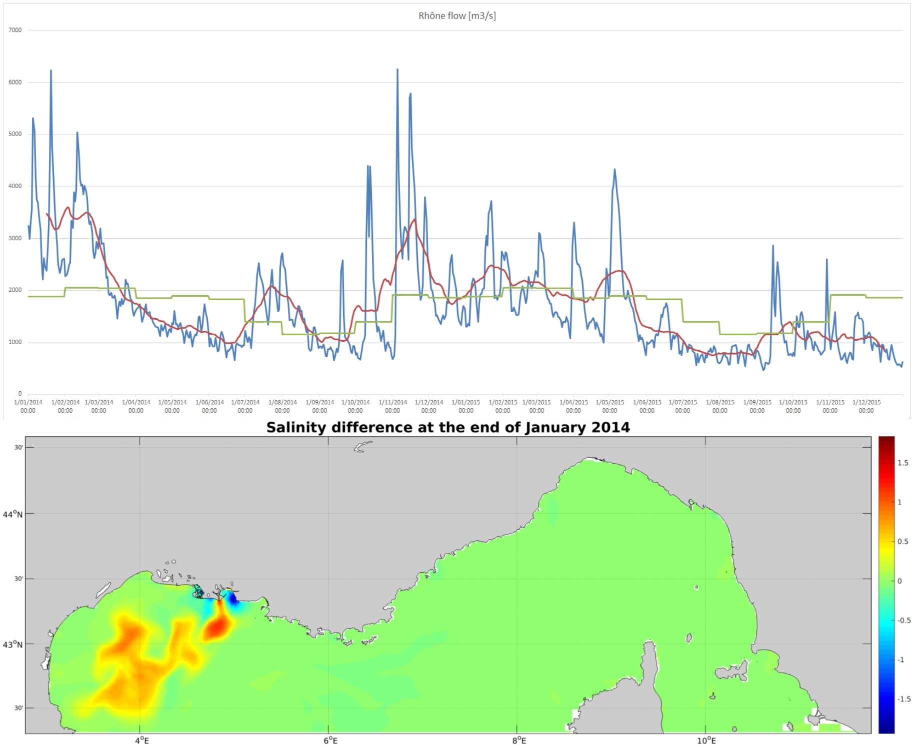

Figure 1. (above) Rhône river discharge from (green) the climatology, (blue) the measurements by the Compagnie du Rhone at the Beaucaire station, (red) the 1-month moving average of the measurements. (below) Difference of surface salinity in the nested grid on 28/Jan/2014, when using climatological or measured Rhône discharge values

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The atmospheric forcing fields of air temperature at 2m height and wind speed at 10m height are perturbed following the same procedure as in Barth et al. (2011); Vandenbulcke et al. (2017). Point-wise, the forcing fields are decomposed in Fourier series (from 3 hours to 1 year). For each member, a random field is generated, using these Fourier modes and random coefficients which have a temporal correlation length corresponding to the respective mode. This random field is added to the original field. The Rhône river discharge is perturbed using a random walk approach, with the expected perturbation after one year set as 20%. The other rivers are outside the observed part of the domain, and their discharge is not perturbed. With all 3 perturbations, an ensemble of 100 members is then spun up for 1 month.

Data assimilation is performed by the Ocean Assimilation Kit (OAK) package (Barth et al., 2008) implementing different filters such as SEEK and the deterministic Ensemble Transform Kalman filter (Bishop et al., 2001). The filter equations are listed in Barth and Vandenbulcke (2017). In this case, the Ensemble Tranform Kalman Filter variant of the EnKF is used. Nerger et al. (2012) summarizes how the spurious long-range correlations can be suppressed using so-called covariance local-

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ization, or domain localization and its addition observation localization. OAK uses the latter variant introduced in Hunt et al. (2007). In essence, the state vector is split into subdomains (water columns). In every water column, the analysis is performed independently (domain localization). In addition, for every water column, only nearby observations are used and the inverse of their error variance is multiplied by a localization function (observation localization). In the current setup, the localization function is a radial Gaussian function with an e-folding distance of 30 km.

The observation errors for temperature and salinity are set respectively at 0.3°C and 0.09 psu. These values were determined after a sensitivity experiment with observation errors of (0.5°C, 0.15 psu), (0.3°, 0.09 psu), (0.2°C, 0.05 psu) or (0.1°C, 0.03 psu); as a trade-off between generating a close emulation of two-way nesting (hence very small observation errors), and generating fields as balanced as possible, that will not cause adjustment shocks into the model (hence larger observation errors). With the latter 2 choices for the observation error, the obtained assimilation increment was not much larger than with the final choice of (0.3°, 0.09 psu), but qualitatively, unrealistic small scale variations started to appear.

From a technical point of view, OAK allows to use a multi-variate multi-grid state vector. As the Mediterranean model is parallized in 64 tiles, the multi-grid feature allows to update directly the tiles from the Mediterranean model restart files, influenced by the nested model, without including the other tiles in the state vector. The procedure thus allows to skip the reconstruction of the complete Mediterranean restart files.

3 Metrics

To assess the upscaling method, five metrics were defined.

3.1 Northern Current intensity

The Northern Current (NC) is the most important large-scale feature of the region of interest. It is considered to have a width of 40-50km during summer and 20-30km during winter; but the most offshore currents do not modify the transport much. Similarly, the NC is considered to be 100-200m deep in summer and 250-400m in winter. Following Alberola et al. (1995), its intensity is obtained by integrating the currents normal to a line from Nice to the location (43.0756°N, 7.5415°E), 214 km to the South-East, indicated in Fig. 2. This metric is useful to compare models (free and upscaled).

At the location of the Dyfamed station, for 2 different depths, the modeled current can be compared directly to measurements.

3.2 Cross-shelf transport

The penetration of off-shore water on the GoL (or inversely when negative transport values are obtained), is critical for the circulation on the shelf, for the shelf-open sea exchanges, etc. It is obtained by integrating the current over the boundary shown in Fig. 2. This metric only allows to compare different models (i.e. free and upscaled).

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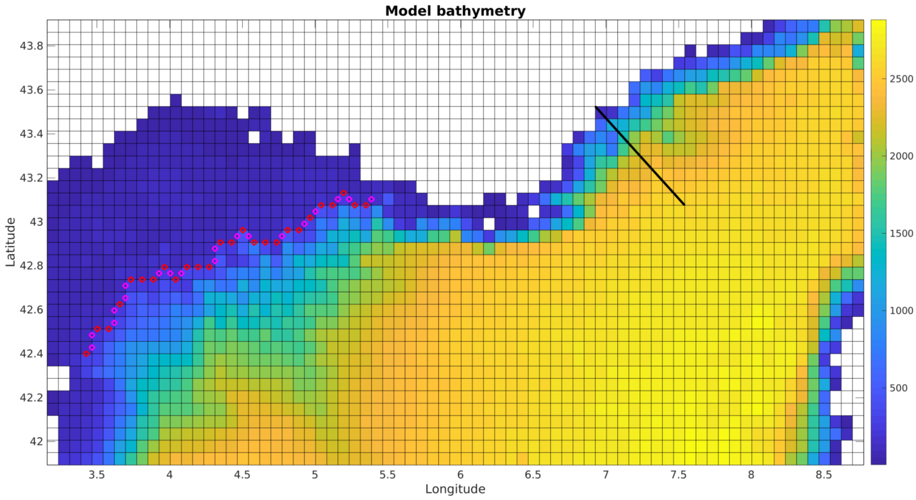

Figure 2. Zoom of the MED model grid, with the positions for computing the Northern Current metric (black line) and the cross-shelf transport metric (magenta and red dots)

3.3 Rhône river plume

The plume of the Rhône River is measured by selecting all points around the river mouth with a salinity smaller than 37psu, and then choosing the most distant one from the river mouth. This provides the plume length and direction, although it may be an approximation: the plume can be curved, in which case its real length is larger than the estimation, or it can cover a large area, in which case the algorithm still obtains an azimuth although in reality it is not well defined.

Although the real Rhône river plume is not measured directly, it can be estimated from satellite chlorophyll-a images. The model-observations comparison is then qualitative. Furthermore, the metric can be used quantitatively to compare models.

3.4 Sea surface temperature

This metric is the root mean square (rms) difference between the model and observed SST. For the latter, the L3 images are used. Furthermore, in order to examine the position of features such as fronts and eddies, the rms difference of the norm of the spatial gradient of the SST is also computed.

3.5 Western Mediterranean Deep Water formation

Following Bosse et al. (2015) and references herein, the formation zone of Western Mediterranean Deep Water (WMDW) is comprised in 41-43°N, 4-6°E. WMDW forms an easily identifiable area in the temperature-salinity diagram, and the present-day characteristics are: temperature of 12.86~12.89°C, salinity of 38.48~38.50 psu, depth is larger than 1000 m. The nested model (NW-Med) southern boundary is at 42.3°N, and hence only a part of the formation zone is included in the area of MED covered by pseudo-observations. Furthermore, the WMDW tail in the modeled temperature-salinity diagram is larger, with the

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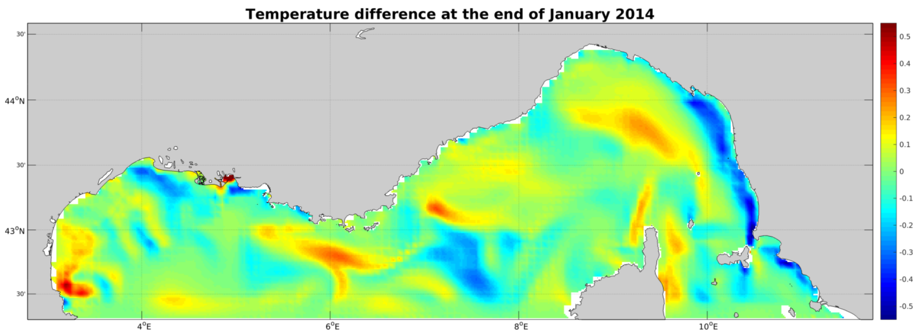

Figure 3. Difference between the parent and nested models at 31/01/2014, projected on the nested model grid.

following characteristics: temperature of 12.7~12.89°C and salinity of 38.4~38.5 psu. The metric measures the total volume [m^3] of WMDW in the domain covered by the NW-Med model, and is used to compare the different models.

4 Results

The difference between the (unperturbed) parent and child models at the end of the spinup (31 January 2014) is represented in Fig. 3 on the child model grid. There are large temperature differences at the shelf break of the Gulf of Lions (the canyons are much better represented in the regional model); which extend all the way from the surface to the bottom of the Gulf of Lions. Other large differences appear in the Eastern and Western Corsican Currents, and their junction resulting in the Northern Current, as well as at the southern open boundary. The difference in salinity (not shown) has large values around the Rhône river plume (over 1 psu), and in a lesser extent in the Eastern Corsican Current. It appears that after a month, the differences are already significant, and if one trusts the regional model more, then it would be beneficial to bring these differences back to the basin-scale model.

At the end of the spin-up, the spread of the ensemble of models (Fig. 4) is very visible over the basin, at all river mouths, but also in other regions (Alboran Sea, Tunesian coastal zone...) as all 3 perturbations are applied at once. The ensemble spread is also visible in depth (i.e. deeper than when only the river discharge is modified).

As an example, the first data assimilation cycle is shown in Fig. 5 depicting SST. Qualitatively, it appears that upscaling changes important features: the Rhône river plume is oriented offshore instead of being mostly along-shore; fronts seem to be more well-defined; and the Northern Current flows along the shelf break instead of covering a large part of the shelf. The nested model, and the “upscaled” model, seem to be in closer agreement with the satellite image, than the free model.

4.1 Cross-shelf transport

The flow accross the shelf break is represented in Fig. 6. Although alternating periods of inflow and outflow appear, the transport seems to show a chaotic behavior. Yet it can be seen that while both models are generally similar, some periods exist

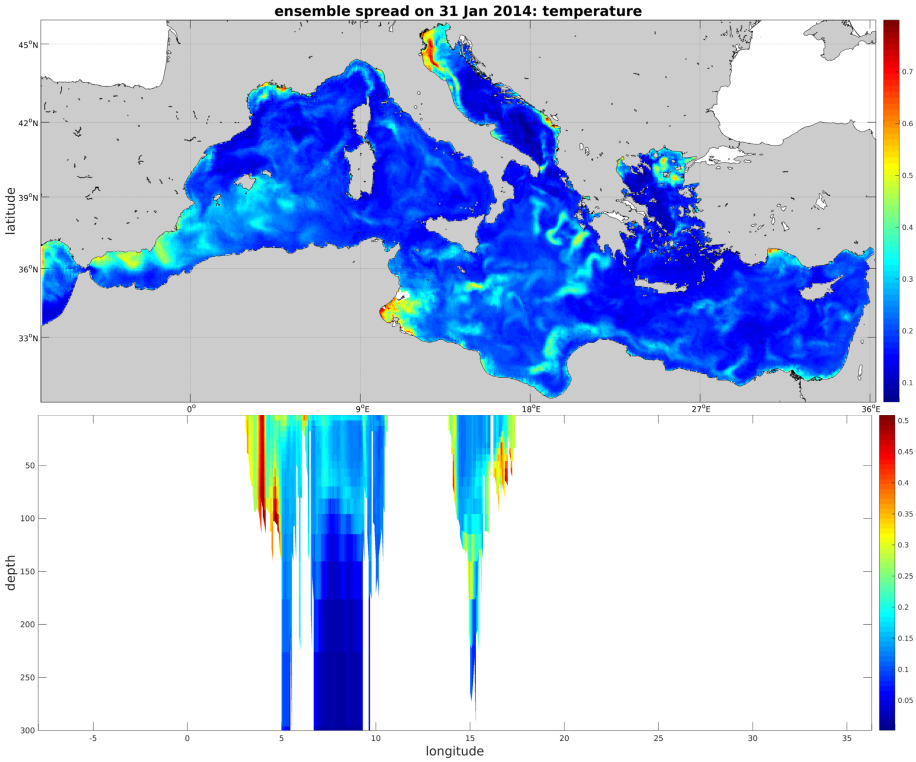

Figure 4. Spread of the ensemble of MED models at 31/01/2014: (upper panel) surface temperature, (lower panel) section at 43°N

where the simulated transport is very different. During the first month (February 2014), the free model predicts a net outflow during the first 2 weeks, followed by a net inflow during the last 2 weeks. The nested model (not shown) and hence also the upscaled model actually predicts the exact opposite. The reasons for the nested model to behave differently than the parent model may be an effect of wind interaction with the (different) bathymetries, or related to the different resolution. The actual transport is not measured or available; but the result of interest here is that the upscaling method is able to align the (parent model) currents with the ones from the nested model, and hence emulate two-way nesting, although only temperature and salinity pseudo-observations are used. The ability to constrain the cross-shelf transport by T/S assimilation is also an indication that the data from a high-resolution glider fleet would be beneficial to constraint the model.

During the remainder of the year, the upscaled model predicts somewhat larger transports (both inward and outward). Generally speaking however, the two transport curves are closer than in February (or at least they are not of opposite signs anymore). Noticeably, in August-September, the upscaled model predicts a period of large inflow on the Gulf of Lions. The free model also predicts this inflow, but delayed by about 2 weeks.

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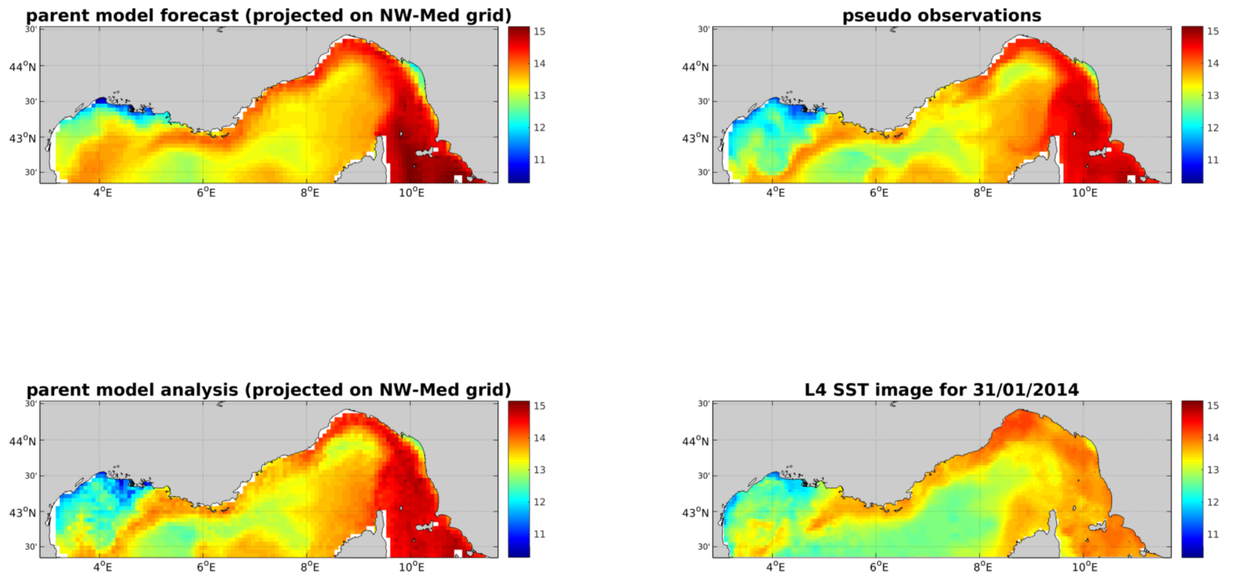

Figure 5. Sea surface temperature after the first upscaling step (31/01/2014), in the free model (upper left), nested model (upper right), upscaled model (lower left) and satellite observation (lower right)

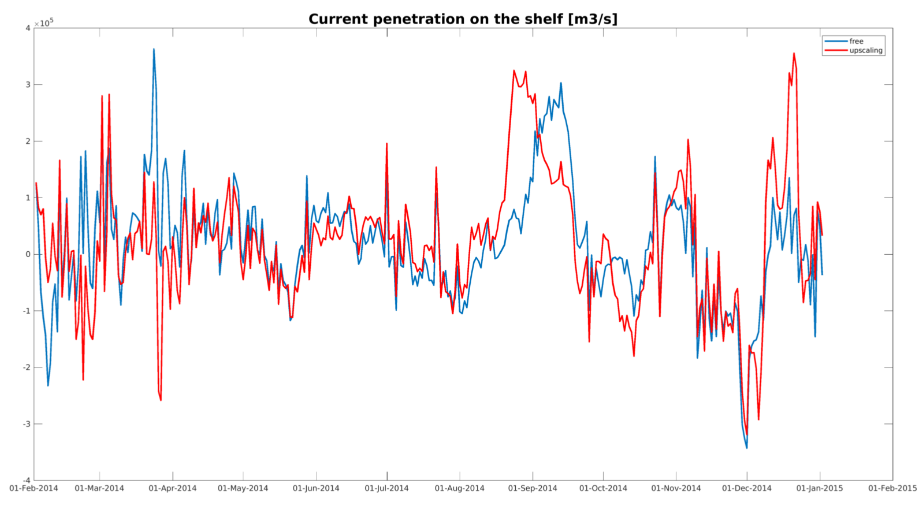

Figure 6. Water transport accross the shelf break during 2014, as obtained by the free (blue curve) and upscaled (red curve) parent models. Positive values indicate a net on-shelf transport.

4.2 Northern Current

The transport by the Northern Current off Nice is represented in Fig. 7. Over the whole period, the root mean square difference between parent and nested models is 0.22 Sv for the free model, and 0.19 Sv for the upscaled model. The same qualitative observations can be made as for the cross-shelf transport. Both models generally agree, but periods exist with relatively impor-

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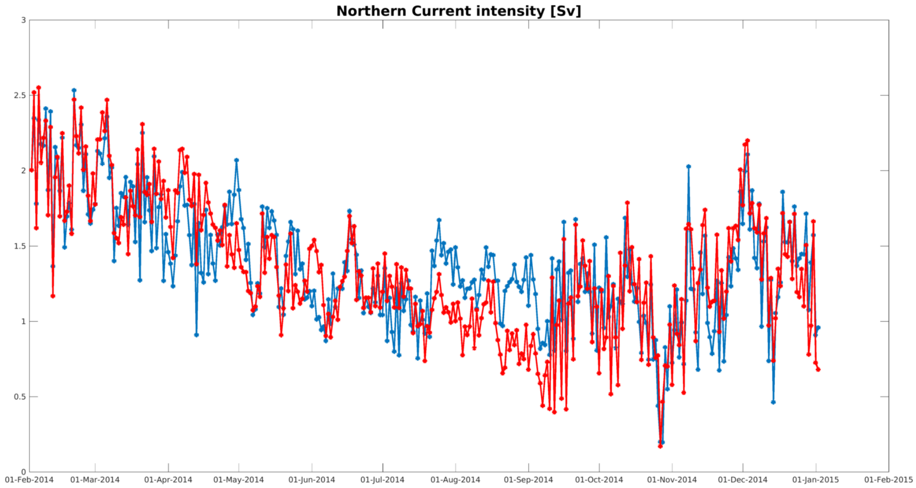

Figure 7. Water transport by the Northern current off Nice (France) during 2014, as obtained by the free (blue curve) and upscaled (red curve) parent models.

tant differences. Interestingly, a large difference appears in August-September, when the free model predicts a larger transport than the upscaled model. This is also the period when the transport accross the shelf break presents a temporal shift in between models.

For the purpose of our study, this metric cannot used to compare the models to (inexistant) real measurements of the Northern Current transport; but (as for the previous metric), they show that our goal is reached and upscaling of scalar fields is able to modify the velocity field of the parent model although only temperature and salinity are observed.

4.3 River plume

The Rhône plume metric is perhaps the metric most significantly altered by upscaling. During the first month of the upscaled simulation, the free model usually places the plume along-shore, to the North-East, whereas the nested model usually orients the plume off-shore to the South-East (see Fig. 8). On top of the resolution-related differences between parent and nested models (in particular the bathymetry and the interaction of the water masses with the wind), both models have different freshwater discharge values, which is usually much higher and has also a much larger variability in the nested model during February 2014. The upscaling method is clearly able to make the parent model ingest the different plume dynamic coming from the nested model. During the remainder of 2014, differences between both models are smaller, with another period (late August - early September) where the opposite case occurs: the free model plume is oriented off-shore, but the nested (and upscaled) model predicts an along-shore plume.

The river plume can qualitatively be compared to real observations by using satellite observations of chlorophyll. During the first month of simulation, where the most significant differences appear, only a few level-3 satellite images are not almost entirely obscured by clouds. An example is given in Fig. 9 for 12 February 2014. One can clearly see the off-shore plume from

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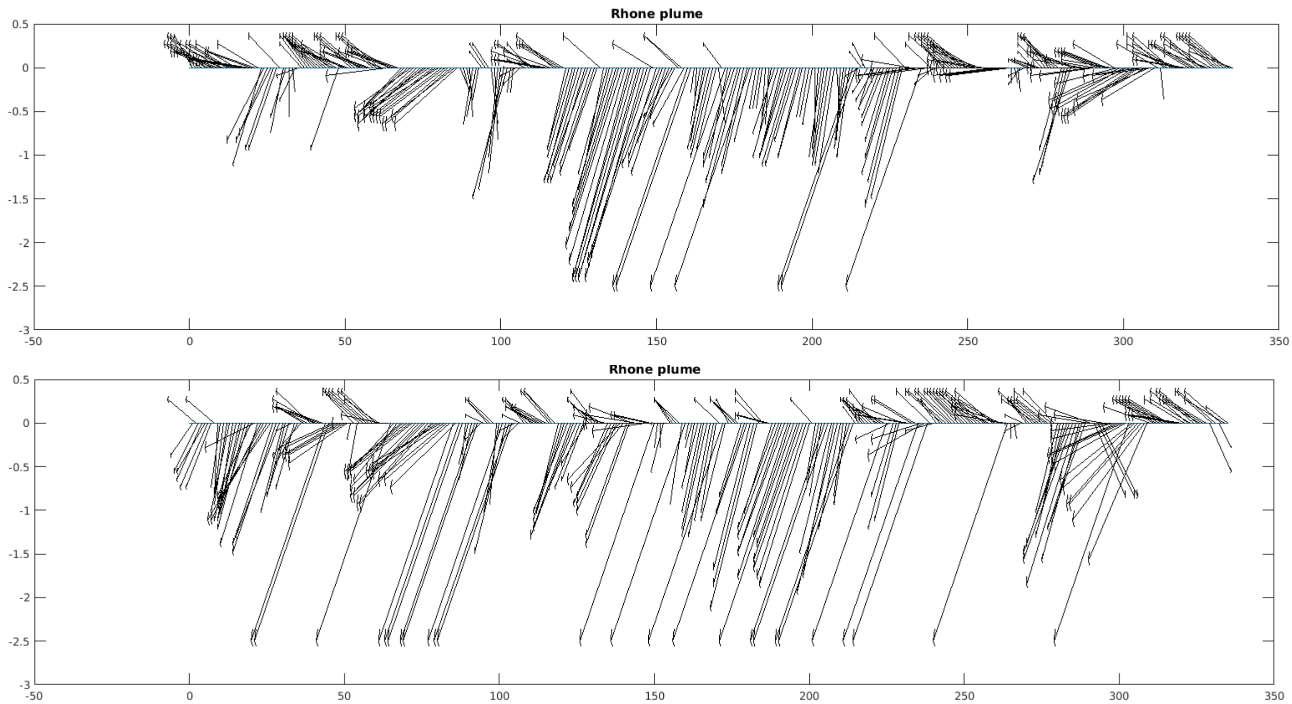

Figure 8. Rhône river plume direction and length during the simulation (Feb-Dec 2014) (upper panel) for the free and (lower panel) upscaled models

the chlorophyll observations, whereas the free model plume is mostly along-shore. The nested and upscaled models correctly place the plume off-shore. Apart from the surface salinity used to characterize the Rhône plume, upscaling also modifies in-depth salinity. In particular, the cores of the Eastern and Western Corsican Currents are saltier in the upscaled model, with differences of about 0.15 psu during the first assimilation cycle.

4.4 SST

The sea surface temperature metric allows to quantify the model error by comparison with L3 satellite images. It appears that generally, the (parent) model is already in very good agreement with observations, even though no data assimilation is performed. Usually, the nested model is better still in some areas (e.g. coastal waters), and the upscaling procedure brings back these local improvements to the parent model. However, the area-wide RMS error is not influenced very much by upscaling, as large areas are essentially unmodified (parent and child models use the same atmospheric forcing fields).

Some days, some processes appear to be missed by the models (both parent and nested), so that the RMS error is relatively large. In this case again, upscaling does not influence the RMS error of the parent model very much, as the nested model is not representing these processes any better than the parent model.

In both cases, this does not imply that the upscaling method is flawed, but rather that, in the current setup, the nested model

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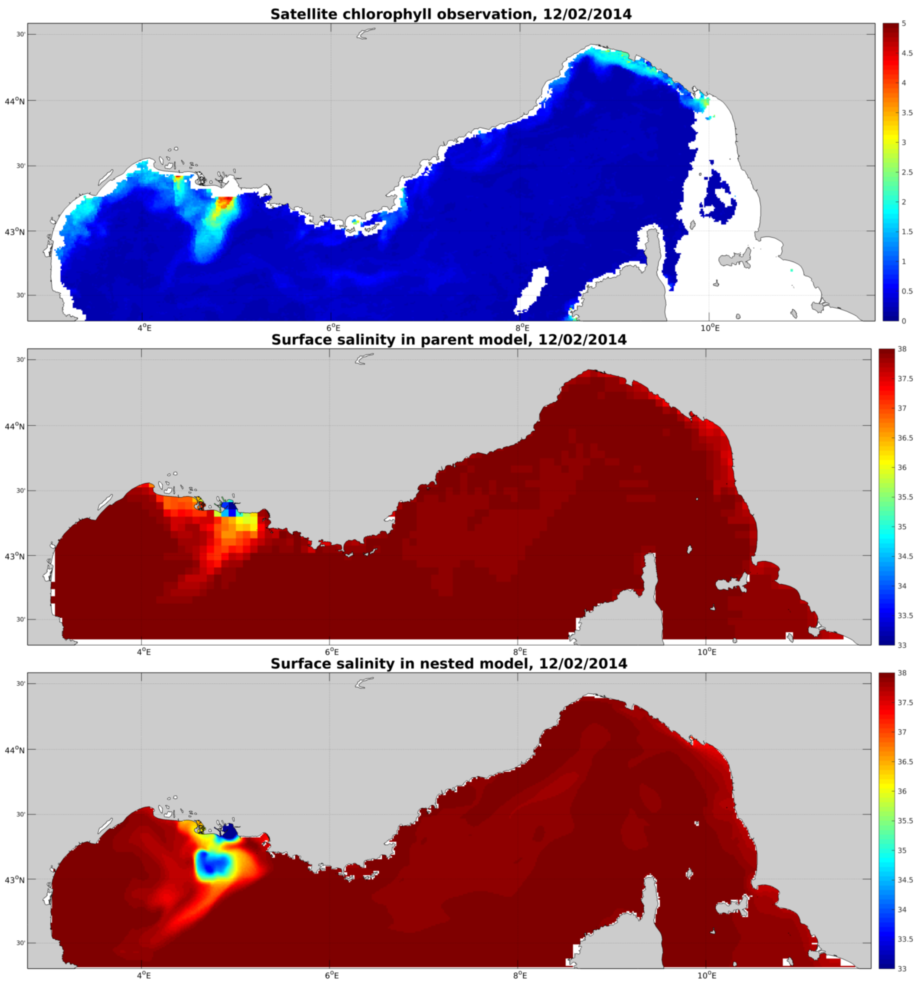

Figure 9. Comparison of the Rhône river plume on 12/Feb/2014 (upper panel) satellite chlorophyll image (middle panel) parent model salinity (lower panel) nested model salinity

is not able to generate an RMS error significantly lower than the parent model; hence upscaling does not have much to feed on. Fig. 10 shows the RMS error during the first 2 months of simulation. A similar plot for the whole of 2014 shows that the situation worsens during summer (errors of 3°C) both for parent and child model; the difference in between models is hidden by the temporal variability of the error (not shown). In any case, the upscaled model is still very close, and slightly better, than both the (free) parent and the nested models.

The model temperature in depth cannot be systematically evaluated against observations. Differences between the parent and the nested model are locally important, e.g. on the bottom of the Gulf of Lions, or in the Eastern Corsican and Northern Current cores (with differences of up to 0.3°C). Upscaling is able to bring these differences back into the parent model.

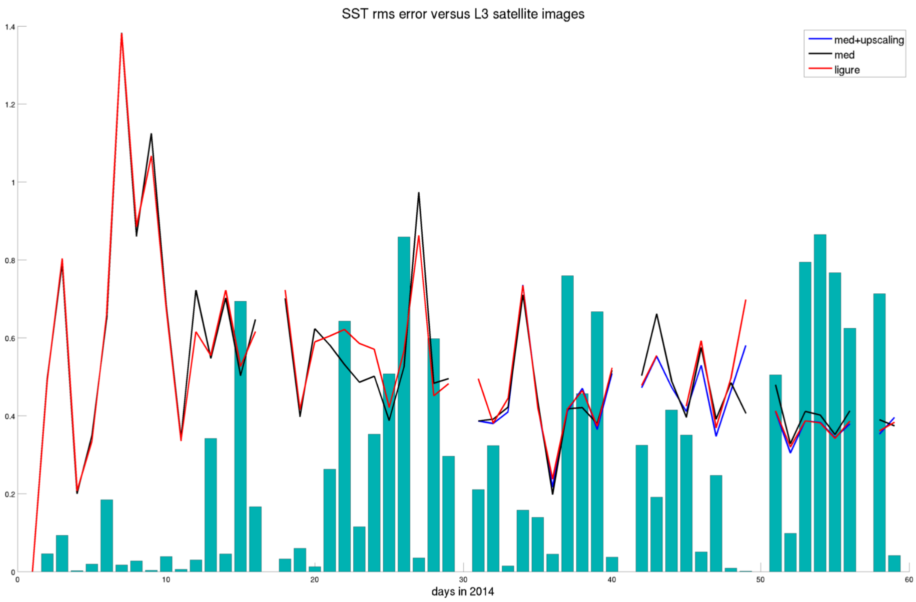

Figure 10. SST RMS error in the free model (black curve), nested model (red curve), upscaled model (blue curve) during the first 2 months of simulation. The bars represent the proportion of unclouded points in the L3 satellite image.

4.5 WMDW

The total amount of Western Mediterranean Deep Water in the free model (blue curve in Fig. 11) and the nested model (green curve) is periodically important (10^3km^3), and both models do not appear to converge during the simulation. On the contrary, a period of large discrepency appears during most of the second half of the year. Upscaling largely modifies the parent model, which in turns provides modified boundary conditions to the nested model, so that after a while, the upscaled model and its child model significantly diverge from the free models. Without measurements and due to the choice of the model domain, it is not possible to assert which pair of models is more realistic. However, the discrepency between parent and child model is much reduced in the upscaled pair of models, which is certainly a desirable characteristic. This can be explained by the fact that the data assimilation also modifies the parent model solution outside the nested area (in the limit of the localization radius used in the data assimilation procedure). Therefor, the water immediately outside the nested domain is modified and made more coherent with the nested solution. East and West of Corsica, the Corsican currents will reintroduce this water into the domain, and one can see how this repeated procedure will ultimately reduce discrepencies between parent and nested models.

5 Conclusions

When a nested model is available, it usually benefits from higher resolution, and improved representation of some relevant processes. However often, and particularly so in the operational oceanography context, there is no feedback from the nested

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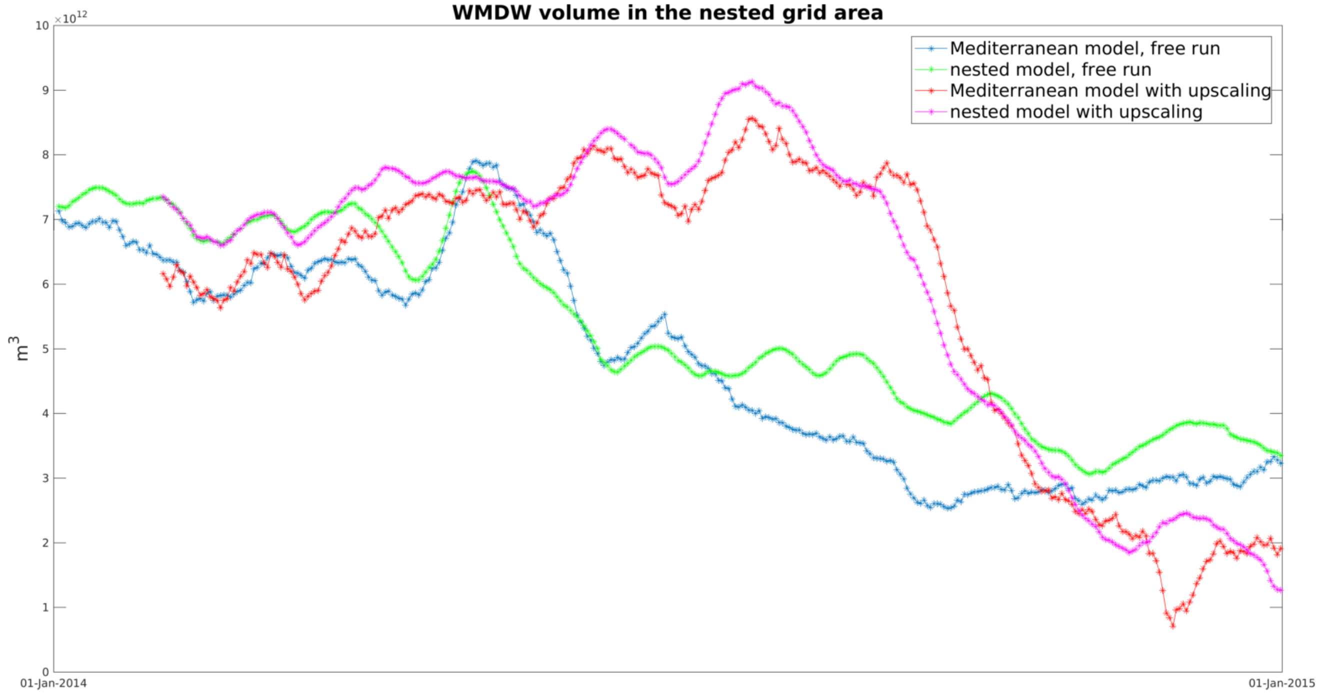

Figure 11. Time serie of total amount of WMDW in the area covered by the nested model: (blue) free parent model (green) nested model in the free model (red) parent model with upscaling (magenta) nested model in the upscaled model

model to the parent model. Data exchanges are limited to the parent model providing initial and/or boundary conditions to the nested model. Thus, the benefit of having a nested model is lost to the parent model.

The upscaling method consists in assimilating results from a regional model into a basin-wide model, in order to emulate the feedback of two-way nesting. The underlying hypothesis is that the nested model is more realistic than the parent model.

The method was tried out using a nested model configuration of the Mediterranean Sea and the North-Western basin, with a resolution ratio of 5. Data assimilation was performed using a localized ensemble Kalman filter; as pseudo-observations, the full 3D fields of temperature and salinity were used. The aim of this study is limited to verifying whether nesting feedback could be emulated by data assimilation; without trying to verify whether the nested model is indeed more realistic than the parent one.

Whether upscaling was able to emulate two-way nesting, was measured using 5 metrics related to processes relevant in the study domain: the intensity of the Northern Current, the cross-shelf transport, the position of the Rhône river plume, sea surface temperature, and the quantity of Western Mediterranean Deep Water. These metrics show that the upscaling method is indeed able to emulate two-way nesting and bring the parent model closer to the nested model. By assimilating only temperature and salinity, velocity and transport metrics were also improved in the parent model. Furthermore, when real observations were available, the nested and upscaled model proved to be more realistic than the free model.

Advantages of using upscaling include the following. The parent model takes advantage of improvements in the nested model due to higher resolution, better representation of local processes, assimilation of local and/or very high resolution measurements such as HF radar observations, and/or use of more realistic forcings such as river discharges or atmospheric fields from a regional weather forecasting model. Over time, discrepencies between parent and nested model are attenuated. The parent model then provides more consistent boundary conditions to the nested model, and artefacts such as wave reflexion at the boundary may be avoided.

In the operational context, a supplementary advantage may appear. If a user is interested in a particular region not entirely covered by a regional model, it may be difficult for him to merge 2 products (the large-scale model, and the finer model not entirely covering the area of interest). By default, the user may then use only the coarser model. If the regional model is upscaled into the large-scale model, this is the only product the user needs to consider.

Competing interests. No competing interests are present.

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References

Alberola, C., Millot, C., and Font, J.: On the seasonal and mesoscale variabilites of the Northern Current during the PRIMO-0 experiment in the western Mediterranean Sea, Oceanologica Acta, 18, 1995.

Alvarez, A., Lopez, C., Riera, M., Hernandez-Garcia, E., and Tintore, J.: Forecasting the SST space-time variability of the Alboran sea with genetic algorithms, Geophysical Research Letters, 27, 2000.

Auclair, F., Casitas, S., and Marsaleix, P.: Application of an inverse method to coastal modeling, J. Atmos Oceanic Technol, 17, 1368–1391, 2000.

Auclair, F., Marsaleix, P., and Estournel, C.: The penetration of the Northern Current over the Gulf of Lions (Mediterranean) as a downscaling problem, Oceanologica Acta, 24, 529–544, 2001.

Auclair, F., Marsaleix, P., and De Mey, P.: Space-time structure and dynamics of the forecast error in a coastal circulation model of the Gulf of Lions., Dyn. Atmos. Oceans, 36, 309–346, 2003.

Barth, A. and Vandenbulcke, L.: Ocean Assimilation Kit documentation, Universite de Liege, GHER, http://modb.oce.ulg.ac.be/mediawiki/index.php/Ocean Assimilation Kit, 2017.

Barth, A., Alvera-Azcarate, A., Rixen, M., and Beckers, J.: Two-way nested model of mesoscale circulation features in the Ligurian Sea, Progress In Oceanography, 66, 171–189, 2005.

Barth, A., Alvera-Azcarate, A., Beckers, J.-M., Rixen, M., and Vandenbulcke, L.: Multigrid state vector for data assimilation in a two-way nested model of the Ligurian Sea, Journal of Marine Systems, 2006.

Barth, A., Alvera-Azcarate, A., and Weisberg, R. H.: Assimilation of high-frequency radar currents in a nested model of the West Florida shelf, Journal of Geophysical Research, 113, 2008.

Barth, A., Alvera-Azcarate, A., Beckers, J.-M., Staneva, J., Stanev, E., and Schulz-Stellenfleth, J.: Correcting surface winds by assimilating high-frequency radar surface currents in the German Bight, Ocean Dynamics, 61, 599–610, 2011.

Bishop, C., Etherton, B., and Majumdar, S.: Adaptive sampling with the Ensemble Transform Kalman Filter part I: the theoretical aspects., Monthly Weather Review, 129, 420–436, 2001.

Bosse, A., Testor, P., Mortier, L., Prieur, L., Taillandier, V., d'Ortenzio, F., and Coppola, L.: Spreading of Levantine Intermediate Waters by submesoscale coherent vortices in the northwestern Mediterranean Sea as observed with gliders, Journal of Geophysical Research: Oceans, 120, 1599–1622, 2015.

Debreu, L., Vouland, C., and Blayo, E.: AGRIF: Adaptive grid refinement in Fortran, Computers and Geosciences, 8, 8–13, 2008.

Debreu, L., Marchesiello, P., Penven, P., and Cambon, G.: Two-way nesting in split-explicit ocean models: Algorithms, implementation and validation, Ocean Modelling, 49-50, 1 – 21, https://doi.org/https://doi.org/10.1016/j.ocemod.2012.03.003, 2012.

Guinehut, S., Larnicol, G., and Le Traon, P.: Design of an array of profiling floats in the North Atlantic from model simulations, Journal of Marine Systems, 35, 2002.

Guinehut, S., Le Traon, P., Larnicol, G., and Philipps, S.: Combining ARGO and remote-sensing data to estimate the ocean three-dimensional temperature fields - A first approach based on simulated observations, Journal of Marine Systems, 46, 85–98, 2004.

Hunt, B., Kostelich, E., and Szunyogh, I.: Efficient data assimilation for spatiotemporal chaos: A local ensemble transform Kalman filter, Physica D: nonlinear phenomena, 230, 112–126, 2007.

Le Traon, P.-Y., Antoine, D., Bentamy, A., Bonekamp, H., Breivik, L., Chapron, B., Corlett, G., Dibarboure, G., DiGiacomo, P., Donlon, C., Faugère, Y., Font, J., Girard-Ardhuin, F., Gohin, F., Johannessen, J., Kamachi, M., Lagerloef, G., Lambin, J., Larnicol, G., Le Borgne, P., Leuliette, E., Lindstrom, E., Martin, M., Maturi, E., Miller, L., Mingsen, L., Morrow, R., Reul, N., Rio, M., Roquet, H., R., S., and Wilkin, J.: Use of satellite observations for operational oceanography: recent achievements and future prospects, Journal of Operational Oceanography, 8, 2015.

Madec, G.: NEMO ocean engine, Note du Pôle de modélisation, Institut Pierre-Simon Laplace(IPSL), France, No 27, ISSN No 1288-1619, 2008.

Millot, C.: Circulation in the Western Mediterranean Sea, Journal of Marine Systems, 20, 423–442, 1999.

Nerger, L., Janjic, T., Schroter, J., and Hiller, W.: A regulated localization scheme for ensemble-based Kalman filters, Q. J. R. Meteorol. Soc, 138, 802–812, 2012.

Onken, R., Robinson, A. R., Kantha, L., Lozano, C. J., Haley, P. J., and Carniel, S.: A rapid response nowcast/forecast system using multiply nested ocean models and distributed data systems, Journal of Marine Systems, 56, 2005.

Schulz-Stellenfleth, J. and Stanev, E.: Analysis of the upscaling problem - A case study for the barotropic dynamics in the North Sea and the German Bight, Ocean Modelling, 100, 109–124, 2016.

Vandenbulcke, L., Beckers, J., and Barth, A.: Correction of inertial oscillations by assimilation of HF radar data in a model of the Ligurian Sea, Ocean Dynamics, 67, 117–135, 2017.