DOWNSCALING EFFECTS ON MODELLING WAVES, TIDES AND STORM SURGE

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This paper presents the results of downscaling effects when modelling waves, tides and storm surge using a nested modelling system. In this study, the coupled POLCOMS/ProWAM models are used, with 3 nested computational domains, the largest of which covers part of north-eastern Atlantic Ocean with a coarse resolution grid and the smallest covers the surrounding waters of south-west Cornish coast of the UK with a finer resolution grid. Applying the identical surface wind forcing to all 3 computational domains and the wave and tide boundary conditions provided from the coarse to finer domains, the computed wave heights, tides and surge levels are examined at selected locations to study the downscaling effects. The results show that downscaling could considerably increase accuracy of model predictions in the local domain. For the particular test conditions used in the present study, 3-level and 2-level downscaling produces similar results in the local domain. The results also indicate that downscaling with reduction of grid resolution by 6 times is acceptable for the study site.

Keywords: downscaling effect; nested model; wave, tide and surge modelling; POLCOMS; WAM; ProWAM; Celtic Sea

INTRODUCTION

The value of the UK's assets at risk from coastal flooding have significantly increased in recent years, and currently stands at ~£132.2bn, with some 4 million properties in England and Wales alone under threat (Office of Science and Technology, 2004). The EPIRUS (Ensemble Prediction of Inundation Risk and Uncertainty arising from Scour) project, funded by the UK NERC (Natural Environment Research Council) under the FREE (Flood Risk from Extreme Events) Programme, uses a "clouds-to-coast" approach with ensemble techniques to study the risk of coastal flooding and erosion under the extreme conditions (Zou et al, 2008). One of the key elements in the project is to use oceanic and coastal process models to transform the global meteorological predictions to oceanic and coastal waves, tides and storm surge.

Due to the wide variation of spatial and temporal scales for different models used in the project, ranging from 1000s km to 10s m in space, it has been necessary and essential to use a nested modelling system, so that the macro-scale processes can be reasonably represented in the micro-scale predictions. As part of the EPIRUS project, the 3D current model - POLCOMS, integrated with the spectral wave model - ProWAM, was used to provide a downscaling system for modelling waves, tides and surge from ocean-base scale (~1000 km) to coastal zone scale (~1 km), see Wolf et al (2002); Osuna et al (2004) and Pan et al (2009a). However, how to correctly and accurately transform the wave and tide characteristics from the large oceanic domain to small coastal zones is a key question that needs to be answered. This will require a better understanding of the interaction and the propagation of perturbations and uncertainties between the computational domains which may also have different grid resolutions. To this end, this paper uses three computational domains with different grid resolutions, set at north-eastern Atlantic Ocean, to investigate and quantify the effects of downscaling.

MODELLING SYSTEM

This study uses the coupled POLCOMS and ProWAM modelling system with 3 nested grids. This modelling system has been extensively calibrated and used in many applications, see Osuna et al (2004), Pan et al (2009a), Pan et al (2009b) and Chen et al (2010). Whilst the full details of both models can be found elsewhere, only brief descriptions to these models are given here.

Wave Model: WAM/ProWAM

WAM is a third generation spectral wave model, which solves the wave action balance equation without any pre-defined shape of the energy spectrum (Günther et al, 1992). A modified version of WAM, ProWAM, by Monbaliu et al (2000) has also included the current effects on wave modelling.

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Tide and Surge Model: POLCOMS

POLCOMS is a baroclinic three-dimensional current model with coverage of both the deep ocean and the continental shelf, developed at Proudman Oceanographic Laboratory (POL, now part of National Oceanography Centre – NOC) (Holt and James, 2001). The model incorporates the third-generation wave model, ProWAM, with an option of two-way coupling to quantitatively predict waves and currents (Flather, 1981; Wolf et al, 2002; Osuna et al, 2004). The model has been widely used to generate tides and surge for both the deep ocean and the continental shelf. Together with coupled ProWAM model as described above, the model also includes the interaction between waves and currents.

Model Setup

In order to examine the effects of downscaling through the nested domains, three computational domains used in the present study are shown in Figure 1, the largest computational domain covers a significant part of north-eastern Atlantic Ocean (denoted as 'oceanic domain' hereafter) with a grid resolution of 1/10° by 1/10°. The second level of downscaling uses a computational domain covering the Celtic Sea (regional domain) with an increased grid resolution of 1/20° by 1/20°, the grid size of which is halved in comparison with the oceanic domain. The third level of downscaling covers part of south-west water adjacent to the Cornish Peninsula (local domain) with a further reduced grid size at the resolution of 1/60° by 1/60°, which is the smallest computational domain in this study. A one-way downscaling technique from the largest domain to the smallest domain was adopted. The hydrodynamics boundary conditions for the smaller domain are provided by the model results from the up-level coarser domain runs. Figure 1 shows the relative positions of the nested computational domains, as well as the locations at which the comparisons of model results from different model domains were made.

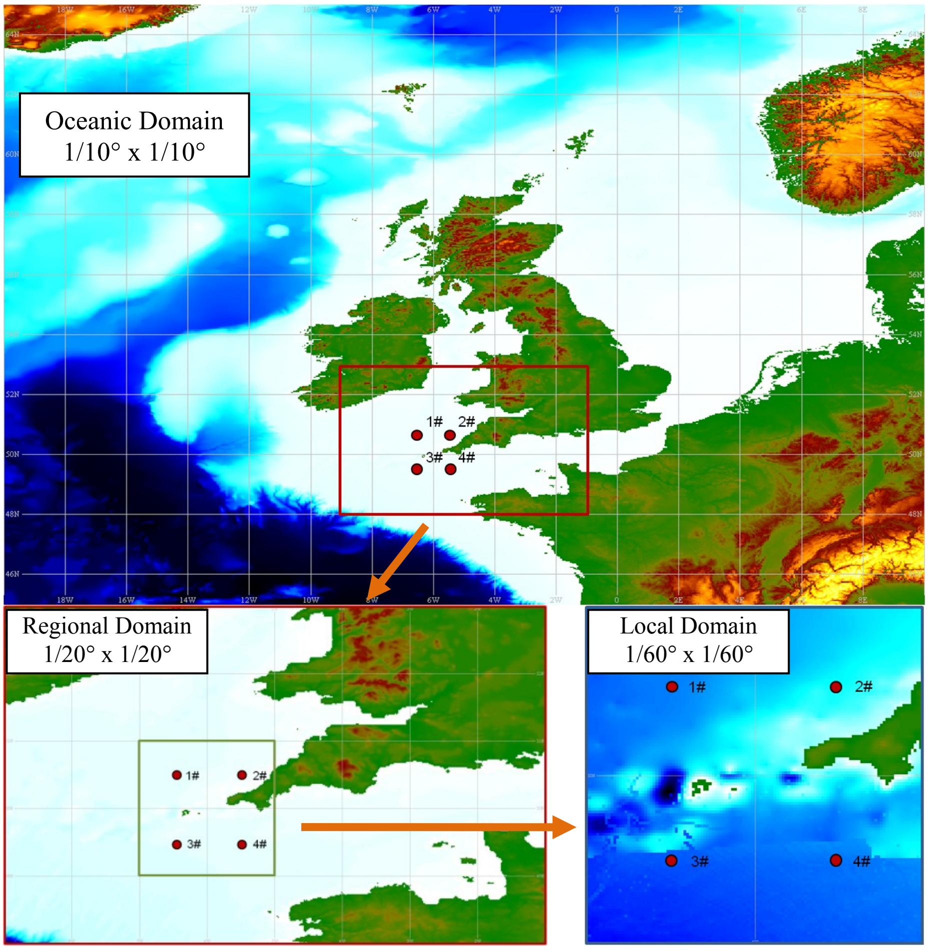

Figure 1. Computational domains for downscaling

RESULTS & DISCUSSION

Comparing the computed significant wave heights produced from three domains indicates that the wave and wind forcing have been well transferred from the coarse grid domain to the fine grid domain. Figure 2 shows the snapshots of significant wave heights within the three domains at an identical time. It can be seen that along the computed wave heights along the boundaries of the smaller domains fit well with those computed at the corresponding locations in the up-level coarse grid domain, and greater details of wave height distributions are revealed progressively from the oceanic to local domains. Sensitivity tests show that the accuracy of the computed wave field in the smaller domains heavily relies on the wave forcing obtained from the larger domain being correctly imposed along the open boundaries of the smaller domain with the same surface wind conditions, Pan et al (2009b).

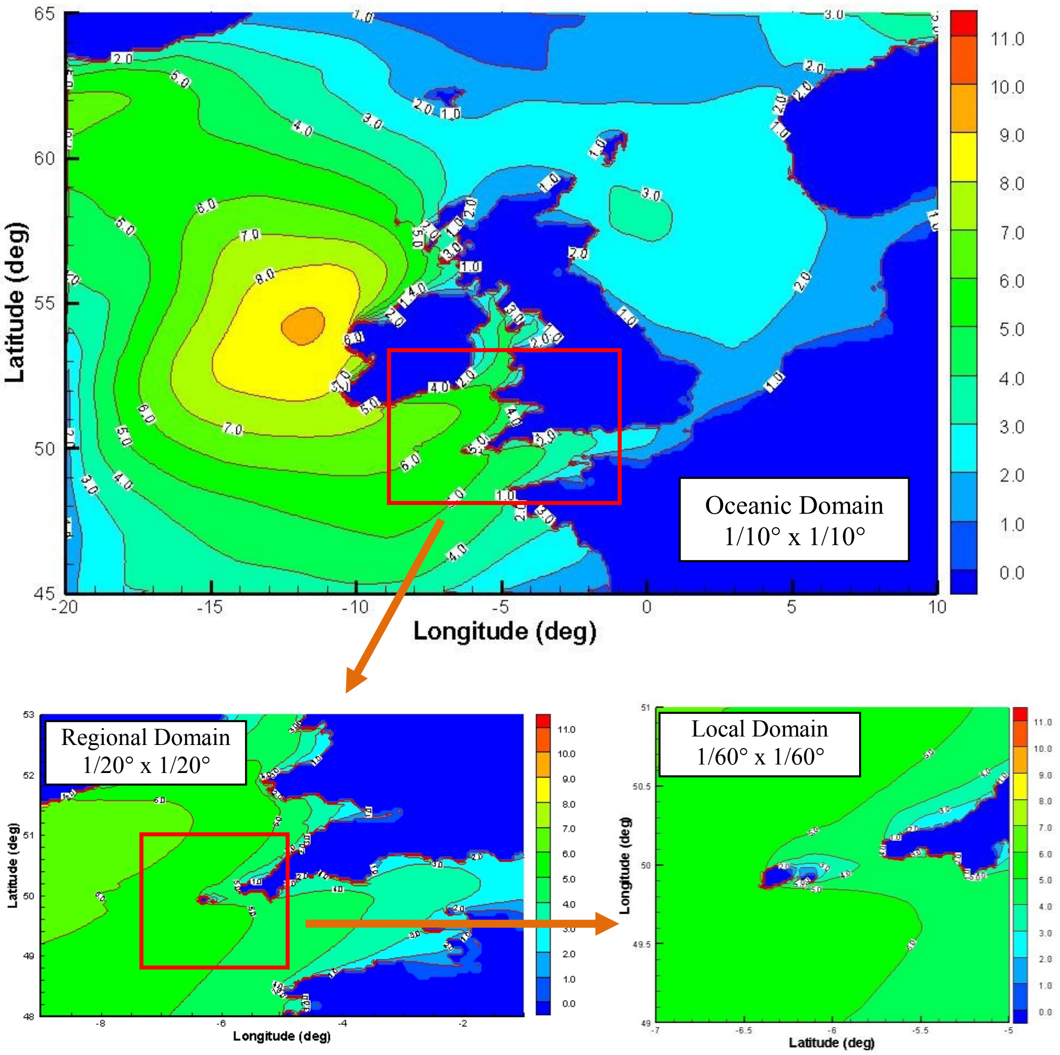

Figure 2. Snapshots of the computed significant wave heights within the three domains

Figure 3 shows the differences of the computed significant wave heights between (a) the oceanic and local domains, and (b) the regional and local domains. The results show that the predicted wave heights are mostly affected in the shallow water areas near the land boundaries, mainly due to the model resolution. Such effects are seen more pronouncedly between the oceanic and local domains, as expected. The downscaling also affects the tides and storm surge in the shallow water areas, as well as the phase of tides and depth-averaged currents. Figure 4(a) shows the difference of the predicted tidal range averaged over the computational period between the regional and local domains, and Figure 4(b) shows that of root-mean-square (RMS) tidal currents. The main differences of the mean tidal range and storm surge are again found in the shallow water areas next to the land.

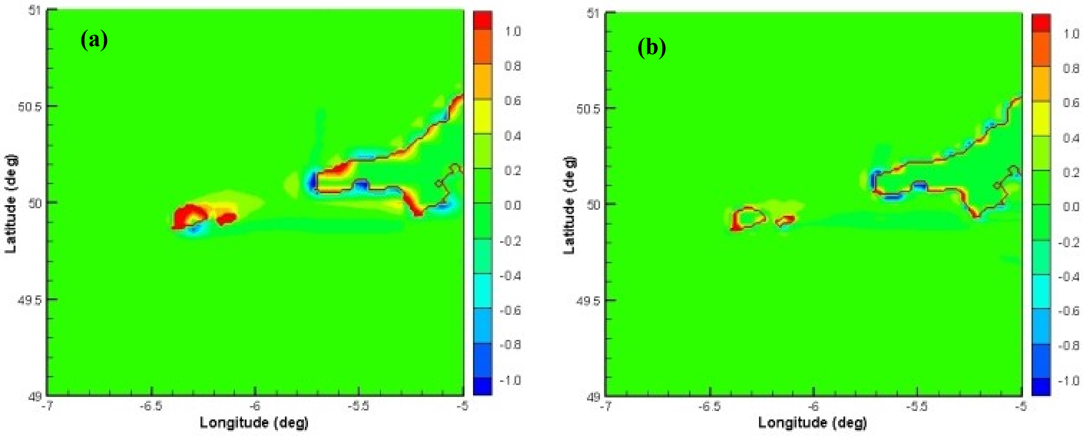

Figure 3. Differences of the computed wave heights between (a) oceanic & local domains, and (b) regional & local domains

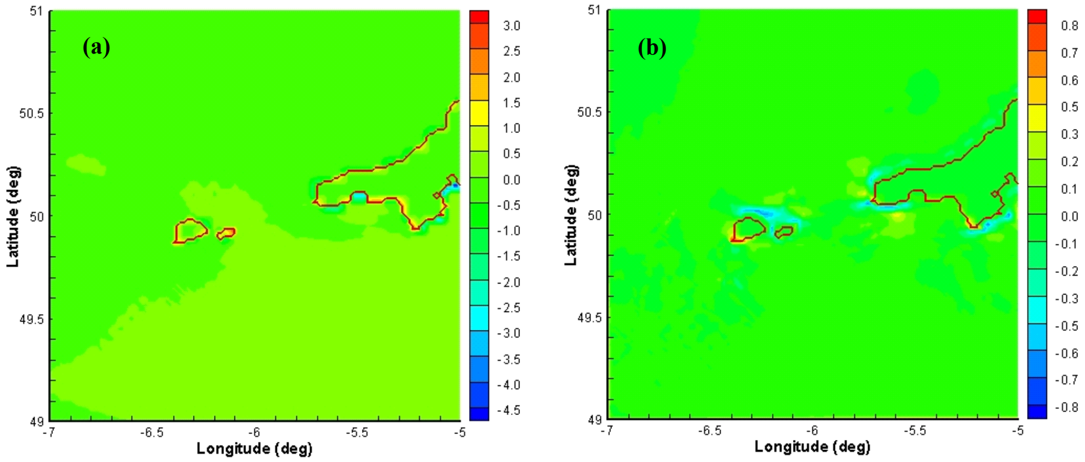

Figure 4. Differences of the computed (a) tidal range and (b) RMS tidal current between regional & local domains

For the time series of the computed significant wave height, Figure 5 shows the difference of the significant wave heights between the different domains (“coarse”=oceanic domain; “mid”=regional domain; “fine”=local domain), after the initial period of the computation. It is found that change in wind speed, rather than the wind speed itself, has a noticeable effect on the wave height predictions over the different computational domains. For the storm conditions, which are normally associated with high magnitude and rapid change of wind speed, downscaling from coarse domain to fine domain may have considerable impacts on the predicted wave heights. Therefore, it is essential that nested grids are used for predicting storm waves.

Figure 6 shows the similar comparisons for the computed tidal elevations and the velocities of tidal currents between the regional and local domains. The differences of the predicted tidal elevations between the regional and local domains are found to be significant, with a range about 0.05 m for both spring and neap tides, which amounts approximately 5% of the spring tidal range. The difference is also clearly modulated by the tides, exhibiting slightly larger magnitudes for spring tides. For the velocities of tidal currents, the differences between the regional and local domains are also found to be about 5% during the spring tides, but the effects of downscaling during the neap tides are more pronounced as shown in this figure.

A slight phase difference is also found in the comparison of time series of tidal elevation and depth-averaged currents, which is believed to be due to effects of the resolution of the bathymetry on the tidal wave speed, particularly in the shallow waters.

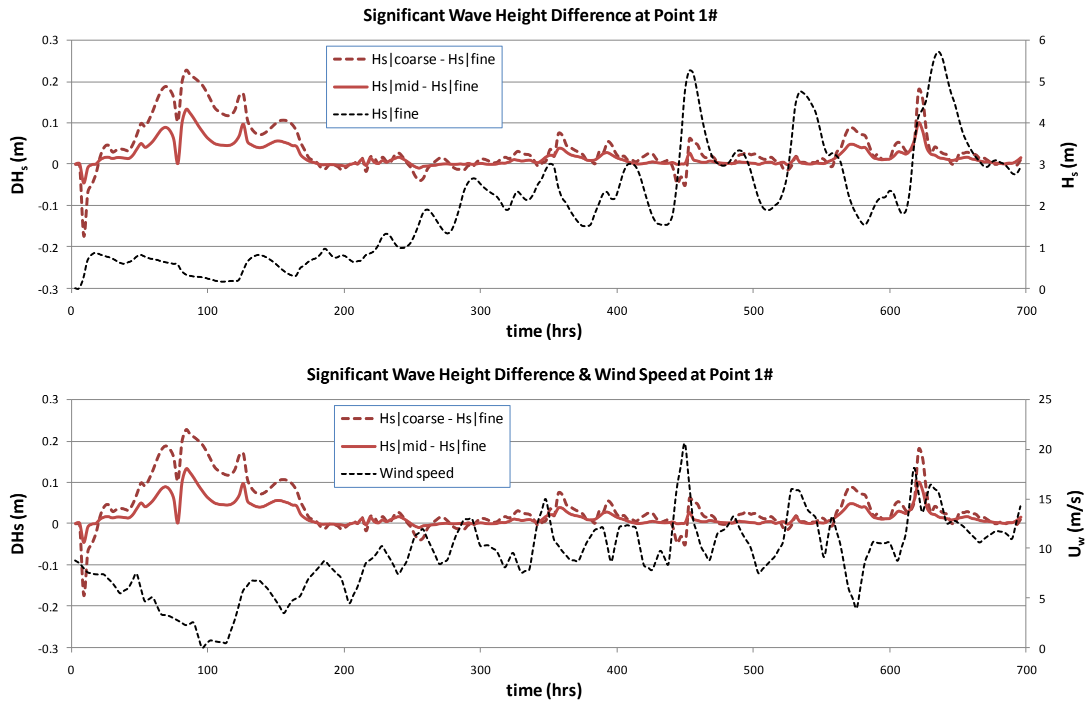

Figure 5. Differences of the computed significant wave height between the different domains against wave height (top) and wind speed (bottom) [“coarse”=oceanic domain; “mid”=regional domain; “fine”=local domain]

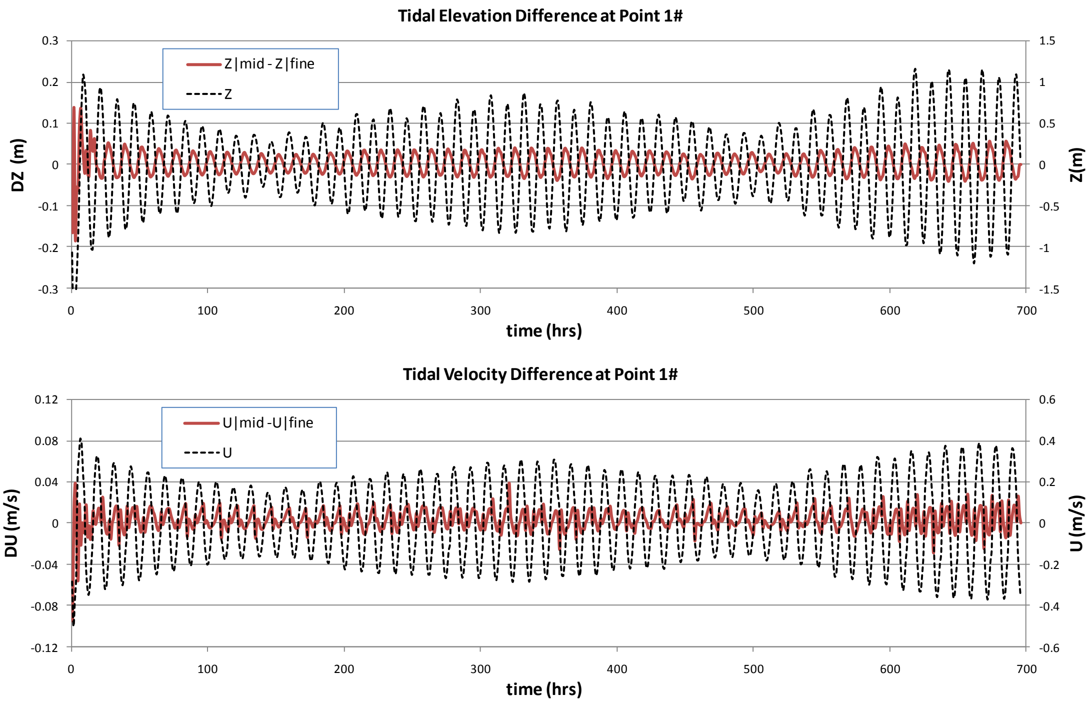

Figure 6. Differences of the computed tidal elevation (top) and tidal current velocity (bottom) between the regional and local domains [“mid”=regional domain; “fine”=local domain]

The examination of the downscaling effects over the nested grids of 3 different resolutions clearly shows the differences of the predicted wave heights, tidal elevations and tidal velocities. However, with 3 levels of downscaling, it requires extensive computing resources, particularly when the ensemble approach is employed (Chen et al, 2010). Therefore, the present study attempts to use model tests with 2-level downscaling (from oceanic to local domains as shown in Figure 7) instead of 3-level downscaling as described previously (see Figure 1) to examine the accuracy of the model results from both downscaling approaches. In the 2-level downscaling exercises, the model was forced with the same forcing conditions as those used in 3-level downscaling and the model results from the 2-level and 3-level modelling are compared.

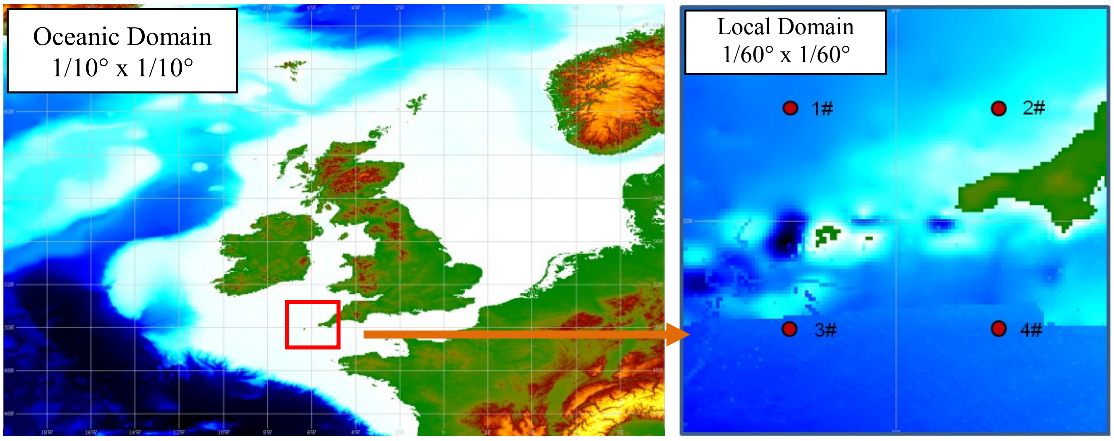

Figure 7. Computational domains used in 2-level downscaling

Figure 8 shows the difference of the wave heights over the local domain, which are computed with 3-level downscaling system as shown in Figure 1 and 2-level downscaling system as shown in Figure 7. It can be seen that the overall difference of the predicted wave heights is not significant, with its magnitude around 1 cm in the most area. However, greater differences can be found in the sheltered areas and those close to the land. Along the boundaries of the domain, the large differences are mainly due to the grid resolution, where the land points in the oceanic domain can be thee sea points in the local domain. The results demonstrate that the 2-level downscaling approach can reasonably predict the wave field in comparison with those predicted with 3-level downscaling. It should be noted that in the 2-level downscaling system, the resolution in the local domain is 6 times higher than that in the oceanic domain. It is apparent that for the present study area, such large ratio of resolution has yielded satisfactory results in predicting waves, tides and surge. This can be very beneficial for the studies which require a large amount of model runs.

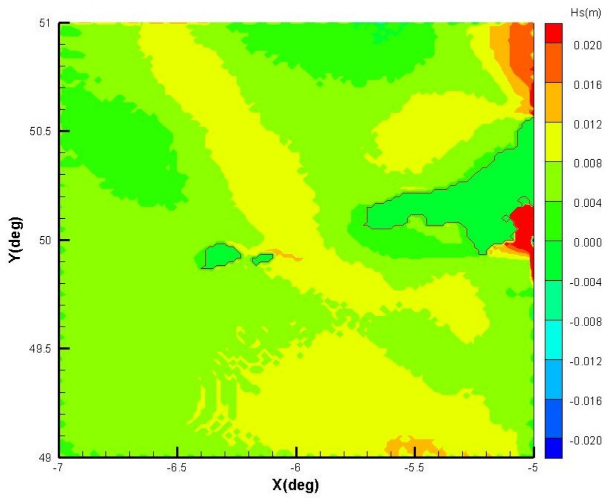

Figure 8. Difference of the wave heights over the local domain computed with 3-level and 2-level downscaling

CONCLUSIONS

A downscaling modelling system was used in predicting waves, tides and surge over a nested system with different grid resolutions. The results show that although the downscaling technique can be a powerful tool for modelling waves, tides and surge, it can have considerable impacts on the predicted wave heights, tidal elevations and currents, which have been examined and quantified. For the particular test conditions used in the present study, 3-level and 2-level downscaling produces similar results in the local domain. The results also indicate that downscaling with reduction of grid resolution by 6 times can be acceptable for downscaling.

ACKNOWLEDGMENTS

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