NWAG Phase II-A Technical Summary[1]

Authors: Geir Evensen and David Szabo

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1 Introduction

The purpose of this document is to summarise investigations that have been conducted since the last NWAG meeting (July 2002). All work specified in the minutes of the last meeting has been completed and written to the web site. However, much of what we have done in the last two months was not previously specified. This document summarises what we have done and the results of those investigations.

The comparisons developed by July required approximately 2500 individual plots. It was obvious that this is an extremely large volume of material to ingest and understand. The comparisons were qualitative and did not provide any metric that can be used to make a quantitative assessment of model performance. For these reasons we took a step back and assessed what could be done to overcome at least some of these difficulties.

The resulting methodology is described in this note and included on the web site in much more detail.

2 Kinetic Energy Statistics

We have made additional calculations in order to obtain a more quantitative comparison of the model performance with respect to the measured data sets. This has been achieved by first separating the velocity into orthogonal components, u – positive to the east and v – positive to the north. Each of these components can be written as follows:

$$u = u_{\text{mean}} + u_{\text{tide}} + u_{\text{meso}}, \tag{1}$$

$$v = v_{\text{mean}} + v_{\text{tide}} + v_{\text{meso}}, \tag{2}$$

where:

mean is the time average over the entire length of each record,

tide is the tidal component,

meso is the time varying component thought to primarily consist of mesoscale motions.

With this separation we can examine the primary processes that the model is representing. Repeating the statistical calculations that had previously been done (such as time series plots, exceedence plots, QQ plots, etc.), but now for each process would only complicate matters and not provide any means of quantitatively assessing model performance. Instead we decided to compute the mean kinetic energy for each record.

The kinetic energy is proportional to and defined as $u^2 + v^2$. The following quantities can then be defined:

$$\mathrm{KE_{mean}} = u^2_{\mathrm{mean}} + v^2_{\mathrm{mean}}, \tag{3}$$

which denotes the average energy in a velocity record associated with the mean flow;

$$\mathrm{KE_{tide}} = \frac{1}{N}\sum_{i=1}^{N}(u^2_{i,\mathrm{tide}} + v^2_{i,\mathrm{tide}}), \tag{4}$$

which is the time average of the energy of the tidal flow; and

$$\mathrm{KE_{meso}} = \frac{1}{N}\sum_{i=1}^{N}(u^2_{i,\mathrm{meso}} + v^2_{i,\mathrm{meso}}), \tag{5}$$

which is the time average of the energy of the mesoscale variability.

Thus, each record (model and measured) are characterised by just three important quantities, and at each depth we can compare the relative amounts of energy in tides, mean flow and the mesoscale flow. Rather than dealing with units of energy we have taken the square root of the energy components, which is in velocity units and is basically a rms speed associated with each component. (This is analagous to using significant wave height, which is proportional to the square root of the energy in a wave record) to characterise a sea state.)

3 Statistical Stability

As mentioned previously, oceanic regimes can be characterised by the levels of energy associated with the kinetic energy components. Such a characterisation is only meaningful if the estimates of the kinetic energy have been averaged over a long enough period of time to be stable. For example it would make little or no sense to compute the mean tidal energy based on a record spanning 20 days. To assess the record length required to achieve stability of the energy estimates we have computed cumulative means of each of the energy components for each of the measured and modelled current records. The cumulative mean is a series of N estimates of the mean based on records from day 1 to day n, where n goes from 1 to N. For example, the 100 day cumulative mean is the mean over the first 100 days of the record. In terms of validation of the model, it is crucial that the cumulative means are stable, which indicates that the respective distributions are stationary. If they are not, we are comparing the model to a moving target, which would cloud meaningful comparisons. A typical result for the model and measurements is shown in Figure 1 for the 98 m level at Mooring 4. The graphs indicate that the estimate of the tide component stabilises (change little in time) once the record is about 100 days long. The mesoscale component is relatively flat but seems to be trending higher in the model and lower in the measurements through most of the record. It is even more difficult to assume that the estimates of the mean energy ever stabilise. The reasons for the evolving values of the mean energy presumably arise from longer term shifts in the mean flows, which are not well sampled in the nearly one year record and may arise from seasonality, short term climate change such as the North Atlantic Oscillation, etc. In this example the mean bounces around 18 cm/s for the first 100 days of the record and then continues to decrease for the next 100 days, indicating that during that period the current likely reversed direction.

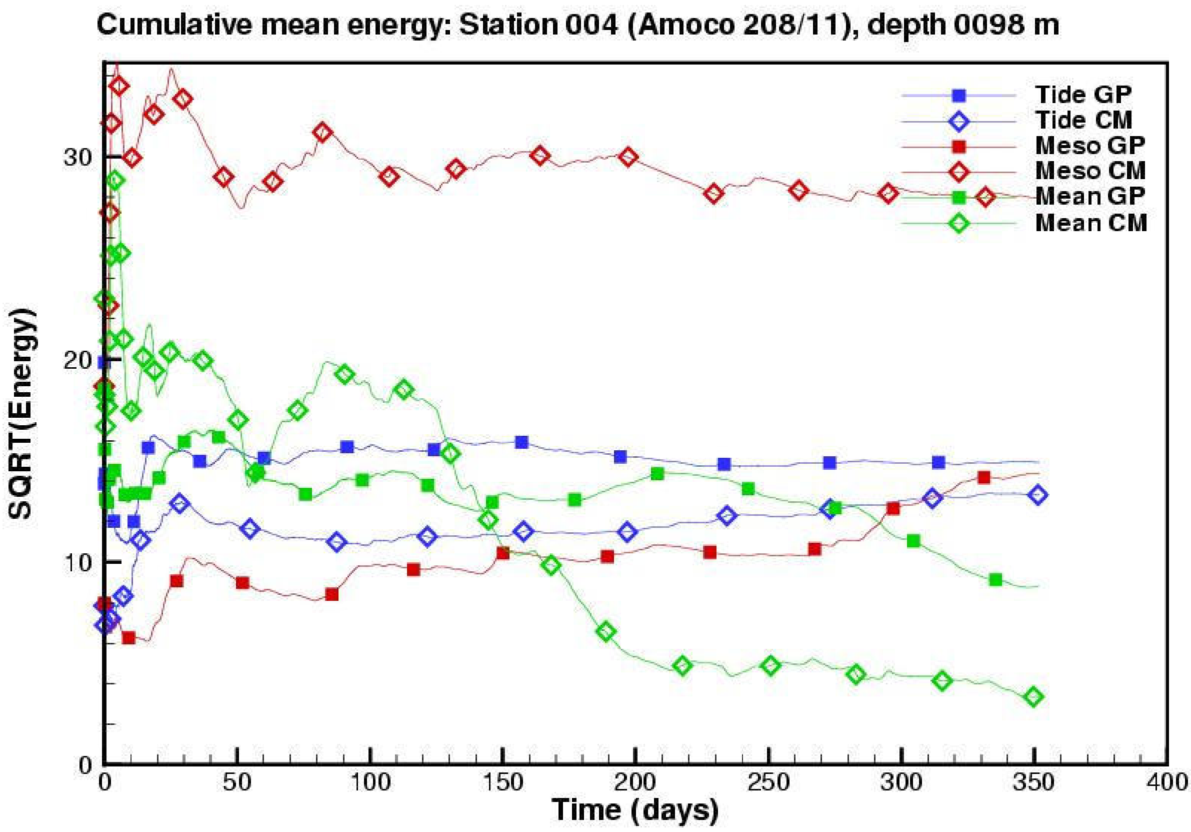

Figure 1: Cumulative means of the square root of the energy components for Mooring 4.

The main point from these computations is that statistical comparison of a model to measured data sets must be based on long records and the results from short records such as Moorings 42 (50 days) and 45 (75 days) should be treated with caution.

4 Correlation

Correlations have now been computed for the tidal velocity and the mesoscale velocity records. We expect that the tidal correlations should be high with little phase difference if the model is performing well. In general we would not expect the mesoscale correlations to be high if the mesoscale was driven by eddies which are not directly modelled. On the other hand if the mesoscale is driven by winds then there is a chance that the mesoscale correlations would be high.

5 Surface Kinetic Energy of the Mean Flow

Figure 2 shows the surface distribution of the square root of the mean kinetic energy in the surface layer of the model averaged over all of the Phase II–A simulation. The plot illustrates the distinct locations of regions of strong mean currents. The mooring locations are also shown, which show that a small spatial distortion in the model simulations can lead to large model/measured differences in the mean flow at a

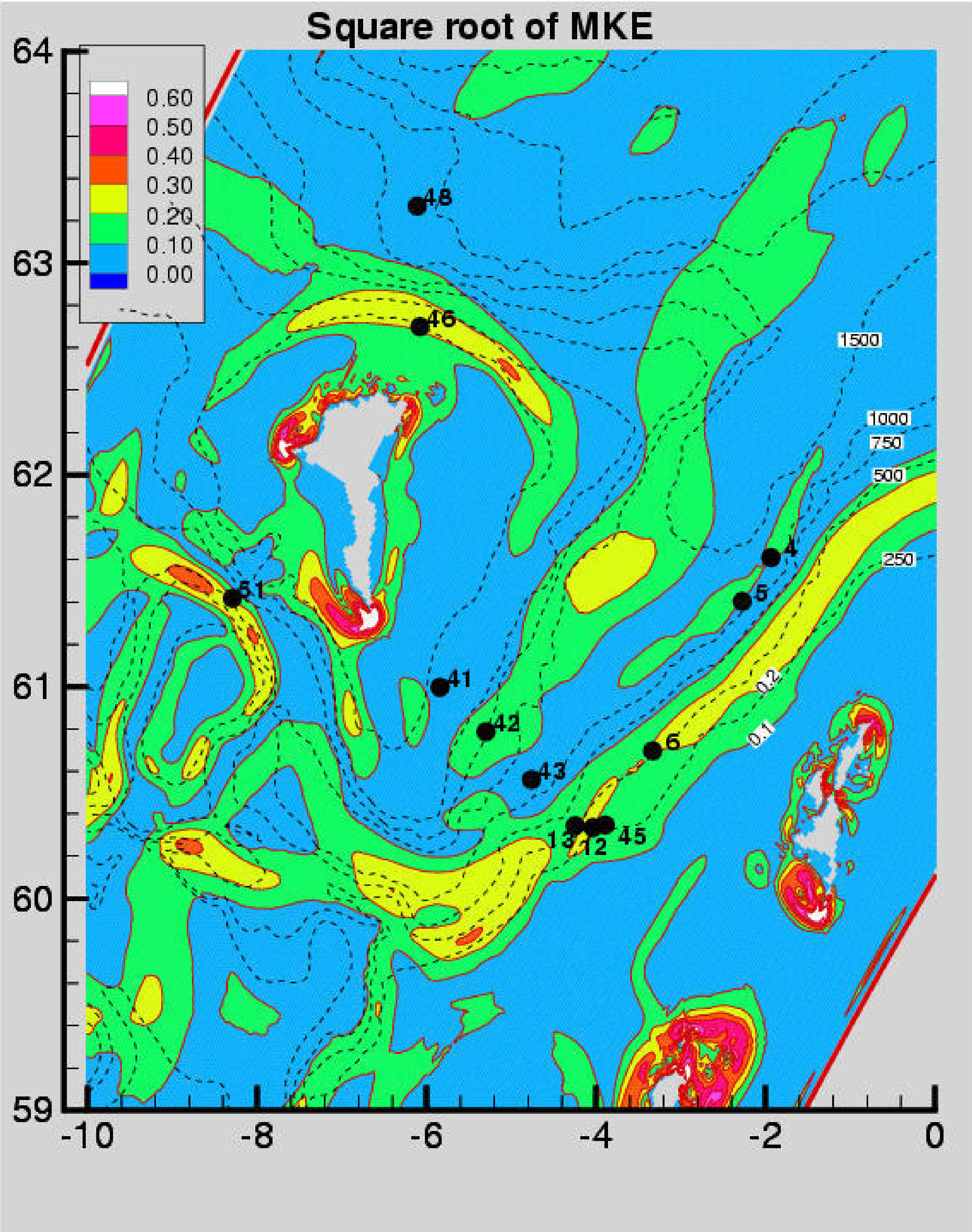

Figure 2: Square root of kinetic energy of the mean flow in the upper layer based on the NWAG model. Mooring locations are indicated by burger dots.

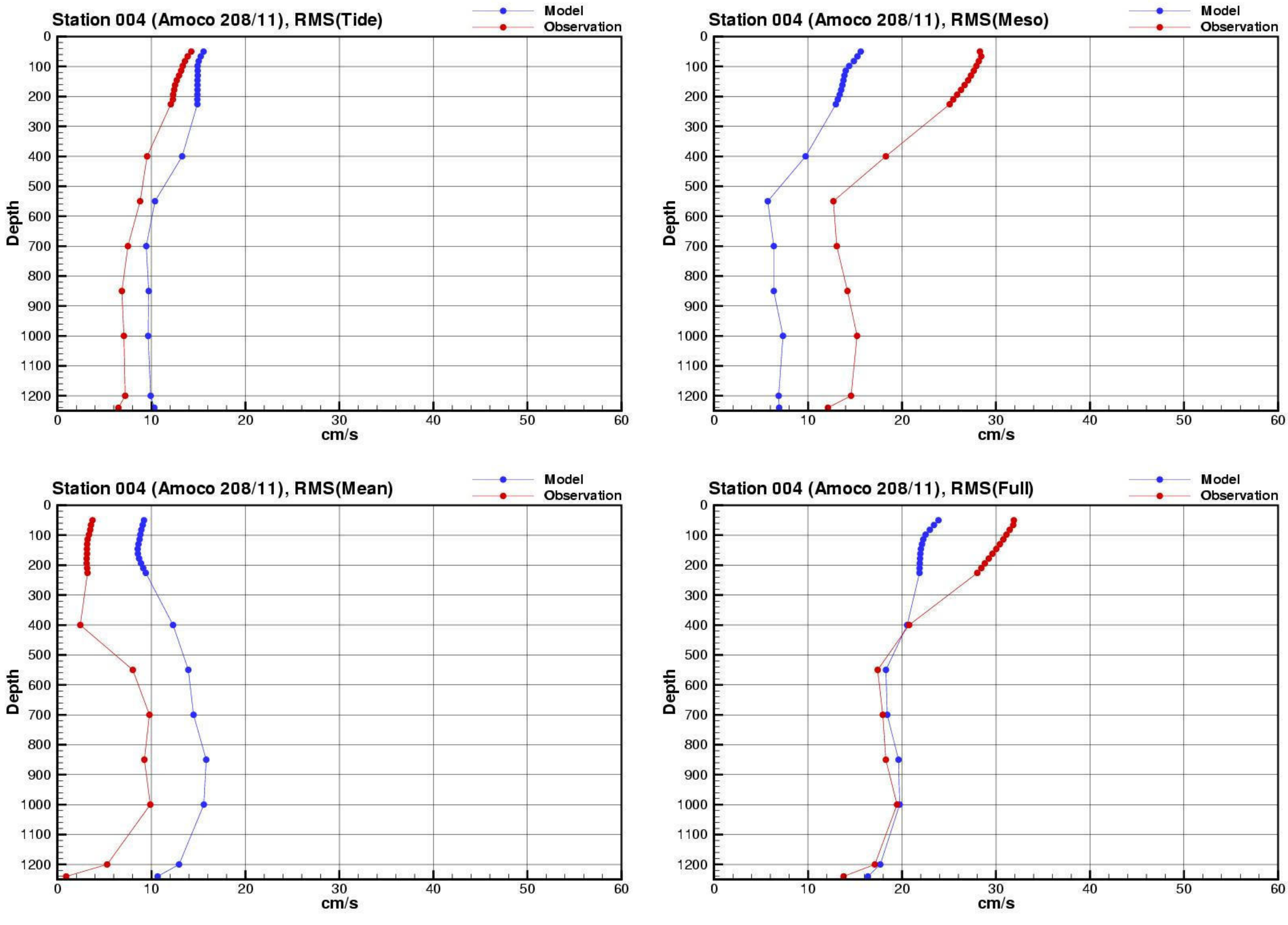

Figure 3: Kinetic energy profile (cm/s) for tides (upper left), mesoscale (upper right) mean (lower left), and total (lower right), at Mooring 4.

specific site. Such a distortion could occur if there are limitations in the model bathymetry. There could also be shifts in the path of the mean flows on seasonal and inter-annual periods, which is known to occur in other current systems. The influence of the topography in steering the mean flow is obvious and the strong mean flows are shown to be extremely narrow. This illustrates that the model can provide spatial information on the energetics, which is not possible with limited site specific measurements. Knowing the spatial distribution of strong currents provides valuable guidance when estimating operational and extreme criteria. For example, knowing whether or not there are large energy gradients near a development would help determine how conservative the criteria should be.

6 Profiles of Kinetic Energy Components

Profile plots of the square root of the kinetic energy are included on the web site for each mooring and each component. Profile plots for Mooring 4 are shown, as an example, in Figure 3, for the tide, mesoscale and mean components.

The existence of an upper and lower layer flow, with much different energy characteristics is clear in these plots. For this reason we decided to examine the two layers separately and to simplify we calculated means

Upper depth average of square root of the kinetic energies									
	Tide		Mesoscale		Mean		Measured energies		
Mooring	Diff bias	Diff stdev	Diff bias	Diff stdev	Diff bias	Diff stdev	Tide	Meso	Mean
UK Shallow Shelf Slope									
006	1.4	1.0	−3.2	1.0	−17.7	0.6	15.5	15.7	31.9
012	4.3	1.5	−2.8	0.7	−7.7	2.4	17.5	14.7	20.9
013	3.1	1.3	−4.7	1.3	−10.2	1.2	17.1	18.9	23.9
045 (S)	3.0	1.1	−7.1	1.1	−19.1	2.3	17.8	12.8	25.2
UK Deep Shelf Slope									
004	2.1	0.5	−13.0	0.5	5.6	0.3	13.0	27.0	3.3
005	−0.7	1.6	−7.2	1.0	4.3	1.6	16.7	24.1	6.7
043	7.1	1.0	−3.8	1.7	−3.4	1.8	18.7	22.7	8.1
Faroes Shelf Slope									
041	7.3	4.6	2.2	0.5	1.5	1.0	26.6	6.7	2.2
042 (S)	6.3	0.6	−7.0	0.4	−3.6	1.0	18.5	17.9	7.5
0046	−2.0	0.8	−0.1	0.4	5.0	1.6	19.3	9.8	14.6
Faroes Shelf Slope Deep									
048	−2.6	3.4	−11.0	3.8	−3.7	2.0	15.7	16.9	9.7
Faroe Bank Channel									
051	−2.1	1.1	5.6	1.7	17.5	3.4	15.3	15.1	2.3
Average	2.3	1.5	−4.3	1.2	−2.6	1.7	17.6	16.9	13

Table 1: Kinetic energy bias and shear quality for all moorings in the upper layer in cm/s. "S" denotes short record; "Diff bias" denote average of differences between model and measurement; "Diff stdev" denote standard deviation of the differences between model and measurement.

over each layer. In many cases the model and measured profiles have very similar vertical shapes and appear to be merely offset from each other as in the example case for Mooring 4. That difference can be quantified by the mean difference, or bias, between the model and measurements. But the profiles are not always similar. So we have to introduce another parameter to compare profile shapes. We have chosen the standard deviation of the differences for each layer to show the similarity in profile shape. If this standard deviation is small then the differences lie mainly in the bias. If not then there are also differences in the profile shape, which must be accounted for.

Figure 3 also shows the kinetic energy for the sum of the three components, i.e. the total velocity. It is obvious from this graph that the negative model bias of the mesoscale energy in the lower layer is offset by the positive model bias of the mean energy in the lower layer. Had we not broken the energy down into components the underlying differences would not be at all clear.

7 Regional Assessment

The results of the kinetic energy calculations are listed in Tables 1 and 2 for the upper and lower layers, respectively. The moorings have been grouped by 'regions' where possible. The calculated measured energy in each component is provided for reference.

Lower depth average of square root of the kinetic energies									
	Tide		Mesoscale		Mean		Measured energies		
Mooring	Diff bias	Diff stdev	Diff bias	Diff stdev	Diff bias	Diff stdev	Tide	Meso	Mean
UK Shallow Shelf Slope									
006	2.6	1.2	−4.2	0.6	−16.0	1.2	14.0	11.7	24.6
UK Deep Shelf Slope									
004	2.7	0.8	−7.3	1.1	7.2	2.0	7.6	14.3	6.5
005	2.9	1.2	−3.0	2.7	4.9	2.7	9.0	15.8	10.4
043	−16.7	1.2	−15.6	1.2	−5.6	4.8	16.7	15.6	5.6
South Faroes Shelf Slope									
042	7.4	2.5	−4.6	2.1	−2.5	1.2	19.8	9.6	4.2
North Faroes Shelf Slope									
048	−0.9	3.4	−1.6	3.8	0.7	2.0	8.9	5.3	2.7
Faroe Bank Channel									
051	1.6	2.2	−0.1	5.4	8.2	14.8	13.7	19.7	49.2
Average	−0.5	1.9	−5.3	2.7	2.1	4.6	12.6	13.4	13.1

Table 2: Kinetic energy bias and shear quality for all moorings in the lower layer in cm/s. "S" denotes short record; "Diff bias" denote average of differences between model and measurement; "Diff stdev" denote standard deviation of the differences between model and measurement.

7.1 UK Shallow Shelf Slope

Moorings 6, 12, 13 and 45(S) are located near the centre of the model domain on or along the UK shelf in fairly shallow water ranging from 293 to 590 meters depth, which encompasses the location of the slope current. The measured energy components have about the same magnitude at each mooring location (Table 1). The total energy is dominated by the mean flow, while tides and mesoscale have roughly equal contributions. (Since Mooring 45 is a very short time series it is excluded from the following discussion.)

The tidal energy is slightly overestimated by the model (1.4 cm/s to 4.3 cm/s). The standard deviation values in Table 1 vary from 1.0 cm/s to 1.5 cm/s, so there is an excellent match in the tidal energy profile. The model underestimates the mesoscale energy by 2.8 to 4.7 cm/s, but the standard deviation is very small (0.7 to 1.3 cm/s) meaning that the shape of the profiles are very similar. The model significantly underestimates the mean flow kinetic energy by 7.7 to 17.7 cm/s, however, the standard deviation ranges from 0.6 to 2.4 cm/s again showing that the vertical profile shapes are nearly identical. The close correspondence of the vertical shapes of the kinetic energy profiles is an indication that the model represents the correct physical processes and water mass distributions.

The only significant difference in energy is the under-representation of the mean flow by the model. As shown in Figure 2, there is a well-defined signature of the Slope Current in the upper layer of the model. This appears in the green (10–20 cm/s) and yellow (20–30 cm/s) bands along the contours of the slope. Moving up or down-stream, the intensity of the mean flow is seen to repeatedly increase and decrease. This appears to be a response from downstream flattening and steepening of the slope. The mean flow energy appears to weaken in the area where these moorings are located. Just upstream of Moorings 12, 13 and 45 the flow is much more intense. Either a widening of the flow or more horizontal variability of the location of the axis of the Slope Current could cause the decrease in energy.

For these moorings it is instructive to evaluate the correlations between the model and the data. The correlation for tides and mesoscale variability at Mooring 6 ranges from 0.65 to 0.7, except for the deepest mooring level. The directional deviation is mostly less than 10 degrees both for the mesoscale flow and

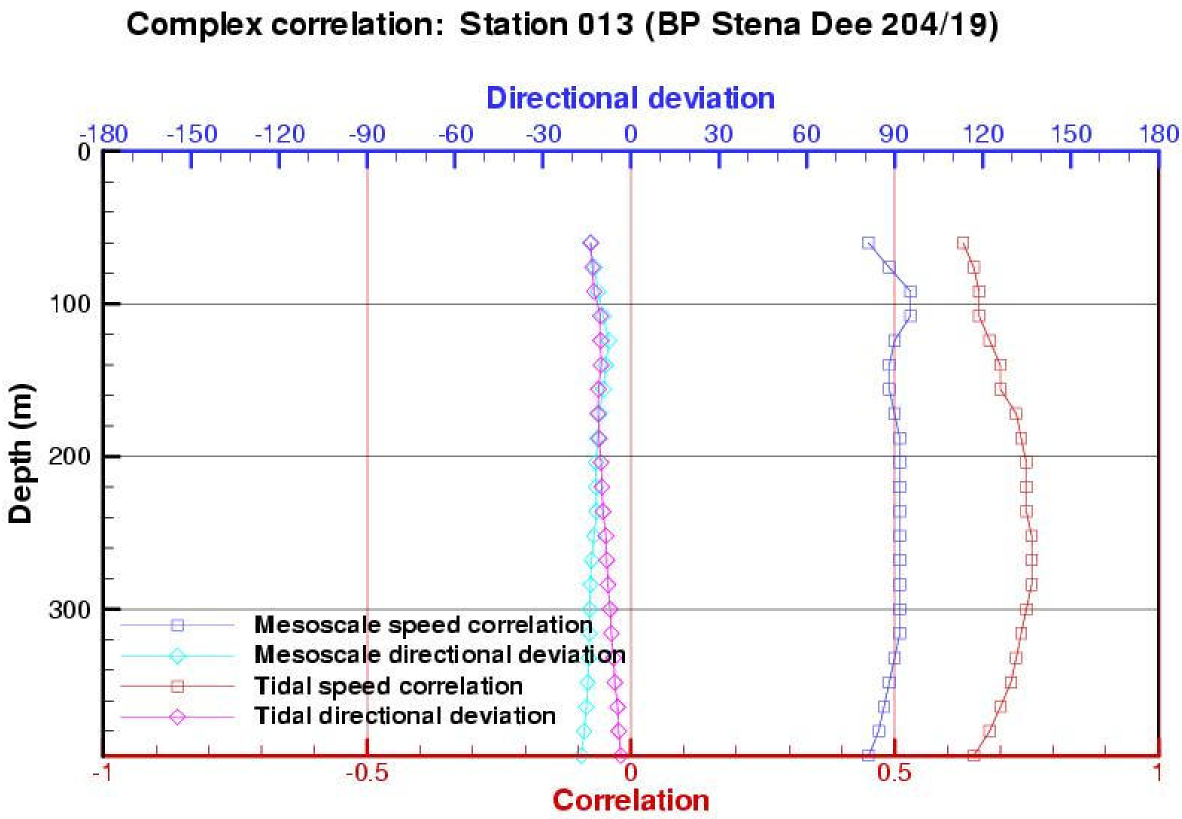

Figure 4: Correlation and directional deviation of tides and mesoscale velocities at Mooring 13.

the tides. A similar result is found for Mooring 12, where both the correlation for tides and mesoscale variability are around 0.7, and the directional deviation for the tides is less than 15 degrees, while there is almost no directional deviation for the mesoscale variability. (This is shown in Figure 4.) Mooring 13, has a high correlation for tides ranging between 0.6 and 0.8, while for the mesoscale it is around 0.5, and the directional deviations are around 10 degrees both for the mesoscale and the tides. The high mesoscale correlations indicate that the model and measured (non-tidal) fluctuating flows are synchronised. Since the model is not assimilating temperature or surface elevation data there is no expectations that mesoscale energy from eddies and meanders would be in tune with the measured data. The preliminary conclusion is that the mesoscale in this area is dominated by wind forcing. If that is true, it indicates that the model should have a clear forecast capability for the UK shelf.

7.2 UK Deep Shelf Slope

Moorings 4, 5 and 43 are located in deep water ranging from 1076 m to 1250 m depth along the UK shelf slope and outside of the Slope Current. Moorings 4 and 5 are quite close together, while Mooring 43 is about 100 km to the SSW. The model performance with relation to the measurements at Moorings 4 and 5 are very similar, however the comparisons at Mooring 43 are much different. For this reason we discuss Mooring 43 separately. The measured energies for the upper layer, Table 1, show that measured energy distributions are very similar at each mooring (same for Mooring 43). The measured mesoscale energy is the dominant component and the mean flow contributes little to the total (same for Mooring 43). The energy profiles for Mooring 4 (Figure 3) indicate that a better separation of upper and lower layers for this site would be at about 550 m. Although Mooring 43 is in a water depth of 1101 m there is only data to about 600 m so the measured data here are really indicative of the upper layer.

The model tidal energies in the upper layer at Moorings 4 and 5 compare very well with the measured data. The model and measured tidal energies have strong shear (decreasing with depth) at each mooring. In all cases the standard deviation of the tidal energy differences are small, indicating very similar vertical shape. The model is biased slightly high at Moorings 4 and 5 (average 2.8 cm/s) and the shape is also well represented (average of 1.0 cm/s). Results are similar in the lower layer.

The mesoscale energy is underestimated by the model in the upper layer at Mooring 4 (−13.0 cm/s) and to a lesser degree at Mooring 5 (−7.2 cm/s). However, the standard deviation of the differences are extremely small (0.5 cm/s at Mooring 4 and 1.0 cm/s at Mooring 5), indicating a match in shape. In the lower layer the comparisons are similar — the model is again biased low at both sites but to a lesser degree.

The model overestimates the mean flow in the upper layer at Moorings 4 (5.6 cm/s) and 5 (4.3 cm/s) and in the lower layer as well by about the same amount. The mean energy increases in the model at all locations between 300 m and 600 m to a subsurface maximum between 600 and 800 m. The standard deviation of the differences are at most 2.7 cm/s (lower layer Mooring 5 in Table 2), indicating a close match of the vertical structure (see Figure 3).

The velocity correlations are fairly good for tides ranging between 0.50 and 0.70 with modest directional deviation. The correlation for the mesoscale variability is high (greater than 0.50) for Moorings 4 and 5 for depths below 500 m, while it is low in the upper layer at these sites.

At Mooring 43 the model overestimates the tidal energy (7.1 cm/s) and underestimates the mesoscale energy (−3.8 cm/s). The standard deviation of the differences in the upper layer is small indicating a good fit of the vertical profile for tides and the mesoscale as was found for Moorings 4 and 5. However, the structure of the mean flow energy is much different at Mooring 43. At this mooring the measured energy of the mean flow shows a decrease in the mean flow energy between 300 and 600 m — opposite the results at Moorings 4 and 5. The model profile of the mean energy is more similar to Moorings 4 and 5 than Mooring 43. This leads to a very high standard deviation at Mooring 43 of the mean energy difference but a very close match at Moorings 4 and 5. Mooring 43 has low correlations for the mesoscale throughout the water column and is probably less influenced by the topographic steering that may be affecting Moorings 4 and 5.

7.3 Faroes Shelf Slope

Mooring 41 is located in shallow water at 300 m depth just south of the Faroes, while Mooring 42 is located deeper on the slope at 790 m. (Note that the record at Mooring 42 is very short and will not be discussed.) Mooring 46 is located north of the Faroes in shallow water (330 m depth). Mooring 41 is dominated by the tidal energy (26.6 cm/s). There is little contribution at Mooring 41 by either mesoscale (6.7 cm/s) or mean (2.2 cm/s) energies. The measured energies indicate that Mooring 46 is also dominated by tidal energy (21.7 cm/s), though the contributions from mesoscale (10.5 cm/s) and mean (16.0 cm/s) are not negligible.

The tidal energy at Mooring 41 is overestimated by the model (7.3 cm/s), while at Mooring 46 it is slightly underestimated (−2.0 cm/s). At both moorings the measured tidal energy is highly sheared in the upper 125 m, then appears uniform to about 250 m and then decreases quickly toward bottom. The model shows a similar 'S' shape structure, but the standard deviation is high at 4.6 cm/s at Mooring 41 and 4.4 cm/s at Mooring 46.

The mesoscale energy is well represented by the model with a slight overestimate at Mooring 41 (2.2 cm/s) and is almost spot on at Mooring 46 (−0.1 cm/s). The shape is well represented at both locations with the standard deviation being less than 1.0 cm/s.

The mean energy is slightly overestimated at Mooring 41 (1.5 cm/s) and significantly overestimated at Mooring 46 (5.0 cm/s). The shape is well matched at Mooring 41, standard deviation of 1.0 cm/s, but not quite as good at Mooring 46, standard deviation of 2.3 cm/s.

The correlations for tidal velocities are very high for Mooring 41 but for the mesoscale is less correlated and shows no significant predictive skill. On the other hand the tide is well correlated only below about 60 m at Mooring 46. The mesoscale correlations are high at Mooring 46 through the water column, ranging from 0.7 to 0.8, and are probably partly controlled by the wind driven interaction with the steep bathymetry at this location. The tidal correlations are fairly high except for the upper 100 m of the water column where there is a problem with the data. All the data from the upper 100 m were removed from the energy diagnostics.

The major discrepancies between the model and measurements are related to the very high tidal energies near the surface at both locations, which are not found in the model. The model mean flow is also too strong at Mooring 46. This is likely due to a slight misalignment of the model mean flow, which is strong and narrow in this region (see Figure 2).

7.4 Faroes Shelf Slope Deep

Mooring 48 is a deep water mooring located at 1733 m water depth. Note that the distance between Mooring 48 and the nearest stored grid point is about 33 km due to a conflict in the storage scheme, which degrades the value of the comparisons. At Mooring 48 the measured energy is dominated by both tide (15.7 cm/s) and mesoscale (16.9 cm/s).

The model tidal energy at Mooring 48 is underestimated by the model (−3.8 cm/s) and the shape is poor as well (standard deviation of 4.4 cm/s). These results are similar to Moorings 41 and 46, as discussed above, where the model does not have the very highly sheared near surface tidal energy that is evident in the measurements.

The model also underestimates the mesoscale (−11.0 cm/s) and to a lesser extent the mean (−3.7 cm/s) energies. The differences are dominantly in the surface 200 m to 300 m of the water column where the highly sheared measured profiles are not replicated by the model.

7.5 Faroe Bank Channel

Mooring 51 is located at 788 m depth in the complex Faroe Bank Channel. The energy at this site is dominated by the mean flow energy in the lower layer (49.2 cm/s). In the upper layer the measured mean flow is minimal (2.3 cm/s). The contributions of tides and the mesoscale are about the same in the upper and lower layers.

The model slightly underestimates the tidal energy in the upper layer (−2.1 cm/s) and overestimates in the lower layer (1.6 cm/s). The tidal energy profile has a subsurface maximum at about 550 m, which is shown by both the model and the measured profiles. The standard deviations are low (1.1 cm/s in the upper layer and 2.2 cm/s in the lower layer).

The mesoscale energy is overestimated in the upper layer (5.6 cm/s) and slightly underestimated (−0.1 cm/s) in the lower layer. The mesoscale profile fit is better in the upper layer (standard deviation of 1.7 cm/s) than the lower layer (standard deviation of 5.4 cm/s). The mesoscale has a subsurface peak at the same level as the tidal energy profile. The model representation of the peak is somewhat shallower than the measured profile, which leads to degradation in the model fit.

The model has strong near surface mean flow energy that is not found in the measurements leading to the model being biased high in the upper layer (17.5 cm/s) and not having the same shape as the measured profile (standard deviation of 3.4 cm/s). This error is probably a high modelled mean flow near the surface, which is also seen as a very localised flow (probably tidally rectified) around the Faroe Bank (see Figure 2). The mean flow is extremely strong in the lower layer and has peak measured values of over 100 cm/s. The model overestimates the mean flow energy by 8.2 cm/s. This is mainly due to the velocity shear layer being slightly shallow in the model. The standard deviations are relatively large at 14.8 cm/s.

The correlations at Mooring 51 are extremely good for the mesoscale variability in the lower layer (close to 0.98), while it is low in the upper layer. Note that this is an area with strong variations in bathymetry and errors in the bathymetry may significantly impact the direction and variability of the current, particularly at depth.

8 Summary and Recommendations

This project has begun the first rigorous validation of a high-resolution ocean model using moored current meter data. In addition to the extensive work invested in implementing and calibrating the model we have also developed a validation methodology, which makes it easy to assess the quality of the components of the modelled current field. In reality little insight can be gained if the velocity field is not decomposed into the tidal, mean and mesoscale components. We have seen that the model generally slightly overestimates the tidal velocities, and slightly underestimates the mesoscale energy. It may also be difficult to represent the exact location of topographically controlled mean flows, e.g. the ones flowing around the Faroes and the Faroe Bank, which are induced by tidal rectification.

Even though there are errors in different model components at different locations the model has proven to provide a very realistic picture of the oceanic flows in the Faroe-Shetland Channel. The major current systems are represented in the model, and the modelled vertical structure of the energy subcomponents are very consistent with observations for most all of the moorings.

We noticed some differences in the energetics of the mean flow. Note that for the length of the mooring periods the energy of the mean flow has not yet converged and a slightly longer time series could provide a much different result. The mean flow energy for the upper layer in the model as shown in Figure 2 has values that reach up to 30 cm/s. The highest measured upper layer energy was 31.9 cm/s (Mooring 6, Table 1) so there is not a large difference overall. Another point is that the spatial variability of the mean flow is extreme in this area. Thus, a slight displacement of a topographically steered current, e.g. due to inaccuracies in the bathymetry, can result in large differences between the modelled and observed mean flow. Since temperature and altimetry data have not been assimilated, the model time period and the measured time period likely reflect different 'years'. It is well known that current systems shift from time to time e.g. the Gulf Stream separation point off North Carolina and quasi permanent shifts of the Kuroshio south of Japan, etc. So it is quite possible that the precise location of the model and measured mean flows would be different due to shifts of the circulation system.

It may be possible to further calibrate the model based on the comparisons completed in Phase II–A. However, that would require significant resources and time. In addition since the measured data sets are quite limited (only 10 sites with reasonably long records) we may be attempting to resolve problems that don't even exist. We recommend that it would be to the advantage of the participants to initiate the scope of Phase II–B. Our reasons are:

- The model system as it exists exhibits no major problem such as instabilities or gross overestimates or underestimates of the flow regime.
- The present model system has shown significant skill in simulating the major currents in the region and in particular the vertical structure of the flow field.
- The longer model run and the additional data comparisons would provide a much better footing to evaluate the model performance.

Note that in this study we got a lot more confidence in model performance where there were several moorings that could be grouped together than for moorings that were isolated. In Phase II–A there were only six long term mooring sites in the UK Sector. The Phase II–B period will add eight new locations in the UK sector and one in the Faroes. In addition nine of the Phase II–A locations will be extended by approximately one year. These additions have to result in much more confidence in the assessment of model performance.

We suggest a few additions to Phase II–B be considered:

1. The validation methodology developed over the last two months has been hurried and we are sure that it can be improved. Some additions to be considered are spectral analysis, more sophisticated tidal analyses, EOF analyses etc.
2. The validation has focussed only on data sets collected during the modelling period. Since we are comparing statistically ‘stable’ parameters, long data sets collected outside of the modelling period could be included and would be quite useful.
3. To our knowledge the measured data sets in the region have never been fully analysed as a group. This would be very worthwhile to show what understanding can be gained from them on their own. A rough estimate is that there has been an industry investment of \$5m to \$10m in the industry measurements made during the 30 month modelling period. You might as well try to get all of the knowledge you can from that resource.

8.1 Future Model Improvements

It may be possible to further calibrate the model based on these results. However, this would require quite a lot of work and numerous additional model simulations. If such a study was carried out the focus should be on:

1. Further optimising the modelling of the tides by adjusting bottom friction, examining the tidal boundary data, and if possible introduce improvements in the representation of bathymetry;
2. examine the impact of higher resolution and/or lower horizontal mixing on the mesoscale variability;
3. examine the impact of changing these parameters on the mean flow, and also examine the impact of varying the transports imposed on the boundaries by the large-scale models.

Such a study would be further complicated by the fact that a change of one parameter, e.g. to improve the tides, also may affect the mesoscale variability and vice versa. Such a study would be very interesting scientifically. It would require significant resources such as a one or two man-year effort of a highly skilled scientist and the required computing resources would be large. Most likely the most cost-effective level would be a postdoctoral researcher.