



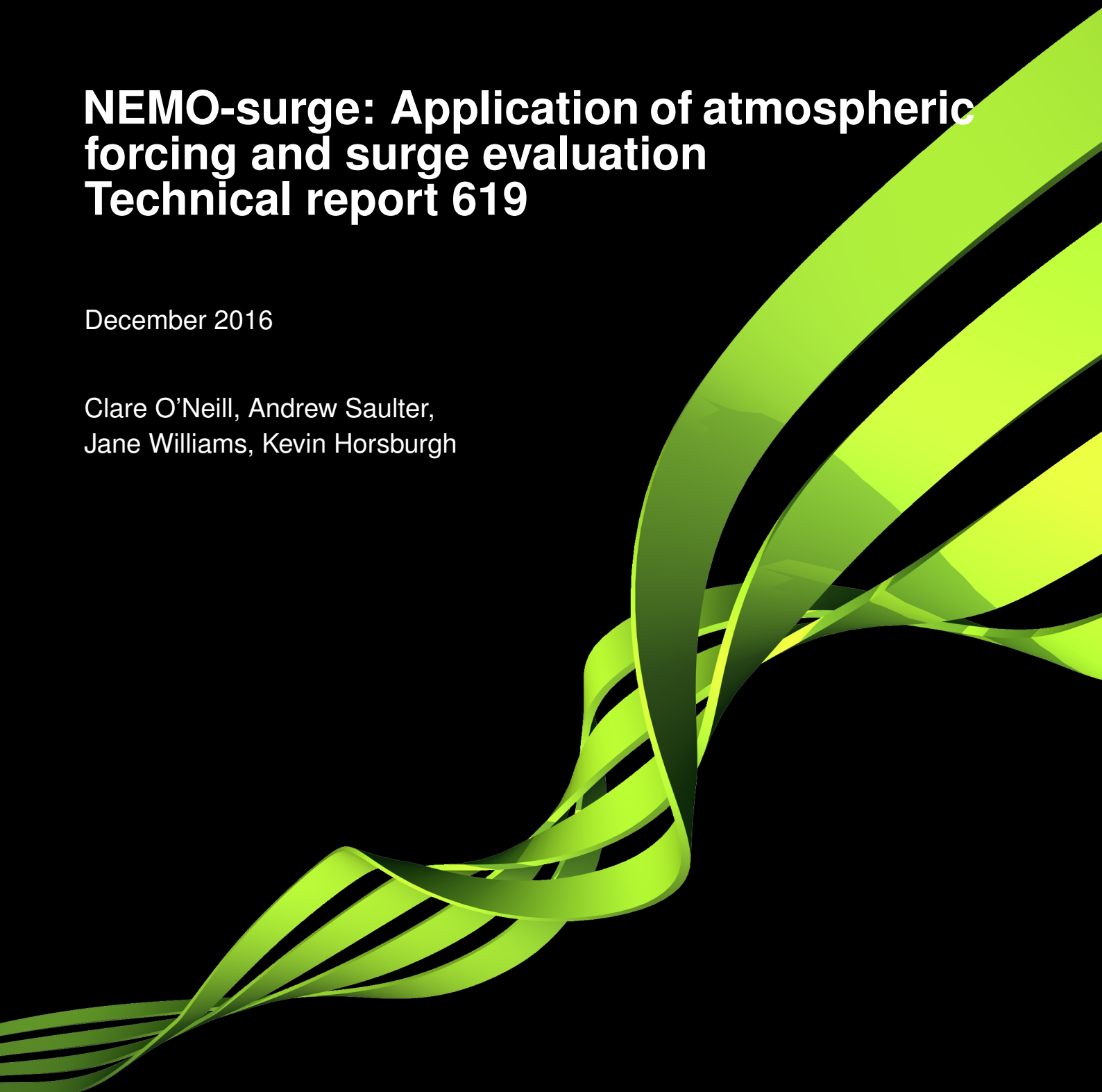
**National  
Oceanography Centre**  
NATURAL ENVIRONMENT RESEARCH COUNCIL

# **NEMO-surge: Application of atmospheric forcing and surge evaluation**

## **Technical report 619**

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## Summary

The prototype NEMO-surge tidal model developed by Furner et al. (2016) has been extended to include storm surge prediction by adding 10 m wind and mean sea level pressure inputs. The sensitivity to the forcing configuration is investigated by testing different wind parameterisation schemes, and varying the atmospheric reference pressure level that is used in the inverse barometer calculation. Following these tests the optimal configuration is finalised and compared with the existing CS3X model over a 2-year hindcast period by validating against observations from UK tide gauges.

The tests have shown some sensitivity to choices made in the parameterisation of atmospheric forcing, and that this response varies spatially. There is no one set of domain-constant parameters that is optimal for every location, so in the current configuration we pick the settings that provide the best compromise. Future work should investigate the use of spatially, and possibly temporally, varying parameters to further improve model performance.

Overall the finalised configuration performs as well as CS3X at predicting surges during the 2-year hindcast, with most statistical metrics showing little overall difference between NEMO-Surge and CS3X. We conclude that on the present evidence NEMO-Surge is a viable replacement for CS3X for storm surge forecasting. The new model should also allow future enhancements to be implemented more easily, due to the use and development of baroclinic NEMO configurations for operational forecasting at the Met Office, National Oceanography Centre and within the wider international science community.

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## 1 Introduction

Presently the Met Office run an operational storm surge forecast system for the UK which was developed by the National Oceanography Centre (NOC) and has been running in various configurations since 1978. This system uses CS3X (Flather, 1994) as the underlying model and runs in deterministic and ensemble modes (Flowerdew et al., 2010). A new Met Office-NOC joint project has been set up to investigate whether a 2D (barotropic) configuration of NEMO (Madec and the NEMO team, 2014) is a viable replacement for CS3X, in an effort to harmonise the operational modelling systems run at the Met Office.

The first stage of the project involved setting up NEMO to run in barotropic configuration, and performing a number of sensitivity experiments aimed at tuning the model to optimise its tidal solution. Those experiments and validation of the finalised tide model setup are described by Furner et al. (2016), who show that the NEMO-Surge tide prediction performance is at least as good as the existing CS3X model.

With the tidal aspect of the model frozen, attention is now drawn to the surge prediction. Storm surges are caused by interactions with two atmospheric forces: surface wind stress and atmospheric pressure gradient (e.g. WMO, 2011). Sensitivity to the model setup for both of these forcings is tested in order to finalise the configuration to be used for storm surge prediction. Sensitivity to the atmospheric pressure configuration is tested by using a range of different values for the (domain-constant) reference pressure level, which is used in the inverse barometer calculation. The wind forcing sensitivity is investigated by testing both Charnock (1955) and Smith and Banke (1975) formulations for calculation of the wind stress, as well as tuning of the associated parameters used in each formulation.

The wind experiments are described and assessed in section 3, and the reference pressure tests are similarly presented in section 4. A final configuration, chosen from the various sensitivity experiments, is fully assessed against observations and CS3X in section 5. Finally, conclusions and discussion are presented in section 6

## 2 Methods

### 2.1 Model runs

The NEMO-surge sensitivity tests were run for the year 2013, which provides several examples of significant surge events (e.g. see SurgeWatch, 2016). The runs were all started from rest in December 2012. This provided a full month to spin up before the analysis window of 1 January 2013–31 December 2013.

Tidal forcing is provided using harmonic constituents produced by a tide model of the North-East Atlantic, as described by Furner et al. (2016). 10 m wind speed and air pressure inputs are taken from archived output of the Met Office atmosphere forecast model (Davies et al., 2005), to match the forcing source used in the operational surge forecast model. Wind and pressure are the only atmospheric inputs used by the model, with other parameters such as heat fluxes ignored. Model outputs verified in this study are hourly snapshots of the total sea surface height.

Following analysis of the sensitivity runs, the final configuration was selected and a longer run made using those settings. This run was performed in the same way as the sensitivity tests except that it was extended to cover 2014 as well.

## 2.2 Analysis

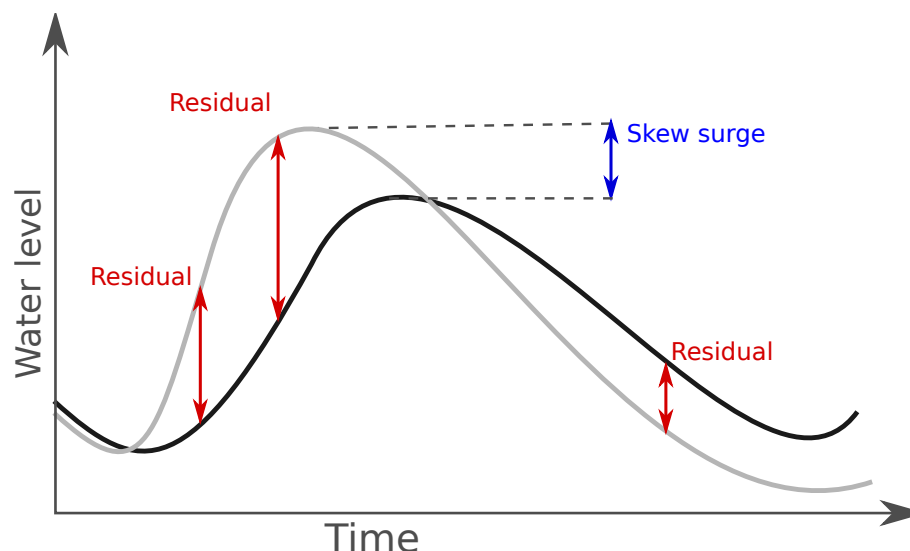
In order to quantitatively compare the experiments, residual and skew surge are compared against observations from the UK National Tide Gauge Network (National Tidal and Sea Level Facility, 2013) at the locations shown in Figure 1. Results are contrasted against a CS3X hindcast which has been run using the same atmospheric inputs as NEMO-Surge.



**Figure 1:** Tide gauge locations. Note that Wick is excluded from the analysis due to data quality problems.

Residual is the difference at some particular time point between the water level that would be expected due to the tide alone, and the actual water level observed/modelled including the atmospheric surge component. Skew surge is the difference in height of the expected peak at high tide and the total peak water level seen, i.e. it ignores differences in the timing of the tidally predicted and actual peak water level. The difference between skew surge and residual is illustrated in Figure 2. The skew surge is generally a more useful metric to forecasters than residual water level (Williams et al., 2016), as it is the amount by which the highest water level will exceed the expected maximum that is most important in terms of flooding.

For both models, residual water level is calculated by subtracting the model total water level output from a tide-only (i.e. no atmospheric forcing) run of the same period. The observations have been similarly processed by subtracting a harmonic tide prediction from the gauge measurements. For both model and observations, the skew surge is then calculated by adding the residual onto the harmonic tide prediction, identifying the peak in water level at each tidal cycle, and comparing it to the expected tide-only peak level (again from the harmonic prediction). It is worth noting that the observed residual and skew surge values will comprise both the meteorologically forced surge predicted by the models and an additional component related to errors in the harmonic prediction of the astronomic tide. Flowerdew et al. (2010) determine this latter component to have a root mean square value which is typically 10 cm for the UK tide gauge network, but up to 29 cm in the Bristol Channel. When compared to root mean square surge errors presented later in this report, this harmonic component of the error is clearly non-trivial. However, it can be ignored for the purposes of this study since the contribution to overall error will be the same for both NEMO-Surge and the CS3X model.

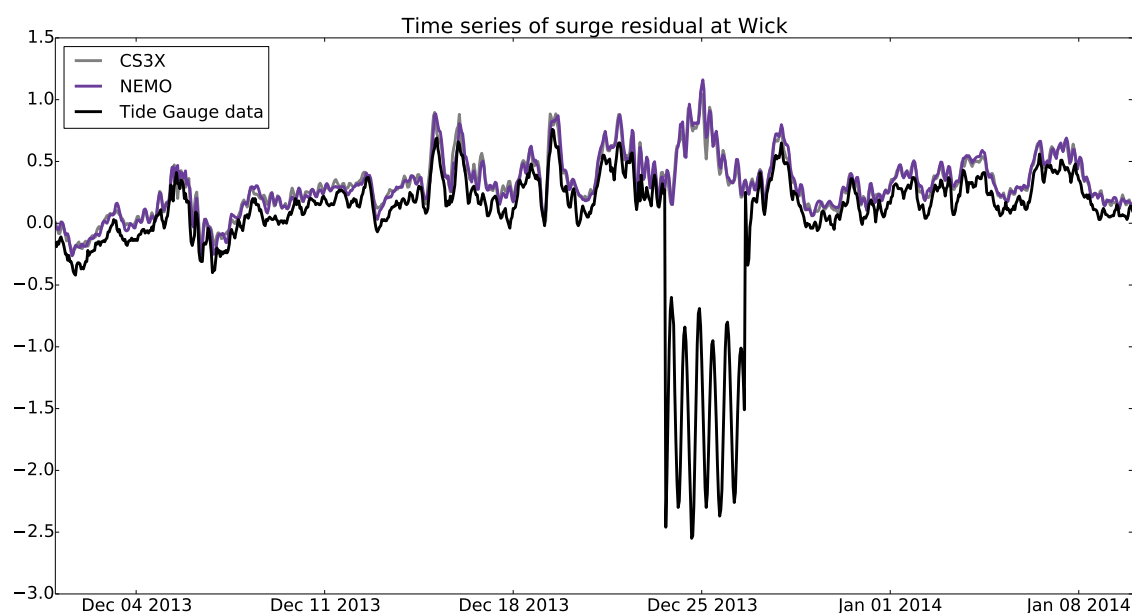


**Figure 2:** Schematic illustrating the difference between residual and skew surge. The black line shows the expected tide-only water level, and the grey line shows the observed/modelled water level including the atmospheric surge component. Then residual is the difference between the two at any given time (red labels), and skew surge is the difference in peak water level regardless of its timing (blue label).

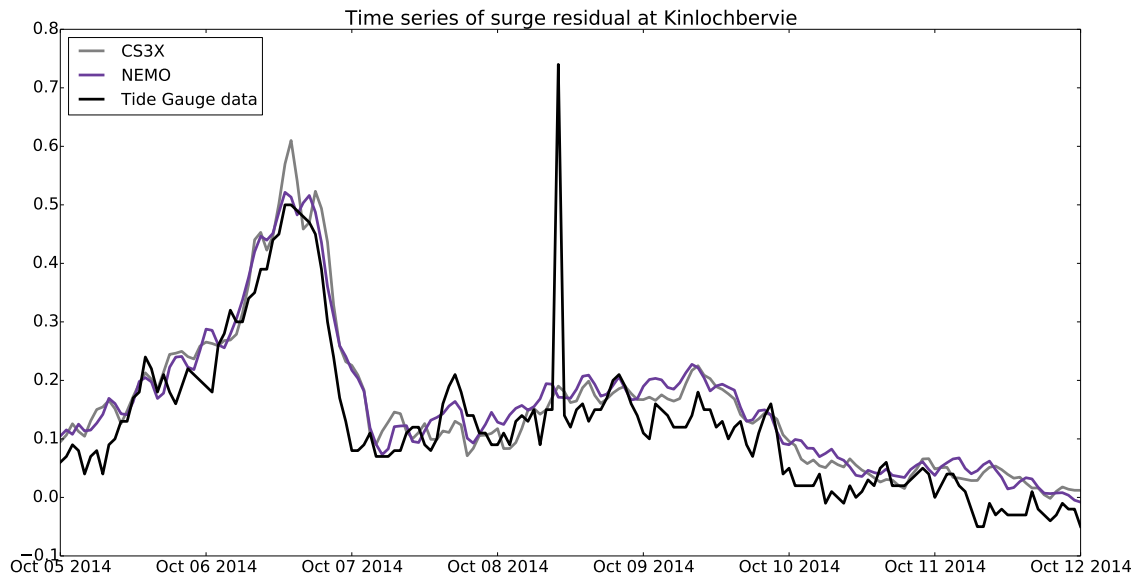
The following metrics are calculated for the residual (hourly timeseries) and skew surge (peaks-only timeseries), and tables and plots will be presented:

- Root mean square (RMS) error
- Mean error (bias)
- Maximum |error|—the largest error (positive or negative) that occurs anywhere in the time-series
- Scatter index—defined as  $\sigma_E/\sigma_O$  where  $\sigma_E$  denotes the standard deviation of model-observation error and  $\sigma_O$  is the standard deviation of the observations. This provides an indication of the non-systematic error
- Normalised standard deviation  $\sigma_M/\sigma_O$ —i.e. the ratio of modelled to observed standard deviation. This indicates how well the models represent the observed range of water level changes regardless of any overall bias up or down.
- Correlation coefficient  $r$

Note that we exclude Wick from the analysis due to a significant number of bad observations which have not been flagged, shown in Figure 3. Additionally, some of the remaining ports contain isolated bad values (example shown in Figure 4) which have a significant impact on the maximum error metric. We attempt to remove these by applying a simple filter which removes any observations that are more than 3 standard deviations away from the mean, as calculated over a centered running window of 24 hours. This method successfully removes most of the problem observations, but does also potentially exclude some legitimate points. However, the number of points removed is small (in fact zero at many ports) and does not make a significant difference to the other metrics.



**Figure 3:** Example timeseries of observations (and corresponding model output) at Wick, illustrating why it has been excluded from the analysis.



**Figure 4:** Example timeseries of observations (and corresponding model output) at Kinlochbervie, showing a spurious value in the observations.

### 3 Wind forcing tests

#### 3.1 Experiment setup

There are two aspects of the wind forcing configuration tested: the use of either the Charnock (1955) or Smith and Banke (1975) (hereafter referred to as S&B) formulation, and the response to changing the tunable parameters associated with each scheme.

In the Charnock formulation, the surface drag coefficient,  $C_D$ , is calculated from a bottom roughness  $z_0$  defined as

$$z_0 = \frac{\alpha u_*^2}{g}$$

where  $u_*^2$  is friction velocity,  $g$  is gravity, and  $\alpha$  is a tunable parameter called the Charnock parameter. This parameter is thought to be wave-dependent, but is frequently treated as a constant in the range 0.012–0.035 (Brown and Wolf, 2009). Suggested values include 0.0185 (found by Wu (1982) to give good performance for all wave states), 0.0275 (found by Williams and Flather (2000) to give good performance for surge modelling, and consequently used by CS3X) and 0.032 (found by Mastenbroek et al. (1993) to be suitable for modelling the North Sea). Taking these results into account, the values tested in this study are: 0.0185, 0.02, 0.024, 0.0275, 0.35.

The S&B scheme uses a linear relationship to calculate the drag coefficient directly from the wind speed, defined as:

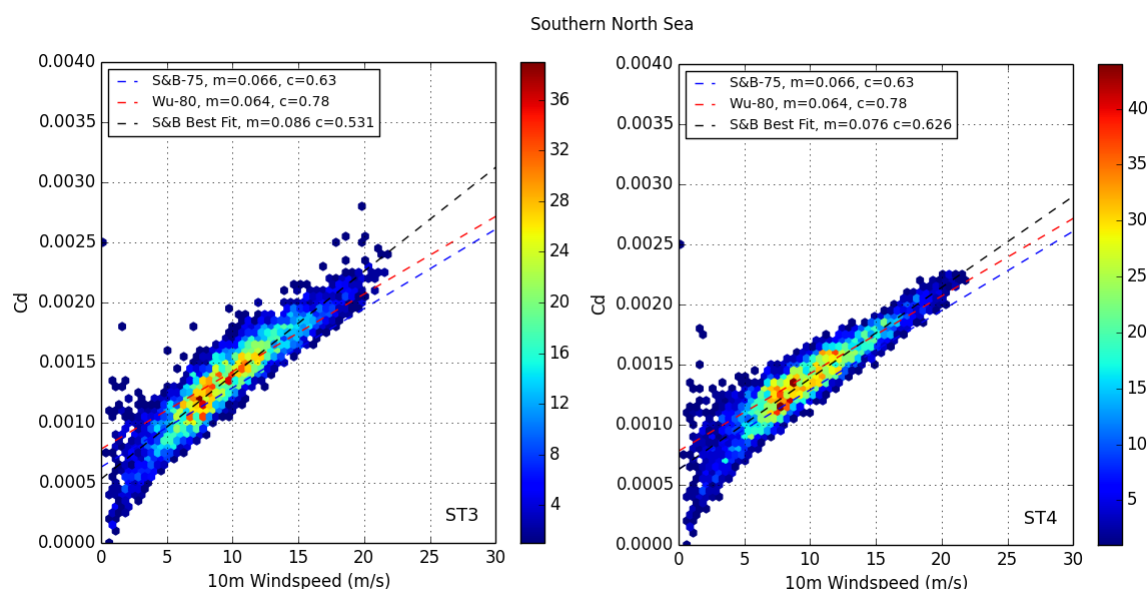
$$C_D = (0.63 + 0.066|U_{10}|) \times 10^{-3}$$

where  $U_{10}$  is the 10 m wind speed.



We test this original configuration, as well as two amended versions using different linear coefficients. These were chosen after fitting a relationship to drag coefficients computed by a WAVEWATCH III simulation of the North Sea (example shown in Figure 5). These amended S&B-type configurations are:

- $C_D = (0.63 + 0.076|U_{10}|) \times 10^{-3}$
- $C_D = (0.53 + 0.085|U_{10}|) \times 10^{-3}$



**Figure 5:** Surface drag coefficient vs the corresponding 10 m wind speed computed from a WAVEWATCH III wave model (for two slightly different wave physics packages). The black dashed line shows the linear best fit.

The full set of runs conducted for the wind forcing tests is shown in Table 1. Note that for all of these experiments the reference pressure level used is 1012 hPa, chosen to match the settings used by the operational CS3X model.

Run name	Wind formulation
Ch185	Charnock parameter: 0.0185
Ch2	Charnock parameter: 0.02
Ch24	Charnock parameter: 0.024
Ch275	Charnock parameter: 0.0275 (Matches CS3X setup)
Ch35	Charnock parameter: 0.035
SB0	S&B coefficients: 0.63 / 0.066 (Original Smith and Banke (1975) form)
SB1	S&B coefficients: 0.63 / 0.076
SB2	S&B coefficients: 0.53 / 0.085

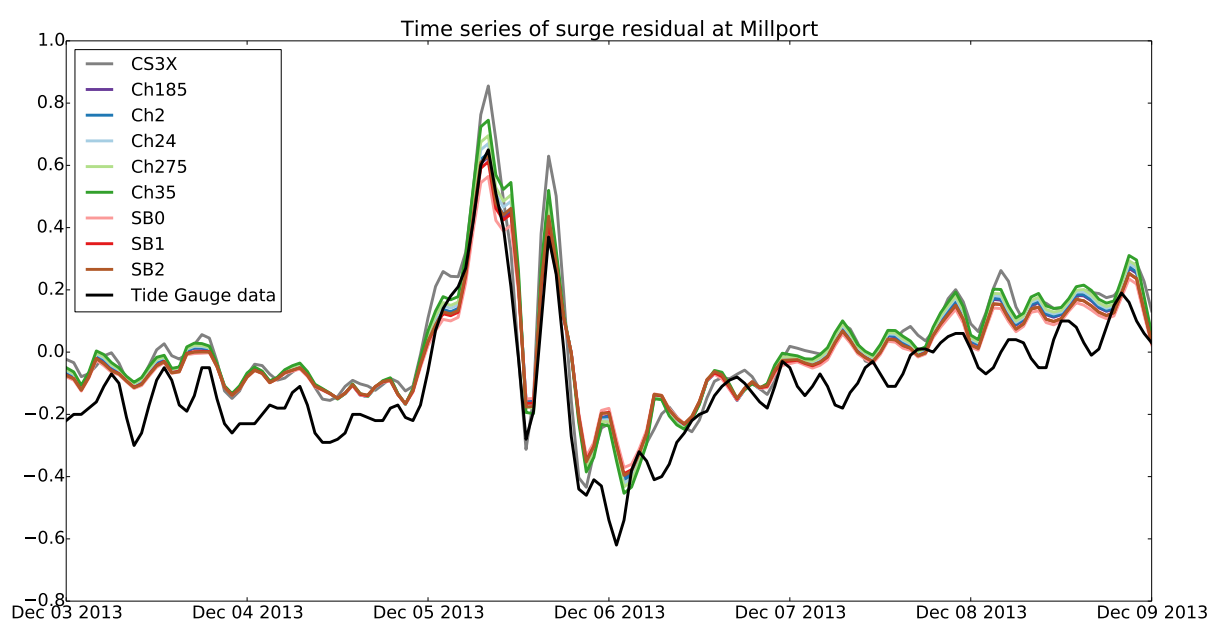
**Table 1:** The model runs conducted for the wind forcing tests

## 3.2 Results

As described in section 2.2, the residual water level and skew surge from each run is compared against observations from the tide gauge network. Full results are shown in Appendix A in Tables

A1 to A6 (residual) and A7 to A12 (skew surge).

Generally there is not much difference between the runs during benign periods, with larger differences appearing during surge events when conditions are windier (e.g. Figure 6). The S&B runs typically produce smaller surges than the Charnock runs, and within the Charnock runs the surge increases as the Charnock parameter is increased. Looking at the statistical tables, the full picture is complex with different ports responding differently to the various wind parameterisations, and with different responses depending on which metric is chosen. However, there are some patterns that emerge.



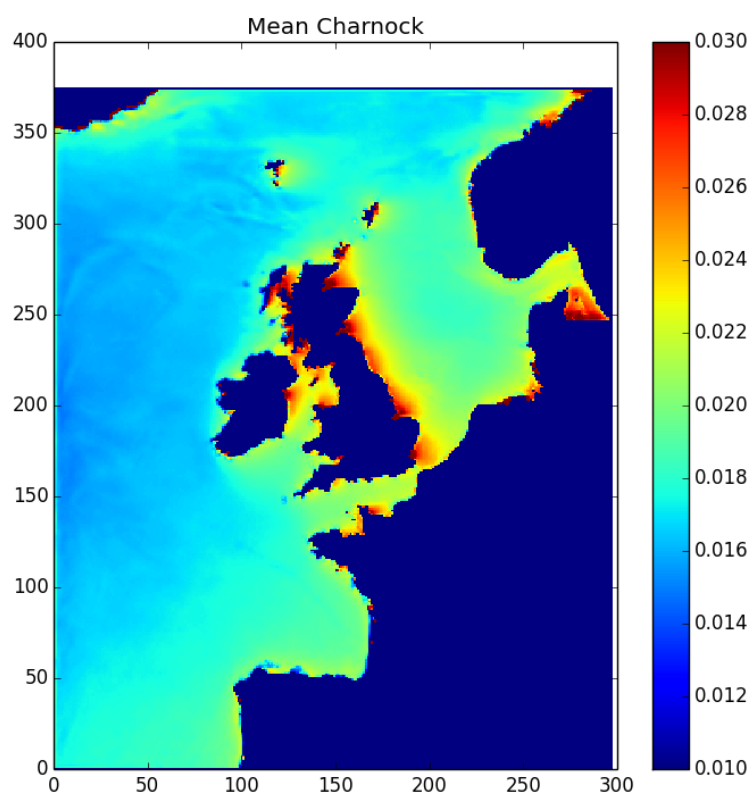
**Figure 6:** Example timeseries of residual water level at Millport for the wind sensitivity tests. Observations are shown in black, CS3X is in grey, and the various wind test runs are shown by the coloured lines.

In most cases, the S&B scheme in its original form (i.e. run SB0) performs poorly compared with the Charnock scheme, particularly when looking at the normalised standard deviation which is significantly too low. This is improved somewhat in the amended S&B schemes (runs SB1 and SB2), but these are still generally outperformed by the Charnock scheme. One exception is several of the Scottish ports which do better with S&B—this is likely due to the fact that there is an overall high bias in this region, and so the lower peak water levels caused by the S&B scheme artificially nudge the timeseries down towards the observations. An example of this effect is shown in Figure 6, which shows the residual water level at Millport. We see that during quiet periods there is a general bias in the model results (for both NEMO-Surge and CS3X). During the surge event of the 5th December most of the model runs consequently over-predict the peak water level. By coincidence the reduced surge predicted by the S&B runs is just enough to offset the bias, bringing them closer to the observed peak, but the *change* in water level during the surge is not as well represented.

We therefore discount the S&B scheme from contention. Looking at the Charnock runs the RMS error, mean error and correlation show very little sensitivity to the choice of Charnock parameter at most locations. There is slightly more impact in the mean error at the Scottish ports, where increasing the Charnock parameter increases the error, for the same reason that the S&B runs produced better statistics there—smaller Charnock parameter values cause smaller surge peak levels, partially offsetting the systematic bias seen in this region. In most other ports the mean error for residual is best with the larger parameter values, whereas for skew surge it is often the opposite. The differences are small however.

The normalised standard deviation (Table A5) shows more sensitivity to the choice of Charnock parameter, where increasing the parameter increases the modelled standard deviation. In most areas the larger values are better, but in some cases (e.g. Sheerness or Immingham) the model ‘overshoots’ with too much variability when using the larger values. Depending on the location the best performance is reached with values 0.024, 0.0275 or 0.035.

Taking the results as a whole, we conclude that the overall most suitable setup is the Charnock formulation with a constant parameter of 0.0275. However, there is considerable spatial variability in which run produced the best result, matching the results of Brown and Wolf (2009) who found that ‘a constant Charnock parameter can be tuned to give good surge results at a given location, but not necessarily optimum everywhere in time and space’. It would therefore be recommended for future work to investigate the use of a spatially, and potentially also temporally, varying parameter; for example using output from a wave model. As an illustration of the spatial variability that could be provided, Figure 7 shows an example of output from a WAVEWATCH III wave model. In this example, the mean Charnock parameter is calculated using all times where the wind speed was greater than  $10 \text{ ms}^{-1}$  during the run period October 2014–March 2015.



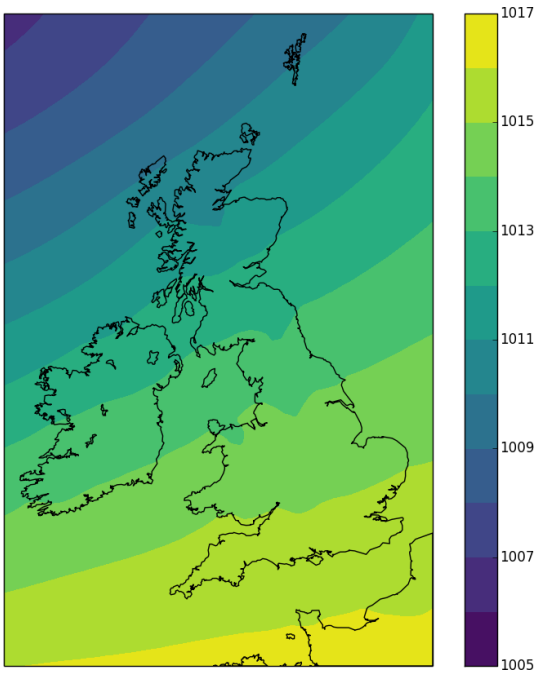
**Figure 7:** Example Charnock parameter output from WAVEWATCH III wave model. Shown are the mean Charnock parameter calculated using all times where wind speeds were greater than  $10 \text{ ms}^{-1}$

## 4 Reference pressure tests

### 4.1 Experiment setup

In NEMO, a reference pressure level is used to provide an absolute correction to the sea surface height. This is a single reference level used across the whole domain and has the effect of raising the entire surface by the same amount. The AMM7 NEMO configuration that NEMO-Surge was based upon uses a value of 1010 hPa, and the operational CS3X model uses a value of 1012 hPa. Figure 8 shows the 2013 annual mean atmospheric pressure over the UK (calculated using the model forcing input files). We see that there is a clear latitude dependency in mean pressure with a range of 1005–1016 hPa across the domain, so the values suggested by the existing models (1010 and 1012 hPa) could both be considered reasonable values to use for the domain-wide single value. However, they are less representative of the southern UK where the mean pressure is higher so we also test a larger value—1014 hPa.

Table 2 shows a summary of the pressure experiments conducted. Note that for all of these runs the wind forcing is applied using a Charnock (1955) formulation with Charnock parameter 0.0275,



**Figure 8:** Mean surface pressure during the 2013 test year (calculated from the model input files)

chosen to match the settings used by the operational CS3X model.

Run name	Reference pressure value
P1010	1010 hPa (Used by NEMO AMM7 configuration)
P1012	1012 hPa (Used by CS3X)
P1014	1014 hPa (More realistic for central and southern UK)

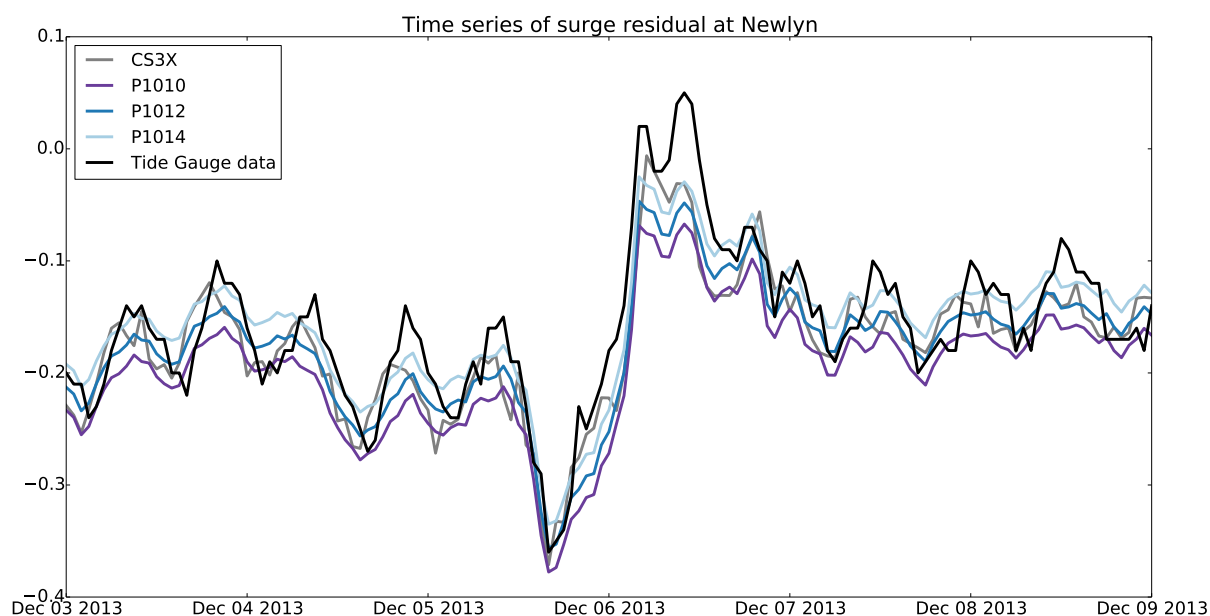
**Table 2:** The model runs conducted for the reference pressure tests

## 4.2 Results

Similarly to the wind tests, the full statistical results are presented in Appendix B in Tables B1 to B6 (residual) and B7 to B12 (skew surge).

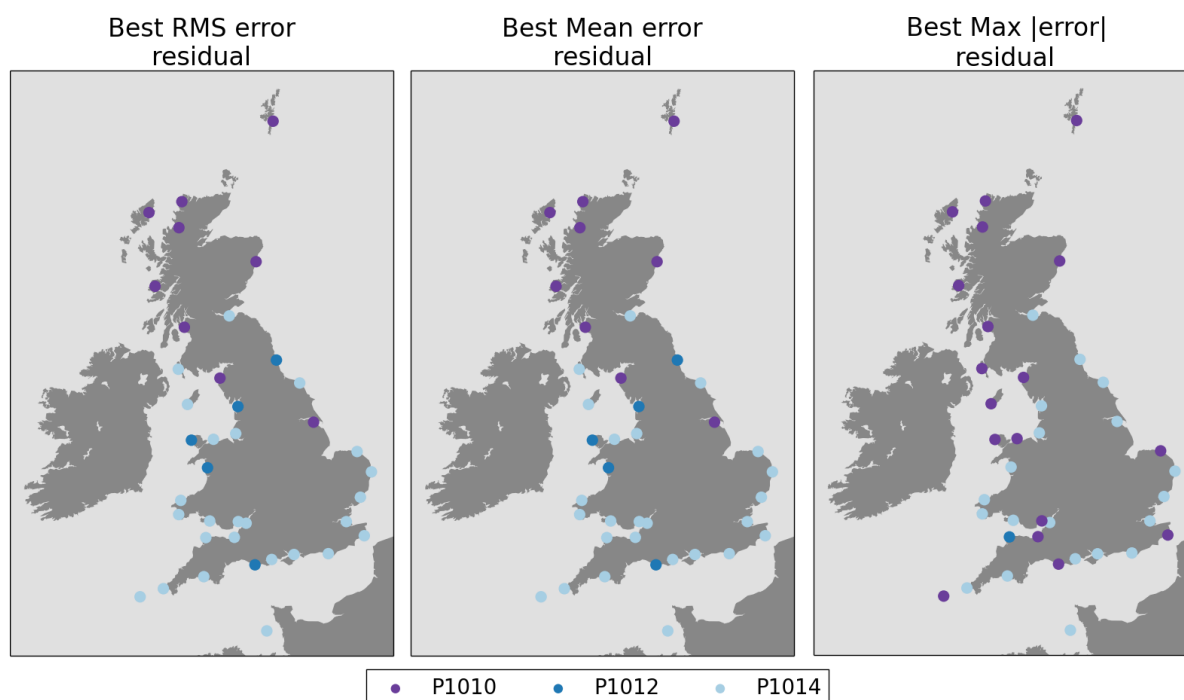
Changing the reference pressure level effectively moves the whole model sea surface up or down, as can be seen the example timeseries shown in Figure 9. Therefore the main impact is on the RMS, mean, and maximum error metrics as these are sensitive to the overall bias. The bias in particular is important here as there is a clear spatial pattern with northern ports tending to be biased high (in both NEMO-Surge and CS3X) and southern ports biased low, mirroring the pattern seen in the mean pressure field shown in Figure 8. Changing the reference pressure level has the effect of shifting this pattern north/south, such that a change that improves the northern ports will make southern ports worse, and vice versa. This is illustrated by Figure 10 which shows the ‘best run’ out of the three pressure tests at each port: The spatial pattern is clear with Scottish ports tending to perform best with a smaller reference pressure and southern ports generally doing best with the higher value.

On the other hand, the scatter index, normalised standard deviation and correlation show very little sensitivity to the change in reference pressure level. This is not unexpected as shifting the overall water level up or down does not alter the variability that is seen at a location. There will be some impact due to the change in total water depth affecting the tide and surge propagation speed, but this effect is small.



**Figure 9:** Example timeseries of residual water level at Newlyn showing the response to changing the reference pressure level. Observations are shown in black, CS3X is in grey, and the three pressure test runs are shown by the coloured lines.

Overall we conclude that 1012 hPa is the best compromise for use as a domain wide value, as using 1010 hPa is detrimental to the southern ports while increasing to 1014 hPa similarly has a negative impact on northern regions. Given the clear spatial pattern in the model bias and the effect that the reference pressure has on this, it may be interesting for future work to investigate whether a spatially varying parameter would improve performance.



**Figure 10:** Map showing which pressure test gave the best residual water level at each port for RMS error (left), mean error (middle) and max |error| (right). The equivalent plot for skew surge was very similar.

## 5 NEMO-surge vs CS3X comparison

Having assessed the wind and pressure sensitivity tests, the final configuration chosen for NEMO-surge is

- Reference pressure level: 1012 hPa
- Wind scheme: Charnock (1955) formulation with Charnock parameter 0.0275.

A 2-year long run using this configuration has been made for the period 2013–2014, and is now compared with an equivalent CS3X run. Tables 3 to 8 show the results for NEMO-Surge and CS3X (for the six statistic types listed in section 2.2) for each port, and for both residual and skew surge. The NEMO-Surge statistics are also shown graphically in Figures 11 and 12 to provide an indication of spatial variation.

### 5.1 Overall performance

Overall the performance of NEMO-Surge is very similar to CS3X, although that is not to say that the sources of error in the two models are necessarily the same.

For RMS error (Table 3), the differences are of the order of millimetres almost everywhere, with NEMO-Surge performing slightly better than CS3X in most cases for the residual (with an overall

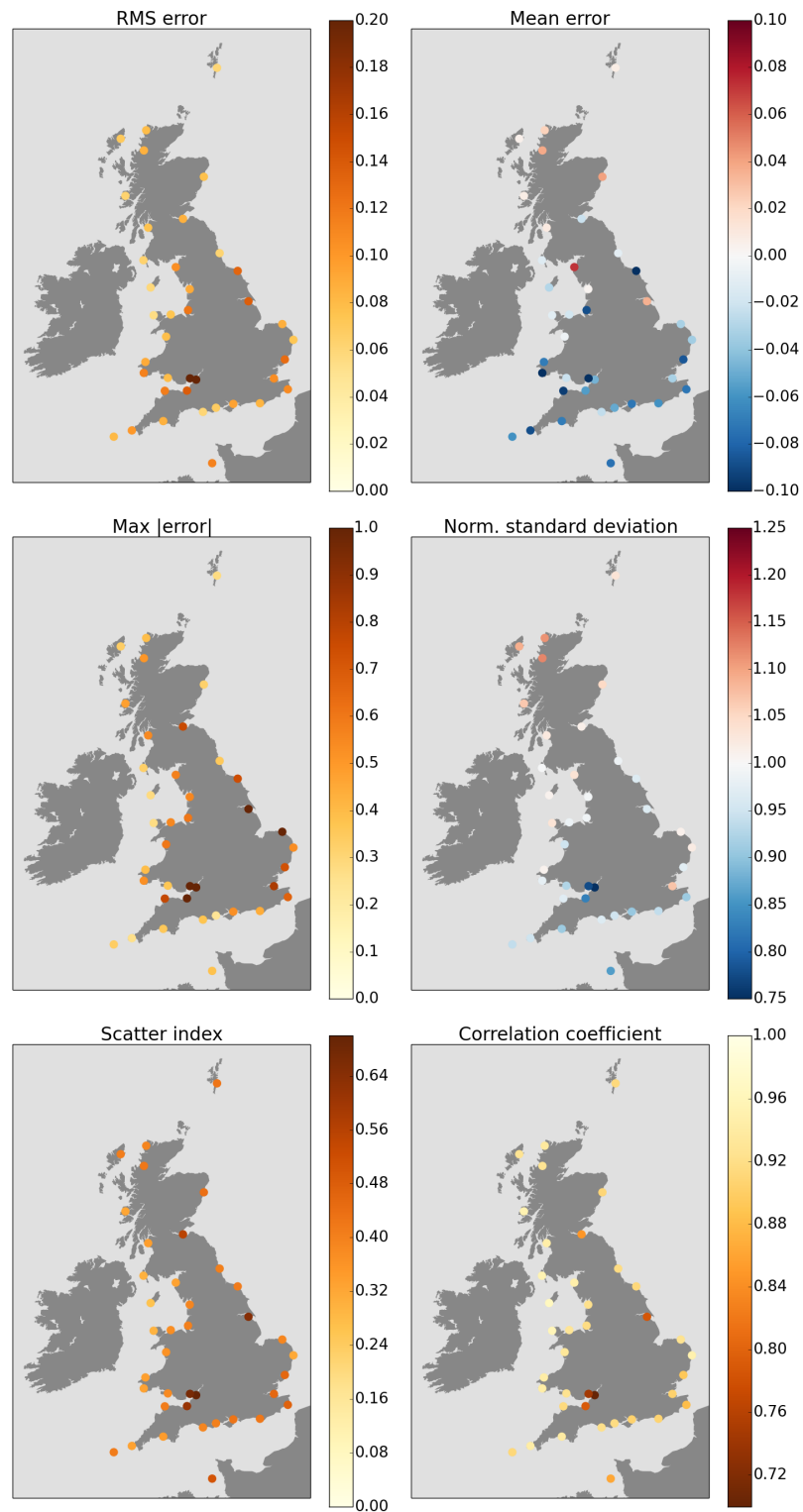
2 mm improvement), and about half of cases for skew surge (with no overall difference). For both models the mean RMS error over all ports is less than 1 cm, though errors are larger in the Bristol Channel region. This is a challenging area to model accurately due to the complex tidal regime, such that future upgrades in grid resolution and the addition of wetting and drying would probably be needed to improve model performance here.

As discussed in previous sections, the mean error (Table 4) has a strong spatial pattern with positive bias in the Scottish ports and negative bias in the south. Again there is very little difference between NEMO-Surge and CS3X for the residual water level, with both having the same overall mean bias of -3.6 cm. The bias in skew surge shows a little more difference, with most ports slightly worse in NEMO-Surge, albeit with a small mean change of 6 mm. Conversely the scatter index (Table 6), which is a measure of the non-systematic errors, shows a consistent improvement with NEMO-Surge for both residual and skew surge. This implies that NEMO-surge generally reproduces the residual signal better than CS3X.

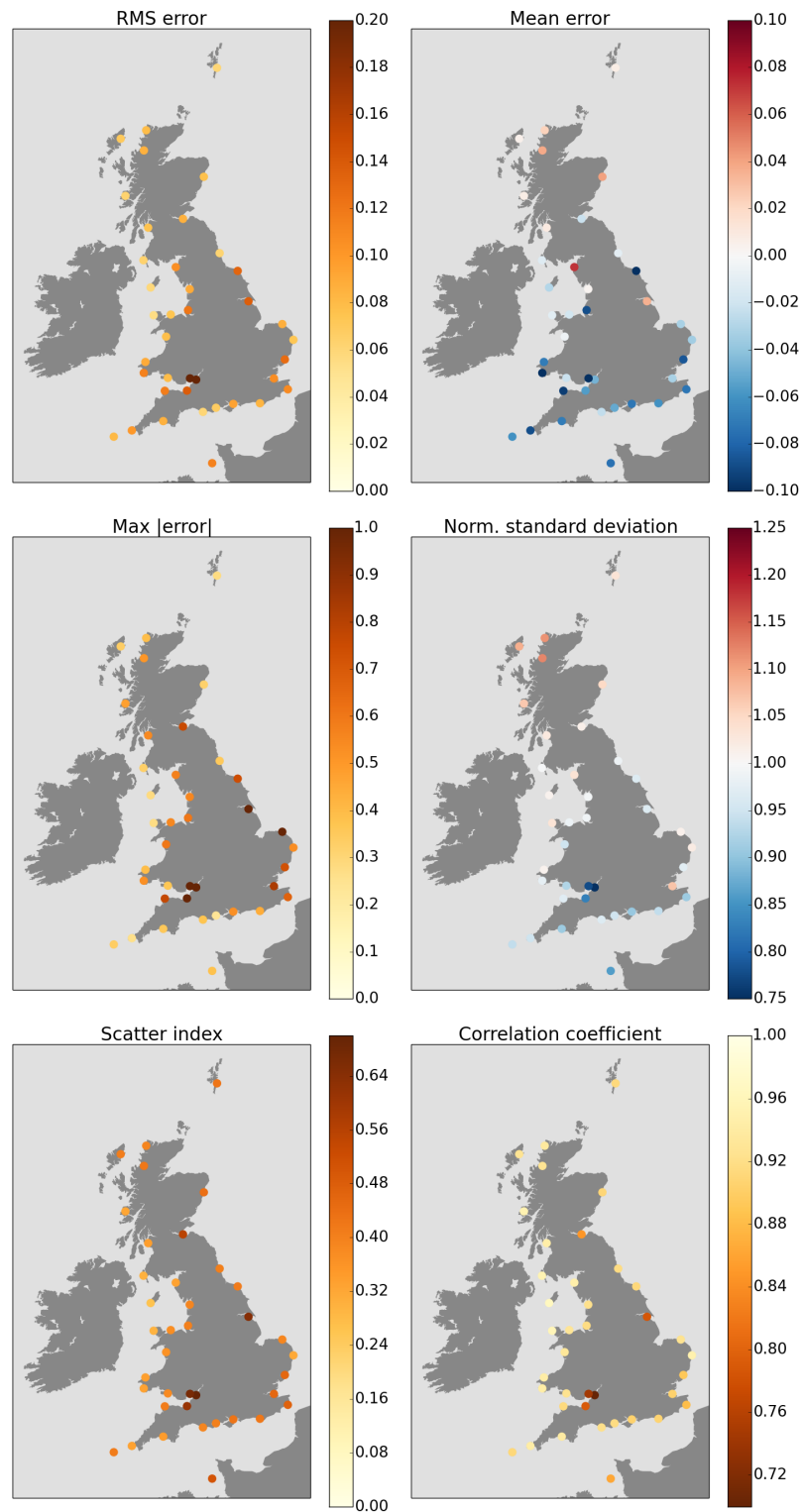
The maximum error (Table 5) shows more differences between the models with some ports considerably better in NEMO-Surge (e.g. Tobermory) while others are worse (e.g. Avonmouth). These differences almost cancel out such that the overall performance is very similar with only 14 mm difference between NEMO-Surge and CS3X for the residual and 7 mm for skew surge. The maximum error is by its nature a harsh test of model performance, particularly for the residual water level, as no allowance is made for errors in timing. This means that a small offset in the timing of an event can lead to very large error. Therefore we see that the maximum error in residual is larger than that for skew surge.

For the normalised standard deviation (Table 7) NEMO-Surge performs better in about half of the ports, although the overall mean value is slightly worse than CS3X for both residual and skew surge. Looking at spatial distribution, this seems to be dominated by the south coast region where each port is worse in NEMO-Surge (though it should be noted the differences are small). The sensitivity tests (Table A5) indicate that the south coast performs better with the larger 0.035 Charnock parameter, so this is an area that may be improved by using a spatially varying parameter. Generally both models perform well for this metric, although the Bristol Channel is again a difficult region with both CS3X and NEMO-Surge only capturing around 70% of the variability in residual at Avonmouth and Newport (both slightly improved in NEMO-Surge). This is also seen in the correlation coefficient (Table 8) where again there is very little difference between models, with both showing an average  $r$  value of 0.9 which is reduced to around 0.7 in the Bristol Channel. Normalised standard deviation for skew surge at Newport is significantly lower for NEMO-Surge than that for CS3X; this behaviour is discussed further in the next section.





**Figure 11:** Map of statistics from NEMO-Surge for each port for residual water level. Lighter/darker colours indicate better/poorer performance.



**Figure 12:** Map of statistics from NEMO-Surge for each port for skew surge. Lighter/darker colours indicate better/poorer performance.

Port	Residual			Skew surge		
	CS3X	NEMO	Diff.	CS3X	NEMO	Diff.
Ilfracombe	0.119	0.117	-0.002	0.112	0.119	0.007
Hinkley Point	0.145	0.139	-0.006	0.130	0.140	0.010
Avonmouth	0.196	0.202	0.006	0.172	0.171	-0.000
Newport	0.235	0.232	-0.002	0.217	0.211	-0.006
Mumbles	0.086	0.079	-0.007	0.075	0.075	-0.000
Milford Haven	0.117	0.115	-0.002	0.114	0.116	0.002
Fishguard	0.090	0.089	-0.001	0.092	0.091	-0.001
Barmouth	0.084	0.078	-0.007	0.082	0.073	-0.009
Holyhead	0.059	0.055	-0.004	0.058	0.055	-0.004
Llandudno	0.076	0.074	-0.002	0.078	0.074	-0.004
Liverpool	0.123	0.122	-0.001	0.115	0.119	0.003
Heysham	0.090	0.090	0.000	0.083	0.079	-0.004
Port Erin	0.061	0.059	-0.002	-	-	-
Workington	0.106	0.106	0.000	0.112	0.102	-0.010
Portpatrick	0.068	0.063	-0.004	0.072	0.065	-0.007
Millport	0.077	0.075	-0.002	0.081	0.073	-0.008
Tobermory	0.072	0.063	-0.009	0.072	0.060	-0.012
Ullapool	0.091	0.087	-0.004	0.088	0.083	-0.005
Stornoway	0.072	0.071	-0.001	0.071	0.070	-0.002
Kinlochbervie	0.085	0.079	-0.006	0.080	0.075	-0.004
Lerwick	0.060	0.060	0.001	0.057	0.060	0.003
Aberdeen	0.074	0.077	0.003	0.064	0.066	0.003
Leith	0.086	0.086	0.000	0.078	0.086	0.008
North Shields	0.064	0.062	-0.002	0.070	0.066	-0.004
Whitby	0.135	0.132	-0.003	0.152	0.149	-0.003
Immingham	0.128	0.137	0.009	0.119	0.115	-0.005
Cromer	0.091	0.087	-0.003	0.103	0.096	-0.007
Lowestoft	0.081	0.073	-0.007	0.077	0.073	-0.004
Harwich	0.134	0.129	-0.005	0.152	0.177	0.025
Sheerness	0.102	0.108	0.005	0.097	0.145	0.048
Jersey	0.116	0.114	-0.002	-	-	-
St Marys	0.083	0.082	-0.001	0.080	0.082	0.001
Newlyn	0.102	0.100	-0.001	0.097	0.098	0.001
Plymouth	0.088	0.086	-0.002	0.081	0.084	0.003
Weymouth	0.062	0.061	-0.002	0.058	0.060	0.002
Bournemouth	0.071	0.068	-0.002	0.077	0.072	-0.004
Portsmouth	0.098	0.095	-0.003	0.100	0.104	0.004
Newhaven	0.087	0.084	-0.003	0.082	0.078	-0.004
Dover	0.113	0.109	-0.004	0.100	0.101	0.001
Mean	0.098	0.096	-0.002	0.096	0.096	0.000

**Table 3:** RMS error for CS3X and NEMO-Surge, and the difference between the two, for residual water level and skew surge. Differences are printed in green/pink where NEMO-Surge is better/worse than CS3X (calculated using higher precision figures than printed here). Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors.

Port	Residual			Skew surge		
	CS3X	NEMO	Diff.	CS3X	NEMO	Diff.
Ilfracombe	-0.094	-0.095	-0.001	-0.087	-0.098	-0.011
Hinkley Point	-0.054	-0.056	-0.002	-0.070	-0.092	-0.022
Avonmouth	-0.050	-0.047	0.003	-0.047	-0.057	-0.010
Newport	-0.167	-0.168	-0.001	-0.158	-0.170	-0.012
Mumbles	-0.019	-0.022	-0.004	-0.024	-0.037	-0.013
Milford Haven	-0.101	-0.100	0.001	-0.093	-0.099	-0.006
Fishguard	-0.070	-0.070	-0.001	-0.072	-0.073	-0.001
Barmouth	0.000	-0.005	-0.005	-0.010	-0.017	-0.007
Holyhead	-0.010	-0.011	-0.001	-0.010	-0.015	-0.004
Llandudno	-0.017	-0.019	-0.002	-0.010	-0.020	-0.010
Liverpool	-0.086	-0.088	-0.003	-0.081	-0.093	-0.012
Heysham	0.004	0.003	-0.002	-0.001	-0.018	-0.017
Port Erin	-0.029	-0.029	-0.000	-	-	-
Workington	0.072	0.072	0.000	0.069	0.056	-0.013
Portpatrick	-0.008	-0.013	-0.005	-0.006	-0.019	-0.013
Millport	0.012	0.009	-0.003	0.020	0.009	-0.011
Tobermory	0.008	0.007	-0.000	0.004	0.001	-0.002
Ullapool	0.039	0.038	-0.002	0.033	0.031	-0.002
Stornoway	0.005	0.005	0.001	-0.001	-0.000	0.001
Kinlochbervie	0.025	0.023	-0.002	0.019	0.018	-0.001
Lerwick	0.007	0.007	0.001	0.007	0.011	0.005
Aberdeen	0.036	0.041	0.004	0.023	0.031	0.008
Leith	-0.022	-0.022	0.000	-0.038	-0.045	-0.008
North Shields	-0.014	-0.010	0.004	-0.036	-0.033	0.003
Whitby	-0.118	-0.114	0.003	-0.140	-0.138	0.002
Immingham	0.035	0.036	0.001	0.061	0.057	-0.005
Cromer	-0.039	-0.032	0.007	-0.036	-0.026	0.010
Lowestoft	-0.042	-0.035	0.007	-0.040	-0.036	0.005
Harwich	-0.090	-0.085	0.004	-0.111	-0.134	-0.023
Sheerness	-0.037	-0.033	0.004	-0.037	-0.071	-0.034
Jersey	-0.074	-0.074	-0.001	-	-	-
St Marys	-0.062	-0.061	0.001	-0.055	-0.059	-0.004
Newlyn	-0.089	-0.088	0.001	-0.083	-0.086	-0.003
Plymouth	-0.071	-0.070	0.001	-0.063	-0.069	-0.006
Weymouth	-0.024	-0.025	-0.000	-0.024	-0.033	-0.009
Bournemouth	-0.052	-0.051	0.001	-0.064	-0.060	0.005
Portsmouth	-0.073	-0.072	0.001	-0.078	-0.086	-0.008
Newhaven	-0.061	-0.060	0.000	-0.040	-0.045	-0.005
Dover	-0.076	-0.073	0.002	-0.051	-0.055	-0.004
Mean	-0.036	-0.036	0.000	-0.036	-0.042	-0.006

**Table 4:** Mean error for CS3X and NEMO-Surge, and the difference between the two, for residual water level and skew surge. Differences are printed in green/pink where NEMO-Surge is better/worse than CS3X (calculated using higher precision figures than printed here). Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors.

Port	Residual			Skew surge		
	CS3X	NEMO	Diff.	CS3X	NEMO	Diff.
Ilfracombe	0.690	0.766	0.077	0.546	0.766	0.220
Hinkley Point	0.855	1.078	0.223	0.855	1.078	0.223
Avonmouth	0.936	1.634	0.698	0.566	0.836	0.270
Newport	1.408	1.266	-0.141	0.977	0.639	-0.338
Mumbles	0.666	0.366	-0.300	0.310	0.366	0.056
Milford Haven	0.436	0.529	0.093	0.268	0.326	0.058
Fishguard	0.343	0.397	0.054	0.226	0.245	0.019
Barmouth	0.674	0.604	-0.071	0.388	0.278	-0.110
Holyhead	0.325	0.276	-0.049	0.315	0.266	-0.049
Llandudno	0.547	0.551	0.004	0.457	0.506	0.049
Liverpool	0.573	0.604	0.031	0.573	0.604	0.031
Heysham	0.552	0.555	0.003	0.399	0.286	-0.114
Port Erin	0.273	0.284	0.011	-	-	-
Workington	0.659	0.577	-0.082	0.571	0.577	0.006
Portpatrick	0.466	0.331	-0.136	0.410	0.331	-0.080
Millport	0.662	0.548	-0.115	0.520	0.403	-0.118
Tobermory	0.659	0.480	-0.179	0.401	0.206	-0.195
Ullapool	0.688	0.511	-0.176	0.337	0.342	0.004
Stornoway	0.374	0.336	-0.038	0.226	0.213	-0.013
Kinlochbervie	0.464	0.393	-0.071	0.326	0.393	0.067
Lerwick	0.261	0.279	0.018	0.223	0.269	0.045
Aberdeen	0.360	0.322	-0.037	0.235	0.247	0.011
Leith	0.563	0.761	0.198	0.272	0.306	0.034
North Shields	0.319	0.354	0.035	0.250	0.237	-0.013
Whitby	0.736	0.746	0.010	0.387	0.394	0.006
Immingham	0.805	1.378	0.573	0.409	0.438	0.029
Cromer	1.048	1.085	0.037	1.015	1.035	0.020
Lowestoft	0.499	0.538	0.039	0.292	0.371	0.079
Harwich	0.738	0.734	-0.004	0.597	0.646	0.050
Sheerness	0.886	0.831	-0.055	0.424	0.535	0.111
Jersey	0.464	0.379	-0.085	-	-	-
St Marys	0.347	0.339	-0.008	0.321	0.319	-0.001
Newlyn	0.264	0.262	-0.002	0.241	0.220	-0.020
Plymouth	0.341	0.358	0.017	0.222	0.278	0.056
Weymouth	0.337	0.373	0.037	0.225	0.220	-0.005
Bournemouth	0.235	0.237	0.002	0.217	0.206	-0.011
Portsmouth	0.640	0.529	-0.111	0.307	0.318	0.010
Newhaven	0.364	0.445	0.081	0.332	0.250	-0.083
Dover	0.690	0.674	-0.017	0.443	0.407	-0.036
Mean	0.568	0.582	0.014	0.408	0.415	0.007

**Table 5:** Maximum [error] for CS3X and NEMO-Surge, and the difference between the two, for residual water level and skew surge. Differences are printed in green/pink where NEMO-Surge is better/worse than CS3X (calculated using higher precision figures than printed here). Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors.

Port	Residual			Skew surge		
	CS3X	NEMO	Diff.	CS3X	NEMO	Diff.
Ilfracombe	0.438	0.409	-0.029	0.461	0.437	-0.024
Hinkley Point	0.649	0.615	-0.034	0.614	0.592	-0.022
Avonmouth	0.737	0.764	0.027	0.754	0.738	-0.016
Newport	0.687	0.668	-0.019	0.716	0.599	-0.117
Mumbles	0.425	0.382	-0.043	0.392	0.360	-0.032
Milford Haven	0.345	0.333	-0.012	0.405	0.377	-0.029
Fishguard	0.350	0.337	-0.013	0.369	0.350	-0.018
Barmouth	0.398	0.365	-0.033	0.405	0.354	-0.051
Holyhead	0.320	0.296	-0.025	0.328	0.301	-0.027
Llandudno	0.387	0.374	-0.013	0.438	0.403	-0.035
Liverpool	0.426	0.404	-0.022	0.441	0.397	-0.044
Heysham	0.393	0.393	0.000	0.407	0.378	-0.029
Port Erin	0.273	0.263	-0.009	-	-	-
Workington	0.333	0.333	-0.000	0.432	0.414	-0.018
Portpatrick	0.329	0.302	-0.026	0.359	0.312	-0.047
Millport	0.347	0.339	-0.008	0.354	0.326	-0.028
Tobermory	0.374	0.325	-0.049	0.376	0.316	-0.061
Ullapool	0.444	0.422	-0.022	0.457	0.432	-0.025
Stornoway	0.416	0.410	-0.006	0.428	0.418	-0.010
Kinlochbervie	0.418	0.392	-0.026	0.412	0.390	-0.022
Lerwick	0.423	0.427	0.004	0.407	0.423	0.015
Aberdeen	0.431	0.438	0.007	0.411	0.407	-0.004
Leith	0.554	0.557	0.003	0.475	0.511	0.036
North Shields	0.414	0.406	-0.009	0.409	0.391	-0.019
Whitby	0.413	0.414	0.002	0.398	0.380	-0.018
Immingham	0.597	0.644	0.047	0.538	0.526	-0.013
Cromer	0.393	0.390	-0.003	0.503	0.482	-0.021
Lowestoft	0.340	0.319	-0.021	0.331	0.322	-0.009
Harwich	0.469	0.457	-0.012	0.546	0.609	0.064
Sheerness	0.426	0.457	0.031	0.466	0.655	0.189
Jersey	0.523	0.506	-0.017	-	-	-
St Marys	0.415	0.411	-0.004	0.441	0.426	-0.015
Newlyn	0.343	0.331	-0.012	0.347	0.332	-0.015
Plymouth	0.356	0.344	-0.012	0.343	0.332	-0.011
Weymouth	0.405	0.392	-0.013	0.389	0.369	-0.020
Bournemouth	0.418	0.403	-0.015	0.385	0.375	-0.010
Portsmouth	0.456	0.427	-0.029	0.414	0.385	-0.029
Newhaven	0.449	0.422	-0.027	0.510	0.455	-0.055
Dover	0.489	0.472	-0.017	0.455	0.448	-0.007
Mean	0.431	0.419	-0.012	0.441	0.425	-0.016

**Table 6:** Scatter index for CS3X and NEMO-Surge, and the difference between the two, for residual water level and skew surge. Differences are printed in green/pink where NEMO-Surge is better/worse than CS3X (calculated using higher precision figures than printed here). Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors.

Port	Residual			Skew surge		
	CS3X	NEMO	Diff.	CS3X	NEMO	Diff.
Ilfracombe	1.000	0.969	-0.031	1.018	0.963	-0.055
Hinkley Point	0.867	0.829	-0.038	0.977	0.942	-0.036
Avonmouth	0.656	0.738	0.082	0.758	0.696	-0.062
Newport	0.754	0.775	0.021	1.134	0.801	-0.332
Mumbles	0.995	0.924	-0.070	1.008	0.927	-0.081
Milford Haven	0.996	0.978	-0.018	1.017	0.974	-0.043
Fishguard	1.041	1.010	-0.031	1.043	1.005	-0.038
Barmouth	1.012	0.948	-0.064	0.907	0.931	0.024
Holyhead	1.064	1.033	-0.030	1.062	1.048	-0.014
Llandudno	1.033	0.986	-0.046	1.075	1.014	-0.061
Liverpool	1.044	0.988	-0.056	1.083	1.020	-0.063
Heysham	1.036	0.994	-0.041	0.960	0.894	-0.066
Port Erin	1.017	1.011	-0.005	-	-	-
Workington	1.056	1.035	-0.020	1.177	1.160	-0.017
Portpatrick	1.058	0.996	-0.062	1.106	1.021	-0.084
Millport	1.076	1.024	-0.052	1.086	1.024	-0.062
Tobermory	1.183	1.068	-0.115	1.184	1.056	-0.127
Ullapool	1.176	1.123	-0.053	1.181	1.135	-0.046
Stornoway	1.125	1.091	-0.033	1.123	1.096	-0.027
Kinlochbervie	1.169	1.113	-0.056	1.154	1.115	-0.039
Lerwick	1.052	1.034	-0.017	1.052	1.040	-0.011
Aberdeen	1.008	1.049	0.041	0.966	1.012	0.046
Leith	0.980	1.015	0.036	0.925	0.909	-0.016
North Shields	0.951	0.987	0.036	0.881	0.941	0.060
Whitby	0.931	0.965	0.035	0.888	0.931	0.042
Immingham	0.916	0.965	0.049	0.851	0.825	-0.026
Cromer	1.025	1.013	-0.012	1.045	1.041	-0.004
Lowestoft	1.036	1.020	-0.016	1.033	1.017	-0.016
Harwich	0.973	0.971	-0.001	0.950	0.972	0.021
Sheerness	1.072	1.071	-0.001	0.956	1.043	0.087
Jersey	0.880	0.860	-0.020	-	-	-
St Marys	0.960	0.938	-0.022	0.960	0.922	-0.038
Newlyn	0.970	0.949	-0.022	0.972	0.946	-0.026
Plymouth	0.933	0.910	-0.023	0.937	0.933	-0.004
Weymouth	0.996	0.966	-0.030	1.007	0.940	-0.068
Bournemouth	0.962	0.951	-0.011	0.990	0.939	-0.050
Portsmouth	0.912	0.905	-0.007	0.988	0.911	-0.078
Newhaven	0.948	0.938	-0.010	0.950	0.916	-0.034
Dover	0.911	0.909	-0.002	0.923	0.884	-0.039
Mean	0.994	0.976	-0.018	1.009	0.972	-0.037

**Table 7:** Normalised standard deviation for CS3X and NEMO-Surge, and the difference between the two, for residual water level and skew surge. Differences are printed in green/pink where NEMO-Surge is better/worse than CS3X (calculated using higher precision figures than printed here). Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors.

Port	Residual			Skew surge		
	CS3X	NEMO	Diff.	CS3X	NEMO	Diff.
Ilfracombe	0.904	0.914	0.010	0.896	0.902	0.006
Hinkley Point	0.767	0.789	0.022	0.807	0.816	0.008
Avonmouth	0.676	0.651	-0.025	0.664	0.676	0.012
Newport	0.727	0.745	0.018	0.782	0.800	0.019
Mumbles	0.909	0.924	0.015	0.924	0.933	0.009
Milford Haven	0.940	0.943	0.003	0.919	0.927	0.008
Fishguard	0.942	0.944	0.002	0.936	0.939	0.003
Barmouth	0.922	0.931	0.009	0.914	0.935	0.021
Holyhead	0.954	0.958	0.005	0.951	0.958	0.007
Llandudno	0.928	0.929	0.001	0.913	0.920	0.007
Liverpool	0.914	0.917	0.003	0.914	0.923	0.010
Heysham	0.926	0.922	-0.004	0.915	0.926	0.012
Port Erin	0.964	0.966	0.002	-	-	-
Workington	0.949	0.947	-0.002	0.934	0.937	0.003
Portpatrick	0.950	0.954	0.004	0.947	0.953	0.006
Millport	0.947	0.944	-0.003	0.946	0.948	0.003
Tobermory	0.955	0.953	-0.002	0.954	0.954	0.000
Ullapool	0.929	0.927	-0.002	0.925	0.926	0.000
Stornoway	0.930	0.927	-0.003	0.925	0.924	-0.001
Kinlochbervie	0.937	0.937	-0.001	0.937	0.938	0.001
Lerwick	0.916	0.912	-0.004	0.922	0.915	-0.007
Aberdeen	0.908	0.910	0.002	0.913	0.918	0.005
Leith	0.843	0.847	0.004	0.881	0.861	-0.020
North Shields	0.911	0.917	0.006	0.913	0.921	0.008
Whitby	0.911	0.912	0.001	0.918	0.925	0.007
Immingham	0.809	0.786	-0.023	0.843	0.851	0.008
Cromer	0.925	0.925	0.000	0.880	0.889	0.009
Lowestoft	0.945	0.950	0.005	0.948	0.949	0.002
Harwich	0.887	0.893	0.006	0.845	0.809	-0.035
Sheerness	0.918	0.905	-0.013	0.887	0.795	-0.092
Jersey	0.853	0.863	0.010	-	-	-
St Marys	0.911	0.912	0.001	0.900	0.905	0.005
Newlyn	0.940	0.944	0.004	0.938	0.943	0.005
Plymouth	0.934	0.939	0.005	0.939	0.943	0.004
Weymouth	0.918	0.921	0.003	0.925	0.929	0.005
Bournemouth	0.910	0.916	0.006	0.925	0.927	0.002
Portsmouth	0.890	0.904	0.014	0.913	0.923	0.010
Newhaven	0.895	0.907	0.012	0.865	0.891	0.026
Dover	0.873	0.882	0.009	0.891	0.894	0.003
Mean	0.902	0.904	0.003	0.901	0.903	0.002

**Table 8:** Correlation coefficient for CS3X and NEMO-Surge, and the difference between the two, for residual water level and skew surge. Differences are printed in green/pink where NEMO-Surge is better/worse than CS3X (calculated using higher precision figures than printed here). Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors.



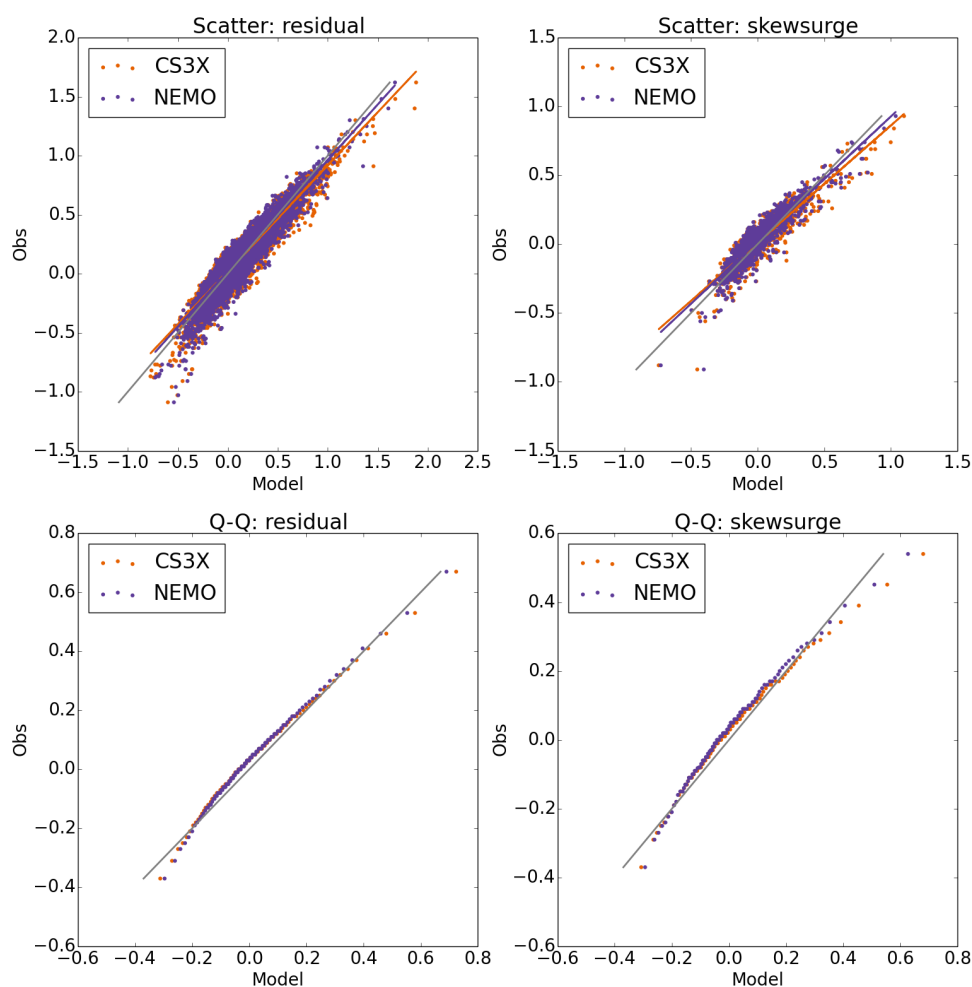
## 5.2 Error distribution

For each port, scatter plots and quantile-quantile (Q-Q) plots have been produced for both residual and skew surge. Using these plots, the ports have been roughly grouped into categories according to their behaviour.

### Non biased ports

For a number of ports, clustered mainly around approximately 53°N, there is little or no bias in either direction. This category includes Barmouth, Cromer, Heysham, Holyhead, Immingham, Llandudno, Lowestoft, Portpatrick, and Port Erin. Figure 13 shows an example for Llandudno where we see both models lie close to the 1:1 line.

#### Llandudno

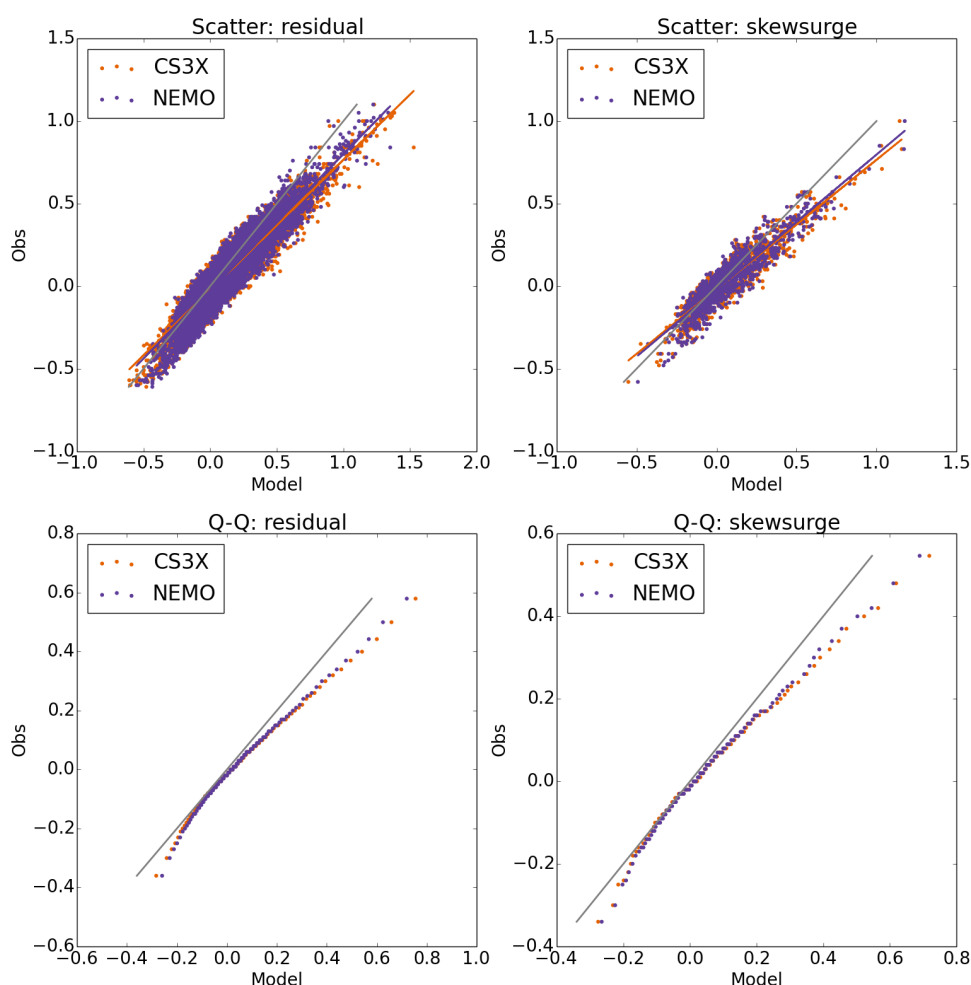


**Figure 13:** Scatter (top) and Q-Q (bottom) plots for residual (left) and skew surge (right) at Llandudno. This is representative of port type 1: small bias

## Overpredicting ports

As already mentioned in the previous section, a number of the northern ports show an overprediction bias. Generally this bias increases with positive surge height, as shown by the example of Ullapool in Figure 14. Included in this category are Aberdeen, Kinlochbervie, Lerwick, Millport, Stornoway, Tobermory, Ullapool, Wick, and Workington.

### Ullapool



**Figure 14:** Scatter (top) and Q-Q (bottom) plots for residual (left) and skew surge (right) at Ullapool. This is representative of port type 2: surge overpredicted

Flather et al. (2000) point out that there is currently an inconsistency in the handling of long-period (>1 day) constituents of the tidal residual, which leads to a systematic offset in the predicted water level at northern ports. This comes about because these frequencies are included in the harmonic analysis method used in the tidal prediction, but result from seasonal variation in meteorological forcing. Since these forcing effects drive the meteorological residual in the surge model, and are

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included as part of the tide by the harmonic analysis, this leads to ‘double-counting’ when comparing model with observations. Equally the increased error with increasing residual or skew surge may suggest that the forcing parameterisation (e.g. Charnock parameter) is set too high.

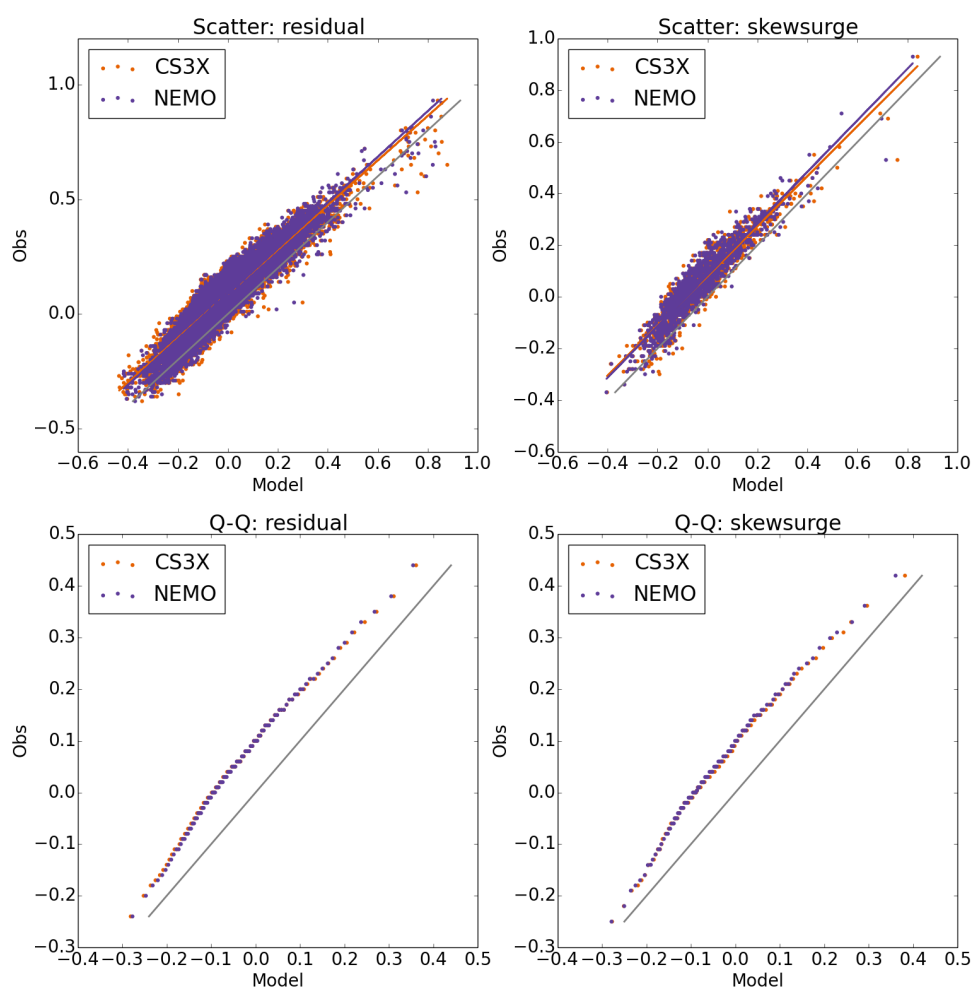
### **Underpredicting ports**

The remaining ports, which form the majority overall, tend to underpredict the surge level. The offset is more or less constant for all positive surge values. These ports may be further split into two groups according to the differences in behaviour between CS3X and NEMO-surge.

In the first group there is no significant difference between the models. This includes Bournemouth, Dover, Fishguard, Milford Haven, Mumbles, Newhaven, Newlyn, North Shields, Plymouth, St Mary’s, and Whitby. An example, for Newlyn, is shown in Figure 15.

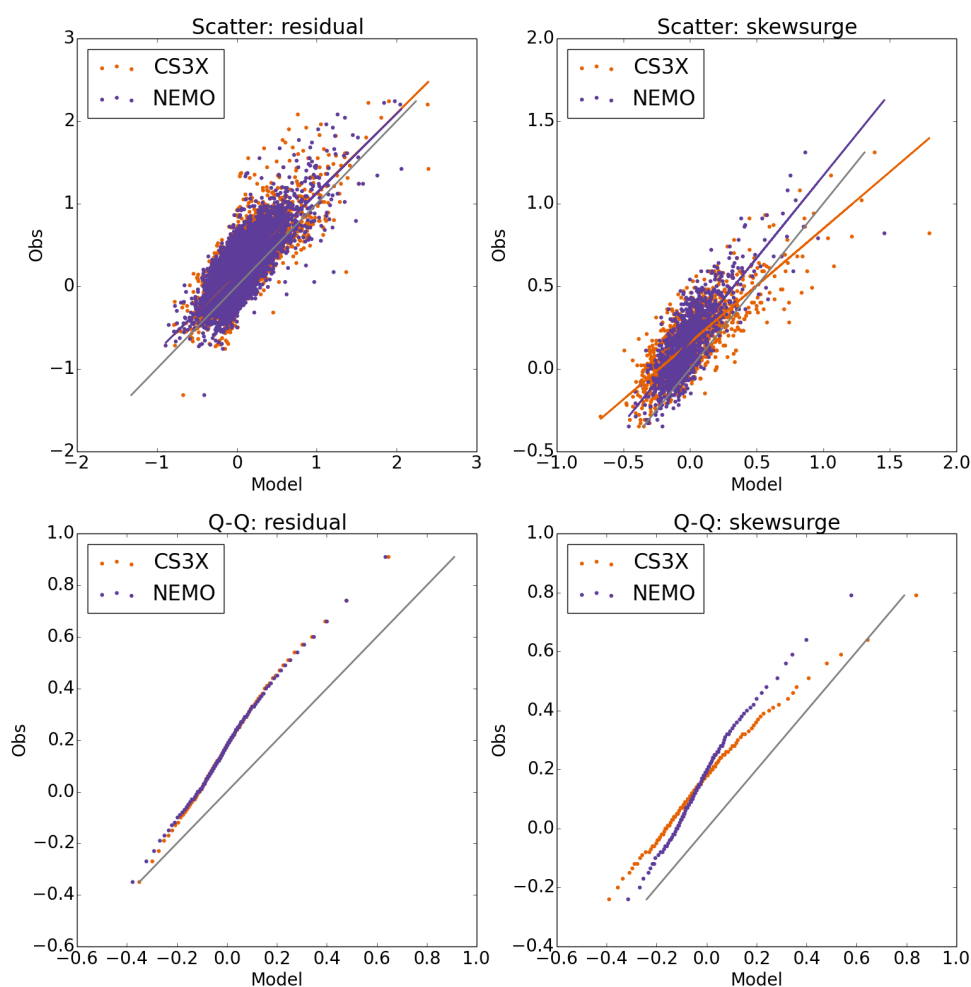
In the second group, the models show very similar behaviour for the residual, but then diverge more in the skew surge, particularly for large surges. This includes Avonmouth, Hinkley Point, Ilfracombe, Leith, Liverpool, Newport, Portsmouth, and Weymouth. Figure 16 shows an example for Newport where we see that the residual behaves similarly in both models, whereas the skew surge is significantly different with CS3X reverting closer to the observations at large surge values. The change in skew surge error at large values can be related to the difference seen between NEMO-Surge and CS3X for normalised standard deviation. Conversely, the more constant offset seen for NEMO-Surge makes the errors more predictable leading to a substantial improvement in scatter index.

## Newlyn



**Figure 15:** Scatter (top) and Q-Q (bottom) plots for residual (left) and skew surge (right) at Newlyn. This is representative of port type 3a: surge underpredicted; CS3X and NEMO-Surge similar

## Newport

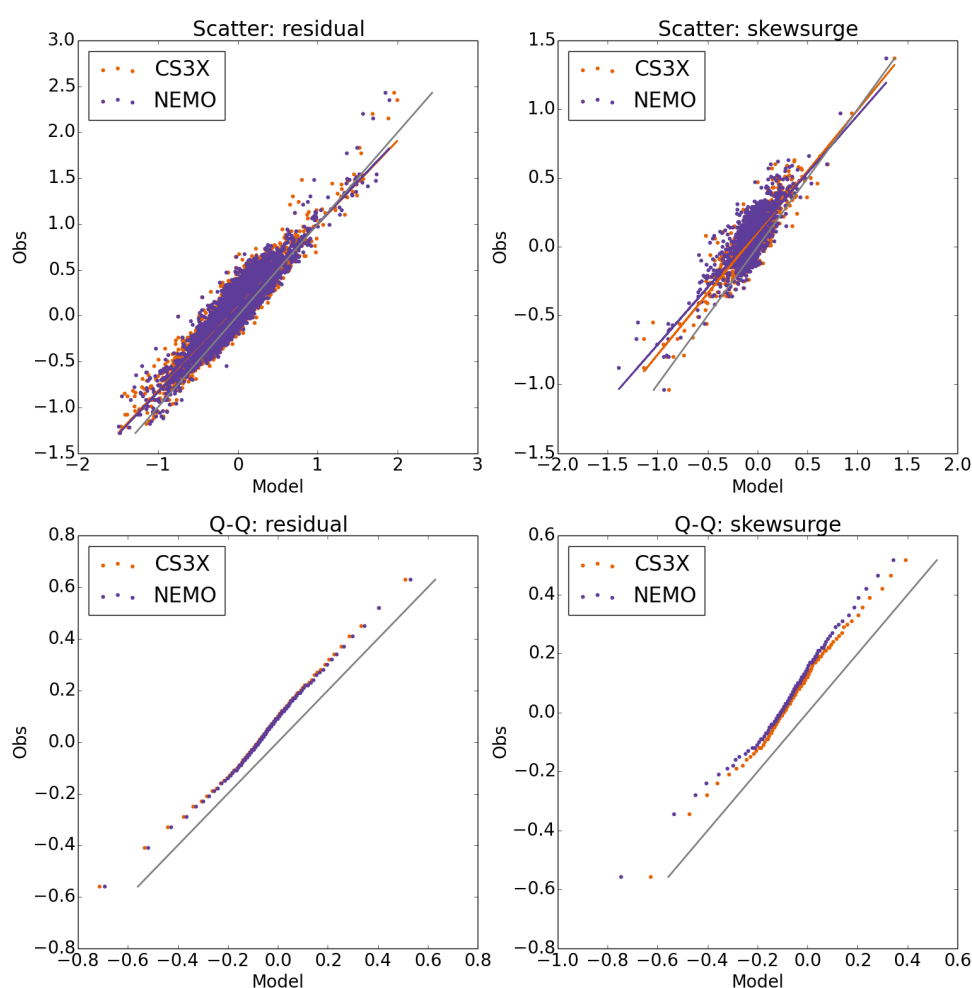


**Figure 16:** Scatter (top) and Q-Q (bottom) plots for residual (left) and skew surge (right) at Newport. This is representative of port type 3b: surge underpredicted; skew surge behaviour different between CS3X and NEMO-Surge

## Special cases

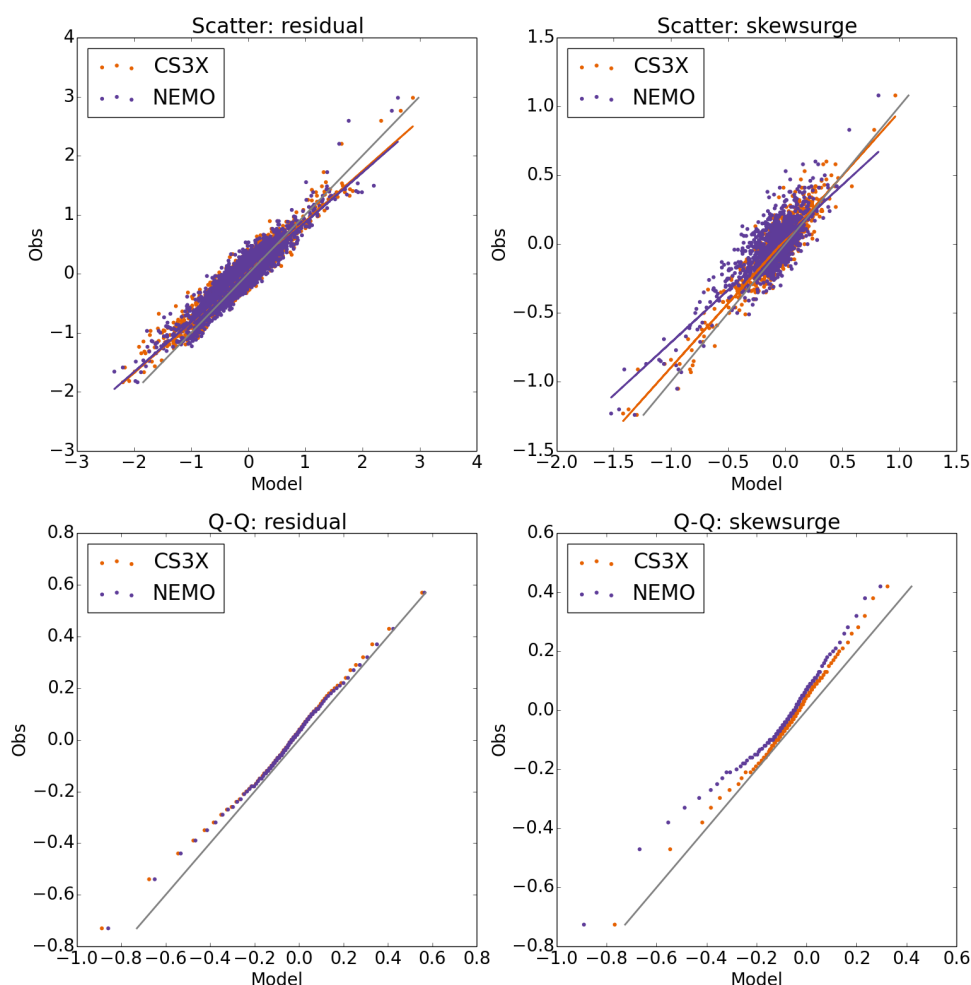
The remaining ports—Harwich and Sheerness—do not fit readily into any of these general groups. They both show a general under prediction for positive skew surge, with the bias increasing with surge size (Figures 17 and 18). At the other end of the distribution negative surges are too extreme, again with this bias dependent on surge size. The reduced skew surge performance for NEMO-Surge seen in the statistics (Tables 3 to 8) can be attributed in large part to the negative skew surges, where the bias is particularly increased compared with CS3X.

### Harwich



**Figure 17:** Scatter (top) and Q-Q (bottom) plots for residual (left) and skew surge (right) at Harwich

## Sheerness



**Figure 18:** Scatter (top) and Q-Q (bottom) plots for residual (left) and skew surge (right) at Sheerness

## 6 Discussion and conclusions

The optimal wind and pressure settings that have been selected following sensitivity tests match those already used in the operational CS3X model, which is not surprising given the work that has gone into optimising that model.

It is encouraging that the performance of NEMO-Surge is extremely similar to CS3X with both models generally performing well during the hindcast period. Following the results of this study, the NEMO-Surge configuration has been added to the Met Office operational system to run in parallel with CS3X, which will enable the forecast performance to be assessed over the 2016–17 winter season.

Although both models perform well there is clearly scope for further improvements. In particular, the patterns of errors discussed in Section 5 show some geographic clustering, implying that there may be consistent underlying processes that can be represented more correctly. By moving to a NEMO-based model these improvements should be simpler to implement due to the active development of the NEMO codebase and existing NEMO expertise within the Met Office, as well as the fact that NEMO-Surge has not required the level of manual tuning to the bathymetry that has been done with CS3X.

In the short term it is possible that using a varying Charnock parameter would be beneficial. In the most simple form this could be a time-constant 2D field generated from an offline wave model, which should be relatively easy to implement. If this is shown to have a positive impact then coupling to a wave model to provide temporally varying values could also be investigated: Staneva et al. (2016) found this added more than 30% to the surge level in parts of the German Bight. However, any benefit from coupling would need to be balanced against the subsequent increase in computing time. As well as the Charnock parameter, the use of a spatially varying bottom roughness coefficient and reference pressure level may also lead to improvements.

Looking further into the future, the Met Office is currently developing a higher resolution (1.5 km) replacement for the AMM7 configuration (which formed the basis of NEMO-Surge), so that is a potential basis for a resolution upgrade to NEMO-Surge. Additionally work is now ongoing to implement wetting and drying in NEMO which could bring improvements to the tidal predictions, particularly in areas such as the Bristol Channel which are challenging to model due to the large tidal range. It is also expected that data assimilation of sea surface altimeter data will be implemented into AMM7 in the near future, which again may bring benefits if transferred to NEMO-Surge.

In conclusion, present evidence indicates that NEMO-Surge is a viable replacement for CS3X as the UK's storm surge forecast model, and it has the potential for a wide range of model enhancements to be introduced.

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## Appendix A Statistics tables for wind tests

### A.1 Residual

#### Residual: RMS error

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	0.114	0.112	0.112	0.111	0.111	0.111	0.114	0.113	0.112
Hinkley Point	0.148	0.143	0.143	0.142	0.142	0.141	0.146	0.144	0.144
Avonmouth	0.211	0.211	0.211	0.212	0.212	0.213	0.212	0.212	0.212
Newport	0.215	0.213	0.213	0.212	0.212	0.211	0.216	0.214	0.214
Mumbles	0.082	0.076	0.076	0.075	0.075	0.075	0.080	0.078	0.078
Milford Haven	0.114	0.113	0.113	0.112	0.112	0.112	0.115	0.114	0.113
Fishguard	0.082	0.082	0.082	0.082	0.081	0.082	0.084	0.083	0.083
Barmouth	0.082	0.078	0.077	0.076	0.076	0.076	0.082	0.080	0.079
Holyhead	0.056	0.051	0.051	0.051	0.051	0.053	0.054	0.052	0.052
Llandudno	0.074	0.075	0.074	0.073	0.073	0.073	0.080	0.077	0.076
Liverpool	0.121	0.122	0.122	0.120	0.120	0.119	0.127	0.124	0.123
Heysham	0.086	0.089	0.088	0.087	0.087	0.088	0.094	0.091	0.090
Port Erin	0.056	0.056	0.056	0.055	0.054	0.055	0.062	0.059	0.058
Workington	0.106	0.103	0.104	0.105	0.106	0.110	0.104	0.103	0.104
Portpatrick	0.067	0.064	0.064	0.063	0.063	0.063	0.070	0.066	0.066
Millport	0.078	0.075	0.075	0.075	0.076	0.078	0.078	0.076	0.076
Tobermory	0.070	0.060	0.061	0.061	0.062	0.065	0.062	0.061	0.061
Ullapool	0.089	0.079	0.080	0.082	0.084	0.088	0.076	0.077	0.078
Stornoway	0.067	0.064	0.064	0.065	0.066	0.068	0.063	0.063	0.064
Kinlochbervie	0.083	0.073	0.073	0.075	0.077	0.081	0.070	0.071	0.072
Lerwick	0.058	0.058	0.058	0.058	0.058	0.059	0.058	0.058	0.058
Aberdeen	0.080	0.078	0.078	0.079	0.080	0.083	0.077	0.077	0.077
Leith	0.080	0.079	0.079	0.080	0.080	0.083	0.080	0.079	0.079
North Shields	0.060	0.058	0.057	0.057	0.058	0.061	0.062	0.059	0.059
Whitby	0.123	0.123	0.123	0.122	0.122	0.122	0.128	0.125	0.124
Immingham	0.125	0.131	0.132	0.135	0.138	0.144	0.129	0.130	0.130
Cromer	0.090	0.085	0.085	0.087	0.089	0.095	0.088	0.085	0.085
Lowestoft	0.072	0.065	0.065	0.065	0.067	0.073	0.072	0.067	0.066
Harwich	0.102	0.097	0.097	0.097	0.099	0.104	0.101	0.097	0.097
Sheerness	0.096	0.096	0.097	0.100	0.104	0.112	0.096	0.095	0.095
Jersey	0.114	0.111	0.111	0.111	0.110	0.110	0.113	0.112	0.112
St Marys	0.083	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082
Newlyn	0.096	0.094	0.094	0.094	0.094	0.095	0.094	0.094	0.094
Plymouth	0.081	0.080	0.080	0.079	0.079	0.079	0.081	0.080	0.080
Weymouth	0.053	0.051	0.051	0.051	0.051	0.052	0.053	0.052	0.052
Bournemouth	0.071	0.068	0.068	0.068	0.068	0.069	0.069	0.068	0.068
Portsmouth	0.087	0.084	0.083	0.083	0.083	0.083	0.086	0.084	0.084
Newhaven	0.078	0.076	0.076	0.075	0.075	0.075	0.079	0.077	0.077
Dover	0.116	0.113	0.113	0.112	0.113	0.114	0.115	0.113	0.113
Mean	0.094	0.092	0.091	0.092	0.092	0.094	0.094	0.092	0.092

**Table A1:** RMS error for residual water level for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Residual: Mean error

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	-0.090	-0.091	-0.091	-0.090	-0.090	<b>-0.090</b>	<b>-0.092</b>	-0.091	-0.091
Hinkley Point	<b>-0.044</b>	-0.047	-0.046	-0.046	-0.046	-0.045	<b>-0.048</b>	-0.047	-0.047
Avonmouth	<b>-0.034</b>	<b>-0.032</b>	<b>-0.032</b>	<b>-0.032</b>	<b>-0.032</b>	<b>-0.032</b>	<b>-0.033</b>	<b>-0.033</b>	<b>-0.033</b>
Newport	<b>-0.149</b>	-0.152	-0.152	-0.151	-0.151	-0.150	<b>-0.154</b>	-0.153	-0.153
Mumbles	<b>-0.017</b>	-0.020	-0.020	-0.020	-0.019	-0.019	<b>-0.021</b>	-0.020	-0.020
Milford Haven	<b>-0.099</b>	<b>-0.098</b>	<b>-0.098</b>	<b>-0.098</b>	<b>-0.098</b>	<b>-0.097</b>	<b>-0.098</b>	<b>-0.098</b>	<b>-0.098</b>
Fishguard	-0.062	-0.063	-0.063	-0.062	-0.062	<b>-0.062</b>	<b>-0.063</b>	-0.063	-0.063
Barmouth	0.002	-0.005	-0.005	-0.004	-0.003	<b>-0.001</b>	<b>-0.009</b>	-0.007	-0.007
Holyhead	-0.005	-0.007	-0.007	-0.006	-0.006	<b>-0.004</b>	<b>-0.009</b>	-0.008	-0.008
Llandudno	-0.012	-0.016	-0.015	-0.014	-0.013	<b>-0.012</b>	<b>-0.018</b>	-0.017	-0.016
Liverpool	<b>-0.084</b>	-0.089	-0.089	-0.087	-0.086	-0.084	<b>-0.093</b>	-0.091	-0.090
Heysham	0.003	<b>-0.002</b>	<b>-0.002</b>	<b>-0.000</b>	<b>0.001</b>	0.004	<b>-0.007</b>	-0.004	-0.004
Port Erin	-0.022	-0.025	-0.024	-0.024	-0.023	<b>-0.022</b>	<b>-0.027</b>	-0.026	-0.025
Workington	0.075	<b>0.071</b>	<b>0.072</b>	<b>0.074</b>	0.075	<b>0.078</b>	<b>0.067</b>	<b>0.069</b>	<b>0.070</b>
Portpatrick	<b>-0.005</b>	-0.012	-0.012	-0.011	-0.010	-0.009	<b>-0.015</b>	-0.013	-0.013
Millport	<b>0.017</b>	<b>0.011</b>	<b>0.012</b>	<b>0.013</b>	<b>0.014</b>	<b>0.016</b>	<b>0.008</b>	<b>0.009</b>	<b>0.010</b>
Tobermory	0.010	<b>0.008</b>	<b>0.009</b>	<b>0.010</b>	0.011	<b>0.014</b>	<b>0.004</b>	<b>0.006</b>	<b>0.007</b>
Ullapool	0.042	<b>0.036</b>	<b>0.037</b>	<b>0.039</b>	<b>0.040</b>	<b>0.043</b>	<b>0.031</b>	<b>0.034</b>	<b>0.034</b>
Stornoway	0.011	<b>0.008</b>	<b>0.009</b>	<b>0.010</b>	0.011	<b>0.013</b>	<b>0.004</b>	<b>0.006</b>	<b>0.007</b>
Kinlochbervie	<b>0.032</b>	<b>0.025</b>	<b>0.026</b>	<b>0.028</b>	<b>0.029</b>	<b>0.032</b>	<b>0.019</b>	<b>0.022</b>	<b>0.023</b>
Lerwick	0.014	<b>0.011</b>	<b>0.012</b>	<b>0.013</b>	<b>0.014</b>	<b>0.015</b>	<b>0.009</b>	<b>0.010</b>	<b>0.011</b>
Aberdeen	0.051	<b>0.050</b>	<b>0.050</b>	0.052	0.053	<b>0.055</b>	<b>0.047</b>	<b>0.048</b>	<b>0.049</b>
Leith	<b>-0.010</b>	-0.012	-0.012	-0.011	-0.011	-0.010	<b>-0.014</b>	-0.013	-0.012
North Shields	0.000	<b>-0.000</b>	<b>0.000</b>	0.001	0.002	<b>0.003</b>	-0.002	-0.001	-0.000
Whitby	-0.102	-0.102	<b>-0.102</b>	<b>-0.101</b>	<b>-0.101</b>	<b>-0.099</b>	<b>-0.104</b>	-0.103	-0.102
Immingham	<b>0.073</b>	<b>0.072</b>	<b>0.072</b>	<b>0.072</b>	<b>0.072</b>	<b>0.072</b>	<b>0.072</b>	<b>0.072</b>	<b>0.073</b>
Cromer	<b>-0.019</b>	<b>-0.016</b>	<b>-0.016</b>	<b>-0.016</b>	<b>-0.016</b>	<b>-0.015</b>	<b>-0.016</b>	<b>-0.016</b>	<b>-0.016</b>
Lowestoft	<b>-0.026</b>	<b>-0.023</b>	<b>-0.023</b>	<b>-0.022</b>	<b>-0.022</b>	<b>-0.022</b>	<b>-0.024</b>	<b>-0.023</b>	<b>-0.023</b>
Harwich	<b>-0.053</b>	<b>-0.051</b>	<b>-0.051</b>	<b>-0.051</b>	<b>-0.051</b>	<b>-0.051</b>	<b>-0.051</b>	<b>-0.051</b>	<b>-0.051</b>
Sheerness	<b>-0.021</b>	<b>-0.018</b>	<b>-0.018</b>	<b>-0.018</b>	<b>-0.018</b>	<b>-0.019</b>	<b>-0.016</b>	<b>-0.017</b>	<b>-0.017</b>
Jersey	-0.069	-0.070	-0.070	-0.070	-0.070	<b>-0.069</b>	<b>-0.070</b>	-0.070	-0.070
St Marys	<b>-0.062</b>	<b>-0.060</b>	<b>-0.060</b>	<b>-0.061</b>	<b>-0.061</b>	<b>-0.061</b>	<b>-0.059</b>	<b>-0.060</b>	<b>-0.060</b>
Newlyn	<b>-0.082</b>	<b>-0.081</b>	<b>-0.081</b>	<b>-0.081</b>	<b>-0.082</b>	<b>-0.082</b>	<b>-0.080</b>	<b>-0.080</b>	<b>-0.080</b>
Plymouth	<b>-0.063</b>	<b>-0.062</b>	<b>-0.062</b>	<b>-0.062</b>	<b>-0.062</b>	<b>-0.062</b>	<b>-0.061</b>	<b>-0.061</b>	<b>-0.061</b>
Weymouth	<b>-0.009</b>	<b>-0.008</b>	<b>-0.008</b>	<b>-0.008</b>	<b>-0.008</b>	<b>-0.008</b>	<b>-0.008</b>	<b>-0.008</b>	<b>-0.008</b>
Bournemouth	<b>-0.052</b>	<b>-0.051</b>	<b>-0.051</b>	<b>-0.051</b>	<b>-0.051</b>	<b>-0.051</b>	<b>-0.050</b>	<b>-0.050</b>	<b>-0.050</b>
Portsmouth	<b>-0.058</b>	<b>-0.057</b>	<b>-0.057</b>	<b>-0.057</b>	<b>-0.057</b>	<b>-0.057</b>	<b>-0.058</b>	<b>-0.057</b>	<b>-0.057</b>
Newhaven	-0.050	-0.050	-0.050	<b>-0.049</b>	<b>-0.049</b>	<b>-0.048</b>	<b>-0.051</b>	-0.050	-0.050
Dover	<b>-0.078</b>	<b>-0.077</b>	<b>-0.077</b>	<b>-0.077</b>	<b>-0.077</b>	<b>-0.076</b>	<b>-0.078</b>	<b>-0.077</b>	<b>-0.077</b>
Mean	-0.027	-0.028	-0.028	-0.027	-0.027	<b>-0.026</b>	<b>-0.030</b>	-0.029	-0.029

**Table A2:** Mean error for residual water level for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The **green** (**pink**) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Residual: Max |error|

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	0.391	<b>0.363</b>	<b>0.358</b>	<b>0.355</b>	<b>0.353</b>	<b>0.360</b>	<b>0.394</b>	<b>0.375</b>	<b>0.370</b>
Hinkley Point	<b>0.660</b>	0.676	0.678	0.682	0.685	<b>0.691</b>	0.679	0.669	0.669
Avonmouth	<b>0.853</b>	0.921	0.920	0.917	0.915	0.910	<b>0.934</b>	0.930	0.932
Newport	0.918	0.964	0.955	0.932	<b>0.913</b>	<b>0.891</b>	<b>1.020</b>	0.987	0.978
Mumbles	<b>0.452</b>	<b>0.399</b>	<b>0.393</b>	<b>0.378</b>	<b>0.366</b>	<b>0.384</b>	<b>0.436</b>	<b>0.413</b>	<b>0.407</b>
Milford Haven	0.328	<b>0.313</b>	<b>0.315</b>	<b>0.320</b>	<b>0.324</b>	0.332	<b>0.332</b>	<b>0.308</b>	<b>0.307</b>
Fishguard	0.268	0.276	0.270	<b>0.258</b>	<b>0.261</b>	<b>0.266</b>	<b>0.308</b>	0.284	0.274
Barmouth	<b>0.534</b>	<b>0.487</b>	<b>0.486</b>	<b>0.486</b>	<b>0.485</b>	<b>0.484</b>	<b>0.495</b>	<b>0.490</b>	<b>0.491</b>
Holyhead	<b>0.325</b>	<b>0.229</b>	<b>0.237</b>	<b>0.259</b>	<b>0.276</b>	<b>0.310</b>	<b>0.219</b>	<b>0.213</b>	<b>0.224</b>
Llandudno	0.526	0.610	0.600	0.573	0.551	<b>0.509</b>	<b>0.680</b>	0.639	0.628
Liverpool	<b>0.470</b>	0.574	0.576	0.580	0.584	0.591	<b>0.601</b>	0.566	0.566
Heysham	<b>0.469</b>	0.484	0.487	0.495	0.501	0.513	<b>0.592</b>	0.490	0.480
Port Erin	0.273	<b>0.236</b>	<b>0.244</b>	<b>0.266</b>	0.284	<b>0.319</b>	0.275	<b>0.228</b>	<b>0.236</b>
Workington	<b>0.659</b>	<b>0.454</b>	<b>0.470</b>	<b>0.511</b>	<b>0.544</b>	<b>0.610</b>	<b>0.503</b>	<b>0.467</b>	<b>0.456</b>
Portpatrick	<b>0.466</b>	<b>0.302</b>	<b>0.307</b>	<b>0.320</b>	<b>0.331</b>	<b>0.351</b>	<b>0.355</b>	<b>0.312</b>	<b>0.302</b>
Millport	<b>0.662</b>	<b>0.455</b>	<b>0.470</b>	<b>0.505</b>	<b>0.534</b>	<b>0.590</b>	<b>0.407</b>	<b>0.444</b>	<b>0.468</b>
Tobermory	<b>0.659</b>	<b>0.427</b>	<b>0.417</b>	<b>0.439</b>	<b>0.480</b>	<b>0.563</b>	<b>0.484</b>	<b>0.446</b>	<b>0.433</b>
Ullapool	<b>0.688</b>	<b>0.432</b>	<b>0.446</b>	<b>0.482</b>	<b>0.511</b>	<b>0.567</b>	<b>0.365</b>	<b>0.420</b>	<b>0.445</b>
Stornoway	<b>0.367</b>	<b>0.287</b>	<b>0.294</b>	<b>0.309</b>	<b>0.321</b>	<b>0.345</b>	<b>0.255</b>	<b>0.280</b>	<b>0.290</b>
Kinlochbervie	<b>0.464</b>	<b>0.334</b>	<b>0.345</b>	<b>0.371</b>	<b>0.393</b>	<b>0.454</b>	<b>0.290</b>	<b>0.329</b>	<b>0.349</b>
Lerwick	0.261	<b>0.259</b>	0.263	0.272	0.279	<b>0.294</b>	<b>0.245</b>	<b>0.259</b>	0.267
Aberdeen	0.360	<b>0.330</b>	<b>0.324</b>	<b>0.309</b>	<b>0.322</b>	<b>0.362</b>	<b>0.357</b>	<b>0.334</b>	<b>0.329</b>
Leith	<b>0.563</b>	0.672	0.688	0.728	0.761	<b>0.825</b>	0.593	0.654	0.680
North Shields	<b>0.319</b>	0.422	0.410	0.379	0.354	0.353	<b>0.477</b>	0.430	0.407
Whitby	<b>0.597</b>	0.698	0.707	0.728	0.746	<b>0.780</b>	0.658	0.691	0.706
Immingham	<b>0.675</b>	1.278	1.296	1.341	1.378	<b>1.450</b>	1.175	1.242	1.265
Cromer	1.048	<b>0.952</b>	<b>0.976</b>	<b>1.037</b>	1.085	<b>1.179</b>	<b>0.830</b>	<b>0.923</b>	<b>0.961</b>
Lowestoft	<b>0.499</b>	0.653	0.626	0.560	0.511	0.514	<b>0.776</b>	0.675	0.629
Harwich	<b>0.564</b>	0.775	0.749	0.685	0.633	0.765	<b>0.894</b>	0.796	0.751
Sheerness	0.886	0.949	0.927	<b>0.873</b>	<b>0.831</b>	0.949	<b>1.053</b>	0.967	0.928
Jersey	0.374	<b>0.364</b>	<b>0.367</b>	0.374	0.379	<b>0.390</b>	<b>0.367</b>	<b>0.363</b>	<b>0.363</b>
St Marys	<b>0.283</b>	<b>0.268</b>	<b>0.270</b>	<b>0.273</b>	<b>0.276</b>	<b>0.282</b>	<b>0.261</b>	<b>0.264</b>	<b>0.266</b>
Newlyn	0.264	<b>0.256</b>	<b>0.257</b>	<b>0.260</b>	<b>0.262</b>	<b>0.266</b>	<b>0.255</b>	<b>0.250</b>	<b>0.250</b>
Plymouth	<b>0.270</b>	0.287	0.286	0.281	0.278	0.271	<b>0.297</b>	0.290	0.288
Weymouth	0.316	<b>0.303</b>	<b>0.307</b>	0.316	0.324	<b>0.339</b>	<b>0.280</b>	<b>0.294</b>	<b>0.298</b>
Bournemouth	0.235	<b>0.230</b>	<b>0.231</b>	<b>0.235</b>	0.237	<b>0.242</b>	0.239	<b>0.226</b>	<b>0.226</b>
Portsmouth	<b>0.640</b>	<b>0.544</b>	<b>0.541</b>	<b>0.534</b>	<b>0.529</b>	<b>0.518</b>	<b>0.560</b>	<b>0.552</b>	<b>0.550</b>
Newhaven	<b>0.313</b>	0.449	0.448	0.447	0.445	0.441	<b>0.453</b>	0.451	0.451
Dover	<b>0.665</b>	0.683	0.682	0.677	0.674	0.667	<b>0.694</b>	0.686	0.684
Mean	<b>0.502</b>	0.502	0.503	0.506	0.511	<b>0.537</b>	0.515	0.504	0.503

**Table A3:** Max |error| for residual water level for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Residual: Scatter index

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	<b>0.417</b>	<b>0.390</b>	<b>0.389</b>	<b>0.387</b>	<b>0.387</b>	<b>0.389</b>	<b>0.406</b>	<b>0.397</b>	<b>0.396</b>
Hinkley Point	<b>0.650</b>	<b>0.623</b>	<b>0.622</b>	<b>0.619</b>	<b>0.617</b>	<b>0.616</b>	<b>0.636</b>	<b>0.628</b>	<b>0.627</b>
Avonmouth	<b>0.787</b>	0.791	0.791	0.792	0.793	<b>0.796</b>	0.793	0.792	0.792
Newport	<b>0.669</b>	<b>0.643</b>	<b>0.642</b>	<b>0.640</b>	<b>0.640</b>	<b>0.640</b>	<b>0.654</b>	<b>0.647</b>	<b>0.646</b>
Mumbles	<b>0.446</b>	<b>0.408</b>	<b>0.406</b>	<b>0.402</b>	<b>0.401</b>	<b>0.400</b>	<b>0.429</b>	<b>0.417</b>	<b>0.416</b>
Milford Haven	0.333	<b>0.327</b>	<b>0.325</b>	<b>0.322</b>	<b>0.322</b>	<b>0.324</b>	<b>0.348</b>	0.336	0.336
Fishguard	0.331	<b>0.322</b>	<b>0.321</b>	<b>0.320</b>	<b>0.321</b>	<b>0.326</b>	<b>0.338</b>	<b>0.329</b>	<b>0.328</b>
Barmouth	0.386	<b>0.367</b>	<b>0.365</b>	<b>0.361</b>	<b>0.360</b>	<b>0.361</b>	<b>0.388</b>	<b>0.375</b>	<b>0.374</b>
Holyhead	<b>0.302</b>	<b>0.276</b>	<b>0.275</b>	<b>0.276</b>	<b>0.278</b>	<b>0.288</b>	<b>0.293</b>	<b>0.282</b>	<b>0.281</b>
Llandudno	0.372	<b>0.371</b>	<b>0.369</b>	<b>0.366</b>	<b>0.365</b>	<b>0.367</b>	<b>0.394</b>	0.380	0.379
Liverpool	0.407	<b>0.390</b>	<b>0.389</b>	<b>0.387</b>	<b>0.388</b>	<b>0.393</b>	<b>0.407</b>	<b>0.396</b>	<b>0.393</b>
Heysham	<b>0.362</b>	0.373	0.371	0.368	0.367	0.371	<b>0.397</b>	0.382	0.379
Port Erin	0.258	<b>0.256</b>	<b>0.254</b>	<b>0.250</b>	<b>0.250</b>	<b>0.255</b>	<b>0.284</b>	0.267	0.265
Workington	0.311	<b>0.311</b>	<b>0.309</b>	<b>0.308</b>	<b>0.310</b>	0.320	<b>0.334</b>	0.319	0.318
Portpatrick	0.318	<b>0.301</b>	<b>0.299</b>	<b>0.296</b>	<b>0.295</b>	<b>0.297</b>	<b>0.324</b>	<b>0.309</b>	<b>0.307</b>
Millport	0.335	<b>0.328</b>	<b>0.327</b>	<b>0.327</b>	<b>0.329</b>	0.337	<b>0.344</b>	<b>0.333</b>	<b>0.333</b>
Tobermory	<b>0.344</b>	<b>0.296</b>	<b>0.297</b>	<b>0.300</b>	<b>0.304</b>	<b>0.315</b>	<b>0.304</b>	<b>0.298</b>	<b>0.299</b>
Ullapool	<b>0.400</b>	<b>0.360</b>	<b>0.362</b>	<b>0.369</b>	<b>0.376</b>	<b>0.391</b>	<b>0.354</b>	<b>0.357</b>	<b>0.358</b>
Stornoway	0.366	<b>0.350</b>	<b>0.351</b>	<b>0.354</b>	<b>0.358</b>	<b>0.367</b>	<b>0.349</b>	<b>0.349</b>	<b>0.350</b>
Kinlochbervie	<b>0.374</b>	<b>0.333</b>	<b>0.335</b>	<b>0.342</b>	<b>0.348</b>	<b>0.364</b>	<b>0.330</b>	<b>0.330</b>	<b>0.332</b>
Lerwick	0.381	<b>0.381</b>	<b>0.381</b>	0.381	0.382	0.385	<b>0.385</b>	0.382	0.382
Aberdeen	0.393	<b>0.380</b>	<b>0.380</b>	<b>0.383</b>	<b>0.387</b>	<b>0.401</b>	<b>0.389</b>	<b>0.381</b>	<b>0.381</b>
Leith	0.514	<b>0.505</b>	<b>0.505</b>	<b>0.510</b>	0.515	<b>0.532</b>	<b>0.513</b>	<b>0.506</b>	<b>0.507</b>
North Shields	0.381	<b>0.364</b>	<b>0.362</b>	<b>0.361</b>	<b>0.365</b>	0.381	<b>0.392</b>	<b>0.372</b>	<b>0.369</b>
Whitby	0.394	0.396	0.394	<b>0.393</b>	0.395	0.408	<b>0.424</b>	0.404	0.401
Immingham	<b>0.501</b>	0.544	0.549	0.564	0.579	<b>0.615</b>	0.528	0.532	0.533
Cromer	0.407	<b>0.387</b>	<b>0.388</b>	<b>0.395</b>	<b>0.406</b>	<b>0.434</b>	<b>0.403</b>	<b>0.390</b>	<b>0.390</b>
Lowestoft	0.314	<b>0.287</b>	<b>0.286</b>	<b>0.289</b>	<b>0.297</b>	<b>0.326</b>	0.319	<b>0.294</b>	<b>0.290</b>
Harwich	0.402	<b>0.380</b>	<b>0.380</b>	<b>0.385</b>	<b>0.392</b>	<b>0.417</b>	<b>0.401</b>	<b>0.383</b>	<b>0.381</b>
Sheerness	0.398	0.404	0.407	0.420	0.435	<b>0.473</b>	0.405	<b>0.398</b>	0.398
Jersey	<b>0.531</b>	<b>0.507</b>	<b>0.506</b>	<b>0.504</b>	<b>0.504</b>	<b>0.504</b>	<b>0.518</b>	<b>0.512</b>	<b>0.512</b>
St Marys	0.410	0.410	<b>0.409</b>	<b>0.407</b>	<b>0.406</b>	<b>0.405</b>	<b>0.421</b>	0.415	0.414
Newlyn	0.338	<b>0.333</b>	<b>0.332</b>	<b>0.329</b>	<b>0.328</b>	<b>0.327</b>	<b>0.350</b>	0.342	0.342
Plymouth	0.358	<b>0.355</b>	<b>0.353</b>	<b>0.349</b>	<b>0.347</b>	<b>0.345</b>	<b>0.374</b>	0.363	0.363
Weymouth	0.376	<b>0.363</b>	<b>0.362</b>	<b>0.361</b>	<b>0.363</b>	<b>0.369</b>	<b>0.377</b>	<b>0.368</b>	<b>0.368</b>
Bournemouth	0.418	<b>0.406</b>	<b>0.404</b>	<b>0.403</b>	<b>0.403</b>	<b>0.407</b>	<b>0.423</b>	<b>0.412</b>	<b>0.411</b>
Portsmouth	<b>0.449</b>	<b>0.421</b>	<b>0.420</b>	<b>0.417</b>	<b>0.417</b>	<b>0.421</b>	<b>0.440</b>	<b>0.428</b>	<b>0.426</b>
Newhaven	<b>0.426</b>	<b>0.402</b>	<b>0.401</b>	<b>0.399</b>	<b>0.400</b>	<b>0.406</b>	<b>0.422</b>	<b>0.409</b>	<b>0.408</b>
Dover	<b>0.473</b>	<b>0.453</b>	<b>0.452</b>	<b>0.452</b>	<b>0.455</b>	<b>0.467</b>	<b>0.468</b>	<b>0.455</b>	<b>0.453</b>
Mean	0.411	<b>0.397</b>	<b>0.397</b>	<b>0.397</b>	<b>0.400</b>	<b>0.409</b>	<b>0.412</b>	<b>0.402</b>	<b>0.401</b>

**Table A4:** Scatter index for residual water level for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The **green** (**pink**) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).



### Residual: Normalised standard deviation

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	0.960	0.890	0.897	0.914	0.929	0.958	0.843	0.868	0.872
Hinkley Point	0.790	0.716	0.722	0.739	0.753	0.780	0.672	0.695	0.700
Avonmouth	0.578	<b>0.623</b>	<b>0.629</b>	<b>0.644</b>	<b>0.655</b>	<b>0.679</b>	<b>0.583</b>	<b>0.602</b>	<b>0.605</b>
Newport	0.744	0.723	0.729	<b>0.747</b>	<b>0.761</b>	<b>0.790</b>	0.676	0.700	0.704
Mumbles	0.966	0.858	0.865	0.884	0.899	0.929	0.809	0.835	0.839
Milford Haven	0.948	0.892	0.899	0.917	0.931	<b>0.959</b>	0.845	0.869	0.873
Fishguard	1.000	0.929	0.936	0.954	0.968	0.996	0.883	0.907	0.912
Barmouth	0.972	0.863	0.872	0.893	0.910	0.944	0.807	0.837	0.842
Holyhead	1.037	0.954	<b>0.963</b>	<b>0.985</b>	<b>1.003</b>	1.038	0.898	0.929	0.936
Llandudno	0.995	0.897	0.906	0.928	0.946	0.982	0.842	0.874	0.882
Liverpool	1.003	0.893	0.903	0.928	0.948	0.988	0.832	0.867	0.876
Heysham	0.996	0.895	0.906	0.933	0.955	<b>0.997</b>	0.827	0.866	0.875
Port Erin	0.991	0.933	0.942	0.964	0.982	1.018	0.876	0.908	0.915
Workington	1.018	0.934	0.945	0.973	<b>0.997</b>	1.042	0.860	0.901	0.911
Portpatrick	1.028	0.913	0.921	0.943	0.961	<b>0.995</b>	0.856	0.888	0.895
Millport	1.050	0.940	0.950	<b>0.974</b>	<b>0.994</b>	<b>1.032</b>	0.877	0.912	0.920
Tobermory	1.145	<b>0.980</b>	<b>0.989</b>	<b>1.009</b>	<b>1.026</b>	<b>1.059</b>	<b>0.927</b>	<b>0.958</b>	<b>0.965</b>
Ullapool	1.127	<b>1.023</b>	<b>1.031</b>	<b>1.052</b>	<b>1.069</b>	<b>1.103</b>	<b>0.969</b>	<b>1.001</b>	<b>1.009</b>
Stornoway	1.070	<b>1.001</b>	<b>1.007</b>	<b>1.022</b>	<b>1.034</b>	<b>1.057</b>	<b>0.964</b>	<b>0.986</b>	<b>0.992</b>
Kinlochbervie	1.124	<b>1.018</b>	<b>1.026</b>	<b>1.048</b>	<b>1.066</b>	<b>1.100</b>	<b>0.964</b>	<b>0.996</b>	<b>1.004</b>
Lerwick	0.991	0.963	0.964	0.969	0.973	0.982	0.954	0.961	0.964
Aberdeen	0.976	0.973	<b>0.981</b>	<b>1.000</b>	<b>1.015</b>	1.047	0.934	0.961	0.970
Leith	0.959	0.943	0.952	<b>0.976</b>	<b>0.996</b>	<b>1.037</b>	0.896	0.928	0.942
North Shields	0.930	0.905	0.916	<b>0.945</b>	<b>0.969</b>	<b>1.017</b>	0.847	0.885	0.900
Whitby	0.900	0.870	0.883	<b>0.914</b>	<b>0.940</b>	<b>0.991</b>	0.804	0.846	0.862
Immingham	0.966	0.931	0.948	<b>0.990</b>	<b>1.025</b>	1.093	0.834	0.893	0.912
Cromer	1.018	0.921	0.937	0.979	<b>1.012</b>	1.078	0.821	0.880	0.897
Lowestoft	1.014	0.915	0.932	0.973	<b>1.006</b>	1.072	0.816	0.875	0.891
Harwich	0.981	0.894	0.911	0.951	<b>0.985</b>	1.050	0.796	0.854	0.871
Sheerness	1.051	<b>0.955</b>	<b>0.973</b>	<b>1.019</b>	1.056	1.128	0.840	0.905	0.921
Jersey	0.855	0.804	0.810	0.824	0.836	<b>0.858</b>	0.766	0.785	0.788
St Marys	0.955	0.918	0.921	0.928	0.934	0.946	0.897	0.906	0.907
Newlyn	0.931	0.888	0.892	0.902	0.911	0.928	0.858	0.872	0.872
Plymouth	0.913	0.866	0.870	0.881	0.889	0.907	0.836	0.850	0.852
Weymouth	0.970	0.906	0.912	0.928	0.941	0.967	0.867	0.888	0.892
Bournemouth	0.962	0.920	0.925	0.939	0.951	<b>0.975</b>	0.883	0.901	0.904
Portsmouth	0.905	0.856	0.863	0.882	0.897	<b>0.927</b>	0.815	0.839	0.846
Newhaven	0.932	0.878	0.886	0.907	0.925	<b>0.960</b>	0.830	0.858	0.867
Dover	0.899	0.833	0.845	0.874	0.899	<b>0.947</b>	0.762	0.803	0.815
Mean	0.965	0.898	0.907	0.929	0.947	<b>0.983</b>	0.843	0.874	0.882

**Table A5:** Normalised STD for residual water level for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Residual: Correlation

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	<b>0.910</b>	<b>0.921</b>	<b>0.922</b>	<b>0.922</b>	<b>0.922</b>	<b>0.922</b>	<b>0.917</b>	<b>0.919</b>	<b>0.920</b>
Hinkley Point	<b>0.760</b>	<b>0.785</b>	<b>0.786</b>	<b>0.787</b>	<b>0.787</b>	<b>0.788</b>	<b>0.779</b>	<b>0.783</b>	<b>0.784</b>
Avonmouth	<b>0.618</b>	0.612	0.612	0.611	0.611	<b>0.609</b>	0.610	0.611	0.610
Newport	<b>0.743</b>	<b>0.767</b>	<b>0.767</b>	<b>0.768</b>	<b>0.769</b>	<b>0.769</b>	<b>0.762</b>	<b>0.765</b>	<b>0.765</b>
Mumbles	<b>0.898</b>	<b>0.915</b>	<b>0.915</b>	<b>0.916</b>	<b>0.916</b>	<b>0.917</b>	<b>0.909</b>	<b>0.912</b>	<b>0.912</b>
Milford Haven	0.943	<b>0.947</b>	<b>0.947</b>	<b>0.947</b>	<b>0.947</b>	<b>0.946</b>	<b>0.942</b>	<b>0.945</b>	<b>0.945</b>
Fishguard	0.945	<b>0.947</b>	<b>0.947</b>	<b>0.947</b>	<b>0.947</b>	<b>0.947</b>	<b>0.943</b>	0.945	0.945
Barmouth	<b>0.924</b>	<b>0.933</b>	<b>0.933</b>	<b>0.933</b>	<b>0.933</b>	<b>0.933</b>	<b>0.930</b>	<b>0.932</b>	<b>0.932</b>
Holyhead	<b>0.957</b>	<b>0.961</b>	<b>0.961</b>	<b>0.961</b>	<b>0.961</b>	<b>0.961</b>	<b>0.958</b>	<b>0.960</b>	<b>0.960</b>
Llandudno	0.930	0.929	0.930	<b>0.931</b>	<b>0.931</b>	<b>0.932</b>	<b>0.923</b>	0.926	0.927
Liverpool	0.918	<b>0.921</b>	<b>0.921</b>	<b>0.922</b>	<b>0.922</b>	<b>0.922</b>	<b>0.917</b>	<b>0.920</b>	<b>0.920</b>
Heysham	<b>0.934</b>	0.928	0.929	0.930	0.930	0.931	<b>0.923</b>	0.926	0.927
Port Erin	0.967	<b>0.967</b>	<b>0.968</b>	<b>0.968</b>	<b>0.968</b>	<b>0.968</b>	<b>0.963</b>	0.965	0.966
Workington	<b>0.953</b>	0.951	0.951	0.952	0.952	0.952	<b>0.947</b>	0.949	0.949
Portpatrick	0.951	<b>0.955</b>	<b>0.955</b>	<b>0.955</b>	<b>0.956</b>	<b>0.956</b>	<b>0.951</b>	<b>0.953</b>	<b>0.954</b>
Millport	<b>0.948</b>	0.945	0.945	0.945	0.946	0.945	<b>0.941</b>	0.943	0.943
Tobermory	<b>0.957</b>	0.955	0.955	0.955	0.955	0.955	<b>0.953</b>	0.954	0.954
Ullapool	0.936	<b>0.937</b>	<b>0.937</b>	<b>0.937</b>	<b>0.936</b>	<b>0.935</b>	0.936	<b>0.936</b>	<b>0.936</b>
Stornoway	<b>0.940</b>	0.939	0.939	0.939	0.939	0.938	<b>0.937</b>	0.938	0.938
Kinlochbervie	0.945	<b>0.946</b>	<b>0.946</b>	<b>0.945</b>	<b>0.945</b>	<b>0.944</b>	0.944	<b>0.945</b>	<b>0.945</b>
Lerwick	<b>0.927</b>	0.925	0.926	0.926	0.925	0.925	<b>0.923</b>	0.925	0.925
Aberdeen	<b>0.921</b>	<b>0.926</b>	<b>0.927</b>	<b>0.927</b>	<b>0.926</b>	<b>0.924</b>	<b>0.921</b>	<b>0.925</b>	<b>0.926</b>
Leith	0.863	<b>0.867</b>	<b>0.867</b>	<b>0.867</b>	<b>0.867</b>	<b>0.864</b>	<b>0.859</b>	<b>0.865</b>	<b>0.866</b>
North Shields	0.925	<b>0.932</b>	<b>0.932</b>	<b>0.932</b>	<b>0.932</b>	<b>0.929</b>	<b>0.923</b>	<b>0.929</b>	<b>0.930</b>
Whitby	0.919	<b>0.919</b>	<b>0.920</b>	<b>0.920</b>	0.919	0.916	<b>0.912</b>	0.917	0.918
Immingham	<b>0.870</b>	0.844	0.843	0.839	0.837	<b>0.831</b>	0.849	0.848	0.848
Cromer	0.919	<b>0.922</b>	<b>0.922</b>	<b>0.920</b>	<b>0.919</b>	<b>0.915</b>	<b>0.921</b>	<b>0.922</b>	<b>0.921</b>
Lowestoft	<b>0.951</b>	<b>0.959</b>	<b>0.959</b>	<b>0.957</b>	<b>0.956</b>	<b>0.953</b>	<b>0.958</b>	<b>0.960</b>	<b>0.960</b>
Harwich	<b>0.918</b>	<b>0.925</b>	<b>0.925</b>	<b>0.924</b>	<b>0.922</b>	<b>0.918</b>	<b>0.925</b>	<b>0.926</b>	<b>0.926</b>
Sheerness	<b>0.926</b>	0.916	0.915	0.914	0.912	<b>0.908</b>	0.917	0.918	0.917
Jersey	<b>0.847</b>	<b>0.864</b>	<b>0.864</b>	<b>0.864</b>	<b>0.864</b>	<b>0.864</b>	<b>0.861</b>	<b>0.862</b>	<b>0.862</b>
St Marys	0.913	0.912	0.912	<b>0.913</b>	<b>0.914</b>	<b>0.915</b>	<b>0.907</b>	0.910	0.910
Newlyn	0.941	<b>0.945</b>	<b>0.945</b>	<b>0.945</b>	<b>0.945</b>	<b>0.945</b>	<b>0.940</b>	<b>0.943</b>	<b>0.943</b>
Plymouth	0.934	<b>0.938</b>	<b>0.938</b>	<b>0.939</b>	<b>0.939</b>	<b>0.939</b>	<b>0.932</b>	<b>0.935</b>	<b>0.936</b>
Weymouth	<b>0.927</b>	<b>0.932</b>	<b>0.932</b>	<b>0.932</b>	<b>0.932</b>	<b>0.930</b>	<b>0.928</b>	<b>0.931</b>	<b>0.931</b>
Bournemouth	0.910	<b>0.914</b>	<b>0.915</b>	<b>0.916</b>	<b>0.916</b>	<b>0.915</b>	<b>0.907</b>	<b>0.911</b>	<b>0.912</b>
Portsmouth	<b>0.894</b>	<b>0.908</b>	<b>0.909</b>	<b>0.909</b>	<b>0.909</b>	<b>0.907</b>	<b>0.902</b>	<b>0.906</b>	<b>0.907</b>
Newhaven	<b>0.905</b>	<b>0.916</b>	<b>0.917</b>	<b>0.917</b>	<b>0.917</b>	<b>0.915</b>	<b>0.910</b>	<b>0.914</b>	<b>0.914</b>
Dover	<b>0.881</b>	<b>0.894</b>	<b>0.893</b>	<b>0.892</b>	<b>0.890</b>	<b>0.886</b>	<b>0.893</b>	<b>0.895</b>	<b>0.895</b>
Mean	<b>0.907</b>	<b>0.911</b>	<b>0.911</b>	<b>0.911</b>	<b>0.911</b>	<b>0.909</b>	<b>0.907</b>	<b>0.910</b>	<b>0.910</b>

**Table A6:** Correlation for residual water level for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The **green** (**pink**) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).



## A.2 Skew surge

### Skew surge: RMS error

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	0.101	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.106
Hinkley Point	0.116	0.121	0.121	0.121	0.122	0.123	0.121	0.121	0.120
Avonmouth	0.195	<b>0.186</b>	<b>0.186</b>	<b>0.186</b>	<b>0.186</b>	<b>0.186</b>	<b>0.187</b>	<b>0.186</b>	<b>0.186</b>
Newport	0.201	<b>0.187</b>	<b>0.187</b>	<b>0.186</b>	<b>0.186</b>	<b>0.186</b>	<b>0.188</b>	<b>0.187</b>	<b>0.186</b>
Mumbles	0.068	<b>0.066</b>	<b>0.066</b>	<b>0.065</b>	<b>0.065</b>	<b>0.066</b>	0.069	<b>0.067</b>	<b>0.067</b>
Milford Haven	0.106	0.108	0.108	0.108	0.108	0.108	0.109	0.108	0.108
Fishguard	0.084	<b>0.083</b>	<b>0.083</b>	<b>0.083</b>	<b>0.083</b>	<b>0.083</b>	0.086	<b>0.084</b>	<b>0.084</b>
Barmouth	0.081	<b>0.072</b>	<b>0.072</b>	<b>0.071</b>	<b>0.071</b>	<b>0.071</b>	<b>0.077</b>	<b>0.074</b>	<b>0.074</b>
Holyhead	0.057	0.049	0.049	0.050	0.050	0.053	0.052	0.050	0.050
Llandudno	0.077	<b>0.071</b>	<b>0.071</b>	0.071	0.071	0.072	0.075	0.073	0.072
Liverpool	0.108	0.111	0.111	0.111	0.111	0.112	0.113	0.111	0.111
Heysham	0.083	<b>0.079</b>	<b>0.078</b>	<b>0.076</b>	<b>0.075</b>	0.074	0.086	<b>0.082</b>	<b>0.081</b>
Port Erin	-	-	-	-	-	-	-	-	-
Workington	0.111	<b>0.093</b>	<b>0.094</b>	<b>0.095</b>	<b>0.097</b>	0.101	0.092	<b>0.092</b>	<b>0.093</b>
Portpatrick	0.071	<b>0.064</b>	0.064	<b>0.064</b>	<b>0.065</b>	<b>0.066</b>	<b>0.067</b>	<b>0.065</b>	<b>0.065</b>
Millport	0.083	0.072	<b>0.072</b>	<b>0.073</b>	<b>0.074</b>	<b>0.077</b>	<b>0.074</b>	<b>0.073</b>	<b>0.073</b>
Tobermory	0.068	<b>0.056</b>	0.056	<b>0.056</b>	<b>0.057</b>	<b>0.059</b>	<b>0.058</b>	<b>0.057</b>	<b>0.057</b>
Ullapool	0.083	<b>0.071</b>	<b>0.071</b>	<b>0.073</b>	<b>0.075</b>	<b>0.080</b>	0.068	<b>0.069</b>	<b>0.070</b>
Stornoway	0.066	<b>0.061</b>	<b>0.061</b>	<b>0.062</b>	<b>0.063</b>	<b>0.065</b>	<b>0.061</b>	0.061	<b>0.061</b>
Kinlochbervie	0.077	<b>0.066</b>	<b>0.066</b>	<b>0.068</b>	<b>0.070</b>	<b>0.074</b>	0.063	<b>0.064</b>	<b>0.065</b>
Lerwick	0.054	0.054	0.054	0.054	0.055	0.055	0.054	0.054	0.054
Aberdeen	0.068	<b>0.067</b>	<b>0.067</b>	<b>0.068</b>	0.068	0.070	<b>0.066</b>	<b>0.066</b>	0.066
Leith	0.072	0.076	0.077	0.078	0.079	0.082	0.076	0.075	0.075
North Shields	0.062	<b>0.059</b>	<b>0.059</b>	0.058	<b>0.059</b>	<b>0.060</b>	0.064	<b>0.061</b>	<b>0.060</b>
Whitby	0.138	<b>0.137</b>	<b>0.136</b>	0.136	<b>0.136</b>	<b>0.137</b>	0.139	<b>0.137</b>	<b>0.137</b>
Immingham	0.128	<b>0.123</b>	<b>0.123</b>	<b>0.122</b>	0.121	<b>0.122</b>	0.128	<b>0.125</b>	<b>0.124</b>
Cromer	0.115	<b>0.104</b>	<b>0.105</b>	<b>0.109</b>	<b>0.112</b>	0.119	0.102	<b>0.103</b>	<b>0.104</b>
Lowestoft	0.069	<b>0.066</b>	0.066	<b>0.066</b>	<b>0.068</b>	0.074	0.071	<b>0.066</b>	<b>0.066</b>
Harwich	0.116	0.130	0.131	0.135	0.138	0.146	0.124	0.126	0.126
Sheerness	0.087	0.118	0.120	0.125	0.130	0.140	0.109	0.112	0.112
Jersey	-	-	-	-	-	-	-	-	-
St Marys	0.082	0.083	0.083	0.083	0.083	0.084	<b>0.082</b>	<b>0.082</b>	0.082
Newlyn	0.090	0.092	0.092	0.092	0.092	0.093	0.091	0.091	0.091
Plymouth	0.075	0.079	0.079	0.078	0.078	0.079	0.079	0.079	0.079
Weymouth	0.048	<b>0.047</b>	<b>0.047</b>	<b>0.047</b>	0.046	<b>0.047</b>	0.050	0.048	0.048
Bournemouth	0.077	<b>0.072</b>	<b>0.072</b>	<b>0.072</b>	<b>0.072</b>	<b>0.073</b>	<b>0.072</b>	<b>0.072</b>	0.072
Portsmouth	0.083	0.083	0.083	0.083	0.083	0.084	0.084	0.083	0.083
Newhaven	0.071	<b>0.066</b>	0.065	<b>0.066</b>	<b>0.066</b>	<b>0.067</b>	<b>0.067</b>	<b>0.066</b>	<b>0.066</b>
Dover	0.106	0.108	0.108	0.108	0.109	0.112	0.109	0.108	0.107
Mean	0.091	<b>0.089</b>	<b>0.089</b>	<b>0.089</b>	<b>0.090</b>	0.092	<b>0.090</b>	<b>0.089</b>	<b>0.089</b>

**Table A7:** RMS error for skew surge for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The **green** (**pink**) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Skew surge: Mean error

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	-0.076	-0.087	-0.087	-0.087	-0.087	-0.087	-0.087	-0.087	-0.086
Hinkley Point	-0.044	-0.066	-0.066	-0.066	-0.066	-0.066	-0.065	-0.065	-0.065
Avonmouth	-0.039	-0.042	-0.042	-0.043	-0.043	-0.043	-0.041	-0.042	-0.041
Newport	-0.148	-0.148	-0.148	-0.148	-0.148	-0.148	-0.148	-0.148	-0.148
Mumbles	-0.009	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022
Milford Haven	-0.086	-0.092	-0.092	-0.092	-0.092	-0.092	-0.091	-0.091	-0.091
Fishguard	-0.063	-0.065	-0.065	-0.064	-0.064	-0.064	-0.065	-0.065	-0.065
Barmouth	0.004	-0.009	-0.008	-0.007	-0.006	-0.004	-0.012	-0.010	-0.010
Holyhead	-0.001	-0.008	-0.008	-0.007	-0.007	-0.006	-0.009	-0.008	-0.008
Llandudno	0.001	-0.010	-0.010	-0.010	-0.010	-0.009	-0.011	-0.010	-0.010
Liverpool	-0.076	-0.090	-0.089	-0.089	-0.088	-0.088	-0.091	-0.090	-0.090
Heysham	0.010	-0.009	-0.009	-0.009	-0.008	-0.007	-0.011	-0.010	-0.009
Port Erin	-	-	-	-	-	-	-	-	-
Workington	0.075	0.059	0.060	0.060	0.061	0.062	0.058	0.059	0.059
Portpatrick	-0.001	-0.014	-0.014	-0.014	-0.013	-0.012	-0.016	-0.015	-0.015
Millport	0.029	0.016	0.017	0.018	0.018	0.020	0.014	0.015	0.015
Tobermory	0.003	0.000	0.001	0.002	0.003	0.004	-0.003	-0.001	-0.001
Ullapool	0.031	0.024	0.025	0.027	0.028	0.031	0.020	0.022	0.023
Stornoway	0.003	-0.000	0.000	0.002	0.003	0.005	-0.004	-0.002	-0.002
Kinlochbervie	0.023	0.016	0.017	0.019	0.020	0.023	0.011	0.014	0.014
Lerwick	0.010	0.011	0.012	0.013	0.014	0.015	0.008	0.010	0.010
Aberdeen	0.037	0.041	0.041	0.042	0.043	0.044	0.038	0.040	0.040
Leith	-0.024	-0.030	-0.030	-0.030	-0.030	-0.030	-0.029	-0.029	-0.029
North Shields	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.021	-0.021	-0.021
Whitby	-0.124	-0.123	-0.123	-0.123	-0.123	-0.124	-0.123	-0.123	-0.123
Immingham	0.087	0.082	0.082	0.081	0.080	0.078	0.085	0.083	0.083
Cromer	-0.016	-0.011	-0.011	-0.011	-0.011	-0.011	-0.010	-0.010	-0.010
Lowestoft	-0.026	-0.026	-0.026	-0.026	-0.025	-0.024	-0.028	-0.027	-0.027
Harwich	-0.065	-0.080	-0.080	-0.082	-0.084	-0.087	-0.075	-0.077	-0.078
Sheerness	-0.020	-0.039	-0.040	-0.043	-0.045	-0.050	-0.032	-0.036	-0.036
Jersey	-	-	-	-	-	-	-	-	-
St Marys	-0.056	-0.059	-0.059	-0.060	-0.060	-0.061	-0.058	-0.058	-0.058
Newlyn	-0.075	-0.078	-0.078	-0.079	-0.079	-0.080	-0.076	-0.077	-0.077
Plymouth	-0.054	-0.060	-0.060	-0.061	-0.061	-0.062	-0.059	-0.059	-0.059
Weymouth	-0.007	-0.014	-0.014	-0.014	-0.014	-0.013	-0.013	-0.013	-0.013
Bournemouth	-0.064	-0.060	-0.060	-0.060	-0.060	-0.060	-0.059	-0.059	-0.059
Portsmouth	-0.059	-0.063	-0.063	-0.063	-0.063	-0.063	-0.062	-0.062	-0.062
Newhaven	-0.025	-0.027	-0.027	-0.027	-0.027	-0.027	-0.027	-0.027	-0.027
Dover	-0.050	-0.058	-0.058	-0.059	-0.059	-0.059	-0.057	-0.058	-0.058
Mean	-0.025	-0.031	-0.031	-0.031	-0.031	-0.031	-0.032	-0.031	-0.031

**Table A8:** Mean error for skew surge for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The **green** (**pink**) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

**Skew surge: Max |error|**

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	0.277	0.349	0.341	0.322	0.306	0.302	0.388	0.359	0.347
Hinkley Point	0.396	0.419	0.413	0.406	0.404	0.400	0.456	0.431	0.421
Avonmouth	0.566	<b>0.552</b>	<b>0.551</b>	<b>0.550</b>	<b>0.549</b>	0.547	<b>0.558</b>	<b>0.557</b>	<b>0.558</b>
Newport	0.602	<b>0.561</b>	<b>0.554</b>	<b>0.542</b>	0.541	<b>0.552</b>	<b>0.598</b>	<b>0.573</b>	<b>0.564</b>
Mumbles	0.310	0.399	0.393	0.378	0.366	0.343	0.436	0.413	0.407
Milford Haven	0.268	<b>0.256</b>	<b>0.255</b>	<b>0.254</b>	<b>0.254</b>	0.252	0.283	<b>0.258</b>	<b>0.257</b>
Fishguard	0.218	0.235	0.235	0.235	0.235	0.234	0.237	0.236	0.236
Barmouth	0.388	<b>0.282</b>	<b>0.276</b>	<b>0.259</b>	0.246	<b>0.248</b>	<b>0.340</b>	<b>0.305</b>	<b>0.301</b>
Holyhead	0.315	<b>0.221</b>	<b>0.228</b>	<b>0.249</b>	<b>0.266</b>	<b>0.300</b>	0.189	<b>0.206</b>	<b>0.215</b>
Llandudno	0.457	0.557	0.548	0.525	0.506	0.470	0.615	0.581	0.571
Liverpool	0.322	<b>0.261</b>	0.261	<b>0.263</b>	<b>0.264</b>	<b>0.270</b>	0.346	<b>0.270</b>	<b>0.264</b>
Heysham	0.399	<b>0.348</b>	<b>0.337</b>	<b>0.308</b>	<b>0.286</b>	0.245	0.415	<b>0.374</b>	<b>0.362</b>
Port Erin	-	-	-	-	-	-	-	-	-
Workington	0.571	<b>0.399</b>	<b>0.409</b>	<b>0.432</b>	<b>0.450</b>	<b>0.485</b>	<b>0.410</b>	0.384	<b>0.398</b>
Portpatrick	0.410	<b>0.302</b>	<b>0.307</b>	<b>0.320</b>	<b>0.331</b>	<b>0.350</b>	<b>0.310</b>	0.294	<b>0.302</b>
Millport	0.520	<b>0.333</b>	<b>0.345</b>	<b>0.377</b>	<b>0.403</b>	<b>0.453</b>	<b>0.334</b>	0.327	<b>0.329</b>
Tobermory	0.401	<b>0.217</b>	<b>0.215</b>	<b>0.210</b>	0.205	<b>0.238</b>	<b>0.242</b>	<b>0.225</b>	<b>0.225</b>
Ullapool	0.337	<b>0.293</b>	<b>0.302</b>	<b>0.324</b>	0.342	0.375	0.240	<b>0.276</b>	<b>0.288</b>
Stornoway	0.226	<b>0.195</b>	<b>0.195</b>	<b>0.196</b>	<b>0.197</b>	<b>0.204</b>	0.192	<b>0.193</b>	<b>0.193</b>
Kinlochbervie	0.326	0.334	0.345	0.371	0.393	0.436	0.290	0.329	0.349
Lerwick	0.223	0.236	0.242	0.256	0.269	0.292	0.214	0.236	0.249
Aberdeen	0.235	<b>0.216</b>	<b>0.212</b>	<b>0.228</b>	0.247	0.283	<b>0.229</b>	<b>0.213</b>	0.208
Leith	0.259	<b>0.258</b>	0.260	0.275	0.306	0.385	0.292	0.261	0.254
North Shields	0.245	<b>0.233</b>	<b>0.218</b>	0.192	<b>0.202</b>	<b>0.224</b>	0.302	<b>0.245</b>	<b>0.218</b>
Whitby	0.387	0.484	0.468	0.427	0.394	0.330	0.561	0.498	0.469
Immingham	0.409	0.425	0.412	<b>0.378</b>	<b>0.375</b>	0.370	0.504	0.454	0.437
Cromer	1.015	<b>0.902</b>	<b>0.926</b>	<b>0.987</b>	1.035	1.129	<b>0.780</b>	<b>0.873</b>	<b>0.911</b>
Lowestoft	0.292	0.525	0.497	0.427	0.371	0.374	0.659	0.551	0.503
Harwich	0.485	<b>0.452</b>	<b>0.462</b>	0.492	0.542	0.673	0.390	<b>0.426</b>	<b>0.444</b>
Sheerness	0.394	0.420	0.431	0.458	0.481	0.527	0.534	0.433	0.420
Jersey	-	-	-	-	-	-	-	-	-
St Marys	0.280	<b>0.268</b>	<b>0.270</b>	<b>0.273</b>	<b>0.276</b>	0.282	0.258	<b>0.264</b>	<b>0.266</b>
Newlyn	0.216	<b>0.209</b>	<b>0.209</b>	<b>0.208</b>	<b>0.208</b>	0.208	0.229	<b>0.210</b>	<b>0.209</b>
Plymouth	0.201	0.287	0.286	0.281	0.278	0.271	0.297	0.290	0.288
Weymouth	0.180	<b>0.169</b>	<b>0.169</b>	<b>0.169</b>	<b>0.170</b>	<b>0.175</b>	<b>0.173</b>	<b>0.168</b>	0.167
Bournemouth	0.217	<b>0.171</b>	<b>0.177</b>	<b>0.193</b>	<b>0.206</b>	0.230	<b>0.168</b>	<b>0.166</b>	0.165
Portsmouth	0.307	<b>0.249</b>	<b>0.240</b>	0.217	<b>0.224</b>	<b>0.248</b>	<b>0.294</b>	<b>0.259</b>	<b>0.244</b>
Newhaven	0.270	<b>0.253</b>	<b>0.253</b>	<b>0.251</b>	<b>0.250</b>	0.247	0.312	<b>0.266</b>	<b>0.257</b>
Dover	0.322	0.507	0.488	0.443	0.407	0.392	0.597	0.526	0.496
Mean	0.358	<b>0.345</b>	<b>0.344</b>	0.343	<b>0.345</b>	0.361	0.370	<b>0.349</b>	<b>0.346</b>

**Table A9:** Max |error| for skew surge for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Skew surge: Scatter index

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	0.433	0.398	0.397	0.397	0.397	0.402	0.409	0.402	0.402
Hinkley Point	0.607	0.577	0.577	0.577	0.579	0.583	0.580	0.576	0.574
Avonmouth	0.860	0.814	0.813	0.813	0.812	0.813	0.819	0.816	0.816
Newport	0.689	0.579	0.578	0.576	0.575	0.575	0.590	0.583	0.582
Mumbles	0.414	0.381	0.379	0.377	0.376	0.378	0.398	0.387	0.386
Milford Haven	0.374	0.347	0.346	0.343	0.342	0.343	0.367	0.356	0.355
Fishguard	0.352	0.331	0.330	0.329	0.330	0.335	0.348	0.339	0.339
Barmouth	0.397	0.353	0.351	0.348	0.347	0.348	0.376	0.363	0.362
Holyhead	0.318	0.274	0.274	0.277	0.281	0.295	0.286	0.278	0.278
Llandudno	0.412	0.379	0.378	0.376	0.377	0.382	0.397	0.386	0.385
Liverpool	0.397	0.339	0.339	0.342	0.346	0.359	0.350	0.341	0.341
Heysham	0.381	0.362	0.358	0.350	0.345	0.340	0.396	0.377	0.374
Port Erin	-	-	-	-	-	-	-	-	-
Workington	0.384	0.334	0.336	0.345	0.354	0.376	0.334	0.332	0.334
Portpatrick	0.347	0.304	0.304	0.305	0.307	0.316	0.318	0.309	0.309
Millport	0.344	0.309	0.309	0.312	0.315	0.327	0.321	0.313	0.314
Tobermory	0.344	0.282	0.282	0.283	0.285	0.294	0.294	0.285	0.285
Ullapool	0.412	0.356	0.359	0.368	0.376	0.394	0.347	0.352	0.354
Stornoway	0.381	0.351	0.352	0.356	0.361	0.371	0.350	0.350	0.351
Kinlochbervie	0.376	0.324	0.326	0.334	0.342	0.361	0.318	0.320	0.323
Lerwick	0.359	0.359	0.359	0.359	0.359	0.362	0.365	0.361	0.361
Aberdeen	0.378	0.351	0.351	0.352	0.355	0.365	0.363	0.353	0.352
Leith	0.456	0.476	0.478	0.485	0.493	0.515	0.472	0.470	0.470
North Shields	0.385	0.366	0.363	0.358	0.358	0.368	0.399	0.375	0.369
Whitby	0.367	0.358	0.355	0.349	0.348	0.357	0.396	0.369	0.363
Immingham	0.484	0.474	0.473	0.471	0.473	0.484	0.495	0.478	0.473
Cromer	0.590	0.537	0.542	0.558	0.574	0.611	0.524	0.529	0.533
Lowestoft	0.311	0.290	0.290	0.295	0.305	0.336	0.315	0.293	0.289
Harwich	0.508	0.543	0.548	0.564	0.580	0.619	0.523	0.527	0.528
Sheerness	0.429	0.564	0.572	0.593	0.613	0.660	0.525	0.537	0.536
Jersey	-	-	-	-	-	-	-	-	-
St Marys	0.451	0.430	0.429	0.427	0.426	0.426	0.439	0.434	0.433
Newlyn	0.350	0.340	0.338	0.336	0.334	0.334	0.357	0.348	0.348
Plymouth	0.354	0.349	0.347	0.343	0.340	0.337	0.367	0.356	0.355
Weymouth	0.356	0.342	0.340	0.336	0.335	0.336	0.363	0.350	0.347
Bournemouth	0.385	0.374	0.373	0.374	0.375	0.382	0.387	0.379	0.378
Portsmouth	0.379	0.355	0.354	0.355	0.357	0.366	0.370	0.359	0.358
Newhaven	0.455	0.409	0.408	0.408	0.411	0.422	0.424	0.413	0.411
Dover	0.482	0.466	0.466	0.468	0.472	0.486	0.478	0.467	0.465
Mean	0.424	0.399	0.399	0.401	0.404	0.415	0.410	0.402	0.401

**Table A10:** Scatter index for skew surge for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Skew surge: Normalised standard deviation

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	<b>1.003</b>	0.890	0.896	0.911	0.924	0.949	<b>0.852</b>	0.872	0.877
Hinkley Point	<b>0.952</b>	0.851	0.858	0.874	0.888	0.915	<b>0.808</b>	0.831	0.835
Avonmouth	<b>0.676</b>	0.579	0.584	0.595	0.604	0.623	<b>0.549</b>	0.564	0.566
Newport	<b>1.116</b>	0.755	0.762	0.777	0.790	0.816	<b>0.715</b>	0.736	0.740
Mumbles	<b>1.016</b>	0.882	0.889	0.906	0.920	0.948	<b>0.839</b>	0.862	0.867
Milford Haven	<b>0.988</b>	0.893	0.899	0.916	0.930	0.957	<b>0.849</b>	0.872	0.875
Fishguard	1.016	0.925	0.932	0.949	0.963	<b>0.991</b>	<b>0.881</b>	0.904	0.909
Barmouth	0.913	0.867	0.875	0.897	<b>0.914</b>	<b>0.949</b>	<b>0.811</b>	0.842	0.848
Holyhead	1.045	<b>0.971</b>	<b>0.980</b>	<b>1.001</b>	<b>1.018</b>	1.052	<b>0.917</b>	0.947	0.954
Llandudno	1.046	0.928	0.937	<b>0.958</b>	<b>0.976</b>	<b>1.010</b>	<b>0.875</b>	0.906	0.914
Liverpool	1.081	<b>0.953</b>	<b>0.963</b>	<b>0.988</b>	<b>1.008</b>	<b>1.048</b>	<b>0.892</b>	<b>0.928</b>	<b>0.937</b>
Heysham	<b>0.957</b>	0.828	0.837	0.860	0.878	0.915	<b>0.772</b>	0.804	0.813
Port Erin	-	-	-	-	-	-	-	-	-
Workington	1.139	<b>1.047</b>	<b>1.058</b>	<b>1.085</b>	<b>1.108</b>	<b>1.151</b>	<b>0.974</b>	<b>1.014</b>	<b>1.022</b>
Portpatrick	1.076	<b>0.944</b>	<b>0.953</b>	<b>0.974</b>	<b>0.991</b>	<b>1.024</b>	<b>0.889</b>	0.919	<b>0.925</b>
Millport	1.077	<b>0.959</b>	<b>0.969</b>	<b>0.991</b>	<b>1.010</b>	<b>1.047</b>	<b>0.898</b>	<b>0.932</b>	<b>0.938</b>
Tobermory	<b>1.137</b>	<b>0.960</b>	<b>0.968</b>	<b>0.989</b>	<b>1.006</b>	<b>1.038</b>	<b>0.907</b>	<b>0.937</b>	<b>0.943</b>
Ullapool	<b>1.140</b>	<b>1.036</b>	<b>1.044</b>	<b>1.066</b>	<b>1.083</b>	<b>1.118</b>	<b>0.981</b>	<b>1.012</b>	<b>1.021</b>
Stornoway	<b>1.072</b>	<b>1.001</b>	<b>1.007</b>	<b>1.022</b>	<b>1.035</b>	<b>1.059</b>	<b>0.964</b>	<b>0.986</b>	<b>0.992</b>
Kinlochbervie	<b>1.125</b>	<b>1.025</b>	<b>1.034</b>	<b>1.056</b>	<b>1.073</b>	<b>1.108</b>	<b>0.970</b>	<b>1.002</b>	<b>1.011</b>
Lerwick	<b>0.989</b>	0.957	0.959	0.964	0.967	0.975	<b>0.950</b>	0.956	0.959
Aberdeen	0.947	<b>0.949</b>	<b>0.955</b>	<b>0.969</b>	<b>0.981</b>	<b>1.006</b>	<b>0.921</b>	0.940	<b>0.948</b>
Leith	0.908	0.860	0.869	0.890	<b>0.908</b>	<b>0.946</b>	<b>0.826</b>	0.853	0.867
North Shields	0.865	<b>0.871</b>	<b>0.880</b>	<b>0.904</b>	<b>0.925</b>	<b>0.967</b>	<b>0.824</b>	0.856	<b>0.869</b>
Whitby	0.866	0.847	0.858	<b>0.887</b>	<b>0.910</b>	<b>0.958</b>	<b>0.788</b>	0.826	0.840
Immingham	0.862	0.770	0.783	0.817	0.845	<b>0.900</b>	<b>0.693</b>	0.741	0.756
Cromer	1.053	<b>0.966</b>	<b>0.983</b>	<b>1.025</b>	1.060	1.128	<b>0.864</b>	0.924	0.941
Lowestoft	1.006	0.919	0.934	0.973	<b>1.006</b>	1.069	<b>0.825</b>	0.880	0.896
Harwich	0.967	0.883	0.900	0.942	<b>0.976</b>	1.045	<b>0.785</b>	0.843	0.860
Sheerness	0.943	0.910	0.928	<b>0.976</b>	<b>1.015</b>	1.092	<b>0.792</b>	0.858	0.875
Jersey	-	-	-	-	-	-	-	-	-
St Marys	<b>0.975</b>	0.913	0.916	0.924	0.930	0.943	<b>0.892</b>	0.902	0.902
Newlyn	<b>0.936</b>	0.883	0.887	0.897	0.906	0.922	<b>0.854</b>	0.867	0.867
Plymouth	0.914	0.879	0.883	0.895	0.904	<b>0.923</b>	<b>0.845</b>	0.861	0.862
Weymouth	<b>0.987</b>	0.879	0.885	0.901	0.914	0.940	<b>0.842</b>	0.863	0.868
Bournemouth	<b>0.990</b>	0.908	0.914	0.928	0.939	0.963	<b>0.873</b>	0.891	0.894
Portsmouth	<b>0.973</b>	0.864	0.872	0.892	0.908	0.941	<b>0.820</b>	0.847	0.855
Newhaven	0.943	0.865	0.874	0.898	0.917	<b>0.955</b>	<b>0.815</b>	0.846	0.857
Dover	0.932	0.826	0.839	0.870	0.896	<b>0.947</b>	<b>0.750</b>	0.795	0.807
Mean	<b>0.990</b>	0.898	0.907	0.929	0.947	0.982	<b>0.846</b>	0.876	0.884

**Table A11:** Normalised STD for skew surge for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Skew surge: Correlation

Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	<b>0.906</b>	<b>0.918</b>	<b>0.918</b>	<b>0.918</b>	<b>0.918</b>	<b>0.916</b>	<b>0.915</b>	<b>0.917</b>	<b>0.917</b>
Hinkley Point	<b>0.808</b>	<b>0.818</b>	<b>0.818</b>	<b>0.818</b>	<b>0.819</b>	<b>0.818</b>	<b>0.815</b>	<b>0.818</b>	<b>0.819</b>
Avonmouth	<b>0.530</b>	<b>0.581</b>	<b>0.582</b>	<b>0.583</b>	<b>0.583</b>	<b>0.584</b>	<b>0.575</b>	<b>0.578</b>	<b>0.578</b>
Newport	<b>0.793</b>	<b>0.818</b>	<b>0.818</b>	<b>0.819</b>	<b>0.819</b>	<b>0.818</b>	<b>0.813</b>	<b>0.816</b>	<b>0.817</b>
Mumbles	<b>0.916</b>	<b>0.926</b>	<b>0.926</b>	<b>0.926</b>	<b>0.927</b>	<b>0.926</b>	<b>0.921</b>	<b>0.924</b>	<b>0.924</b>
Milford Haven	<b>0.929</b>	<b>0.939</b>	<b>0.939</b>	<b>0.940</b>	<b>0.940</b>	<b>0.939</b>	<b>0.934</b>	<b>0.937</b>	<b>0.937</b>
Fishguard	<b>0.939</b>	<b>0.944</b>	<b>0.944</b>	<b>0.944</b>	<b>0.944</b>	<b>0.944</b>	<b>0.939</b>	<b>0.942</b>	<b>0.941</b>
Barmouth	<b>0.918</b>	<b>0.938</b>	<b>0.938</b>	<b>0.938</b>	<b>0.938</b>	<b>0.937</b>	<b>0.935</b>	<b>0.937</b>	<b>0.936</b>
Holyhead	<b>0.952</b>	<b>0.962</b>	<b>0.962</b>	<b>0.962</b>	<b>0.961</b>	<b>0.960</b>	<b>0.959</b>	<b>0.961</b>	<b>0.960</b>
Llandudno	0.920	<b>0.925</b>	<b>0.926</b>	<b>0.927</b>	<b>0.928</b>	<b>0.928</b>	<b>0.919</b>	<b>0.923</b>	<b>0.923</b>
Liverpool	<b>0.930</b>	<b>0.941</b>	<b>0.941</b>	<b>0.941</b>	<b>0.941</b>	<b>0.940</b>	<b>0.938</b>	<b>0.940</b>	<b>0.940</b>
Heysham	<b>0.925</b>	<b>0.939</b>	<b>0.939</b>	<b>0.940</b>	<b>0.941</b>	<b>0.941</b>	<b>0.932</b>	<b>0.936</b>	<b>0.935</b>
Port Erin	-	-	-	-	-	-	-	-	-
Workington	0.944	<b>0.948</b>	<b>0.948</b>	<b>0.949</b>	<b>0.949</b>	<b>0.949</b>	<b>0.943</b>	<b>0.946</b>	<b>0.946</b>
Portpatrick	<b>0.947</b>	<b>0.953</b>	<b>0.953</b>	<b>0.953</b>	<b>0.952</b>	<b>0.952</b>	<b>0.950</b>	<b>0.951</b>	<b>0.951</b>
Millport	<b>0.948</b>	<b>0.951</b>	<b>0.951</b>	<b>0.951</b>	<b>0.951</b>	<b>0.950</b>	<b>0.949</b>	<b>0.950</b>	<b>0.950</b>
Tobermory	<b>0.956</b>	<b>0.959</b>	<b>0.960</b>	<b>0.960</b>	<b>0.960</b>	<b>0.959</b>	<b>0.957</b>	<b>0.959</b>	<b>0.959</b>
Ullapool	<b>0.934</b>	<b>0.939</b>	<b>0.939</b>	<b>0.939</b>	<b>0.938</b>	<b>0.937</b>	<b>0.939</b>	<b>0.939</b>	<b>0.939</b>
Stornoway	<b>0.935</b>	<b>0.938</b>	<b>0.938</b>	<b>0.938</b>	<b>0.938</b>	<b>0.937</b>	<b>0.937</b>	<b>0.938</b>	<b>0.938</b>
Kinlochbervie	<b>0.944</b>	<b>0.949</b>	<b>0.949</b>	<b>0.949</b>	<b>0.948</b>	<b>0.947</b>	<b>0.948</b>	<b>0.949</b>	<b>0.948</b>
Lerwick	<b>0.935</b>	0.934	0.934	0.934	0.934	0.933	<b>0.931</b>	0.933	0.933
Aberdeen	<b>0.926</b>	<b>0.936</b>	<b>0.937</b>	<b>0.937</b>	<b>0.936</b>	<b>0.934</b>	<b>0.932</b>	<b>0.935</b>	<b>0.936</b>
Leith	<b>0.890</b>	0.880	0.879	0.875	0.871	<b>0.861</b>	0.883	0.883	0.883
North Shields	0.925	<b>0.933</b>	<b>0.934</b>	<b>0.934</b>	<b>0.934</b>	<b>0.931</b>	<b>0.922</b>	<b>0.930</b>	<b>0.932</b>
Whitby	0.933	<b>0.938</b>	<b>0.938</b>	<b>0.939</b>	<b>0.938</b>	<b>0.934</b>	<b>0.929</b>	<b>0.936</b>	<b>0.937</b>
Immingham	<b>0.875</b>	<b>0.888</b>	<b>0.887</b>	<b>0.885</b>	<b>0.882</b>	<b>0.876</b>	<b>0.891</b>	<b>0.891</b>	<b>0.891</b>
Cromer	<b>0.836</b>	<b>0.851</b>	<b>0.851</b>	<b>0.848</b>	<b>0.846</b>	<b>0.842</b>	<b>0.852</b>	<b>0.852</b>	<b>0.851</b>
Lowestoft	0.952	<b>0.958</b>	<b>0.957</b>	<b>0.956</b>	<b>0.954</b>	<b>0.949</b>	<b>0.959</b>	<b>0.960</b>	<b>0.960</b>
Harwich	<b>0.867</b>	0.841	0.839	0.833	0.828	<b>0.818</b>	0.855	0.850	0.849
Sheerness	<b>0.904</b>	0.830	0.827	0.820	0.815	<b>0.804</b>	0.853	0.844	0.845
Jersey	-	-	-	-	-	-	-	-	-
St Marys	<b>0.896</b>	<b>0.903</b>	<b>0.904</b>	<b>0.904</b>	<b>0.905</b>	<b>0.906</b>	<b>0.898</b>	<b>0.901</b>	<b>0.901</b>
Newlyn	<b>0.937</b>	<b>0.942</b>	<b>0.943</b>	<b>0.943</b>	<b>0.943</b>	<b>0.943</b>	<b>0.938</b>	<b>0.940</b>	<b>0.940</b>
Plymouth	0.935	<b>0.939</b>	<b>0.940</b>	<b>0.941</b>	<b>0.941</b>	<b>0.942</b>	<b>0.934</b>	<b>0.937</b>	<b>0.938</b>
Weymouth	<b>0.936</b>	<b>0.942</b>	<b>0.942</b>	<b>0.943</b>	<b>0.943</b>	<b>0.942</b>	<b>0.937</b>	<b>0.940</b>	<b>0.941</b>
Bournemouth	0.925	<b>0.928</b>	<b>0.928</b>	<b>0.928</b>	<b>0.927</b>	0.925	<b>0.923</b>	<b>0.926</b>	<b>0.926</b>
Portsmouth	<b>0.926</b>	<b>0.938</b>	<b>0.937</b>	<b>0.936</b>	<b>0.935</b>	<b>0.931</b>	<b>0.937</b>	<b>0.938</b>	<b>0.937</b>
Newhaven	<b>0.892</b>	<b>0.914</b>	<b>0.914</b>	<b>0.913</b>	<b>0.912</b>	<b>0.908</b>	<b>0.911</b>	<b>0.913</b>	<b>0.913</b>
Dover	0.878	<b>0.887</b>	<b>0.886</b>	<b>0.884</b>	<b>0.882</b>	<b>0.877</b>	<b>0.889</b>	<b>0.889</b>	<b>0.889</b>
Mean	<b>0.904</b>	<b>0.910</b>	<b>0.910</b>	<b>0.909</b>	<b>0.909</b>	<b>0.906</b>	<b>0.908</b>	<b>0.910</b>	<b>0.910</b>

**Table A12:** Correlation for skew surge for the wind forcing tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).



## Appendix B Statistics tables for pressure tests

### B.1 Residual

#### Residual: RMS error

Port	CS3X	P1010	P1012	P1014
Ilfracombe	0.114	<b>0.128</b>	<b>0.111</b>	<b>0.096</b>
Hinkley Point	<b>0.148</b>	<b>0.148</b>	<b>0.142</b>	<b>0.138</b>
Avonmouth	0.211	<b>0.215</b>	0.212	<b>0.210</b>
Newport	0.215	<b>0.226</b>	<b>0.212</b>	<b>0.199</b>
Mumbles	<b>0.082</b>	<b>0.082</b>	<b>0.075</b>	<b>0.073</b>
Milford Haven	0.114	<b>0.130</b>	<b>0.112</b>	<b>0.095</b>
Fishguard	0.082	<b>0.097</b>	<b>0.081</b>	<b>0.067</b>
Barmouth	<b>0.082</b>	<b>0.079</b>	<b>0.076</b>	<b>0.078</b>
Holyhead	0.056	<b>0.057</b>	<b>0.051</b>	<b>0.053</b>
Llandudno	0.074	<b>0.079</b>	<b>0.073</b>	<b>0.072</b>
Liverpool	0.121	<b>0.135</b>	<b>0.120</b>	<b>0.106</b>
Heysham	<b>0.086</b>	<b>0.090</b>	0.087	0.090
Port Erin	0.056	<b>0.065</b>	<b>0.054</b>	<b>0.050</b>
Workington	0.106	<b>0.093</b>	0.106	<b>0.121</b>
Portpatrick	0.067	<b>0.069</b>	<b>0.063</b>	<b>0.063</b>
Millport	0.078	<b>0.075</b>	<b>0.076</b>	<b>0.082</b>
Tobermory	<b>0.070</b>	<b>0.062</b>	<b>0.062</b>	<b>0.069</b>
Ullapool	0.089	<b>0.076</b>	<b>0.084</b>	<b>0.095</b>
Stornoway	0.067	<b>0.065</b>	<b>0.066</b>	<b>0.072</b>
Kinlochbervie	0.083	<b>0.072</b>	<b>0.077</b>	<b>0.087</b>
Lerwick	0.058	<b>0.057</b>	0.058	<b>0.066</b>
Aberdeen	0.080	<b>0.069</b>	0.080	<b>0.094</b>
Leith	<b>0.080</b>	<b>0.085</b>	0.080	0.080
North Shields	0.060	0.061	<b>0.058</b>	<b>0.062</b>
Whitby	0.123	<b>0.139</b>	<b>0.122</b>	<b>0.106</b>
Immingham	<b>0.125</b>	0.129	0.138	<b>0.148</b>
Cromer	0.090	<b>0.094</b>	<b>0.089</b>	<b>0.088</b>
Lowestoft	0.072	<b>0.076</b>	<b>0.067</b>	<b>0.063</b>
Harwich	0.102	<b>0.110</b>	<b>0.099</b>	<b>0.090</b>
Sheerness	<b>0.096</b>	<b>0.109</b>	0.104	0.102
Jersey	0.114	<b>0.123</b>	<b>0.110</b>	<b>0.100</b>
St Marys	0.083	<b>0.097</b>	<b>0.082</b>	<b>0.068</b>
Newlyn	0.096	<b>0.112</b>	<b>0.094</b>	<b>0.078</b>
Plymouth	0.081	<b>0.096</b>	<b>0.079</b>	<b>0.065</b>
Weymouth	0.053	<b>0.058</b>	<b>0.051</b>	<b>0.052</b>
Bournemouth	0.071	<b>0.084</b>	<b>0.068</b>	<b>0.055</b>
Portsmouth	0.087	<b>0.097</b>	<b>0.083</b>	<b>0.071</b>
Newhaven	0.078	<b>0.089</b>	<b>0.075</b>	<b>0.064</b>
Dover	0.116	<b>0.127</b>	<b>0.113</b>	<b>0.100</b>
Mean	0.094	<b>0.099</b>	<b>0.092</b>	<b>0.089</b>

**Table B1:** RMS error for residual water level for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The **green** (**pink**) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Residual: Mean error

Port	CS3X	P1010	P1012	P1014
Ilfracombe	-0.090	<b>-0.110</b>	-0.090	<b>-0.070</b>
Hinkley Point	-0.044	<b>-0.065</b>	-0.046	<b>-0.026</b>
Avonmouth	-0.034	<b>-0.052</b>	<b>-0.032</b>	<b>-0.012</b>
Newport	-0.149	<b>-0.171</b>	-0.151	<b>-0.131</b>
Mumbles	-0.017	<b>-0.039</b>	-0.019	<b>0.001</b>
Milford Haven	-0.099	<b>-0.117</b>	<b>-0.098</b>	<b>-0.078</b>
Fishguard	-0.062	<b>-0.082</b>	-0.062	<b>-0.042</b>
Barmouth	<b>0.002</b>	<b>-0.023</b>	-0.003	0.017
Holyhead	<b>-0.005</b>	<b>-0.026</b>	-0.006	0.014
Llandudno	-0.012	<b>-0.033</b>	-0.013	<b>0.006</b>
Liverpool	-0.084	<b>-0.106</b>	-0.086	<b>-0.066</b>
Heysham	0.003	-0.019	<b>0.001</b>	<b>0.021</b>
Port Erin	-0.022	<b>-0.043</b>	-0.023	<b>-0.003</b>
Workington	0.075	<b>0.055</b>	0.075	<b>0.095</b>
Portpatrick	<b>-0.005</b>	<b>-0.030</b>	-0.010	0.010
Millport	0.017	<b>-0.006</b>	<b>0.014</b>	<b>0.034</b>
Tobermory	0.010	<b>-0.009</b>	0.011	<b>0.031</b>
Ullapool	0.042	<b>0.020</b>	<b>0.040</b>	<b>0.060</b>
Stornoway	0.011	<b>-0.009</b>	0.011	<b>0.031</b>
Kinlochbervie	0.032	<b>0.009</b>	<b>0.029</b>	<b>0.049</b>
Lerwick	0.014	<b>-0.006</b>	<b>0.014</b>	<b>0.033</b>
Aberdeen	0.051	<b>0.033</b>	0.053	<b>0.072</b>
Leith	-0.010	<b>-0.031</b>	-0.011	<b>0.009</b>
North Shields	<b>0.000</b>	-0.018	0.002	<b>0.022</b>
Whitby	-0.102	<b>-0.120</b>	<b>-0.101</b>	<b>-0.081</b>
Immingham	0.073	<b>0.052</b>	<b>0.072</b>	<b>0.092</b>
Cromer	-0.019	<b>-0.035</b>	<b>-0.016</b>	<b>0.004</b>
Lowestoft	-0.026	<b>-0.042</b>	<b>-0.022</b>	<b>-0.002</b>
Harwich	-0.053	<b>-0.071</b>	<b>-0.051</b>	<b>-0.031</b>
Sheerness	-0.021	<b>-0.038</b>	<b>-0.018</b>	<b>0.002</b>
Jersey	-0.069	<b>-0.090</b>	-0.070	<b>-0.050</b>
St Marys	-0.062	<b>-0.081</b>	<b>-0.061</b>	<b>-0.041</b>
Newlyn	-0.082	<b>-0.102</b>	<b>-0.082</b>	<b>-0.062</b>
Plymouth	-0.063	<b>-0.082</b>	<b>-0.062</b>	<b>-0.042</b>
Weymouth	-0.009	<b>-0.028</b>	<b>-0.008</b>	0.012
Bournemouth	-0.052	<b>-0.071</b>	<b>-0.051</b>	<b>-0.031</b>
Portsmouth	-0.058	<b>-0.077</b>	<b>-0.057</b>	<b>-0.037</b>
Newhaven	-0.050	<b>-0.069</b>	<b>-0.049</b>	<b>-0.029</b>
Dover	-0.078	<b>-0.096</b>	<b>-0.077</b>	<b>-0.057</b>
Mean	-0.027	<b>-0.047</b>	-0.027	<b>-0.007</b>

**Table B2:** Mean error for residual water level for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The **green** (**pink**) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).



### Residual: Max |error|

Port	CS3X	P1010	P1012	P1014
Ilfracombe	0.391	<b>0.375</b>	<b>0.353</b>	<b>0.356</b>
Hinkley Point	0.660	0.661	0.685	0.709
Avonmouth	0.853	0.938	0.915	0.891
Newport	0.918	<b>0.905</b>	<b>0.913</b>	0.933
Mumbles	0.452	<b>0.386</b>	<b>0.366</b>	<b>0.364</b>
Milford Haven	0.328	0.345	<b>0.324</b>	<b>0.303</b>
Fishguard	0.268	0.282	<b>0.261</b>	<b>0.240</b>
Barmouth	0.534	<b>0.506</b>	<b>0.485</b>	<b>0.464</b>
Holyhead	0.325	<b>0.256</b>	<b>0.276</b>	<b>0.296</b>
Llandudno	0.526	0.530	0.551	0.572
Liverpool	0.470	0.606	0.584	0.563
Heysham	0.469	0.520	0.501	0.482
Port Erin	0.273	<b>0.263</b>	0.284	0.305
Workington	0.659	<b>0.522</b>	<b>0.544</b>	<b>0.566</b>
Portpatrick	0.466	<b>0.310</b>	<b>0.331</b>	<b>0.351</b>
Millport	0.662	<b>0.514</b>	<b>0.534</b>	<b>0.554</b>
Tobermory	0.659	<b>0.460</b>	<b>0.480</b>	<b>0.501</b>
Ullapool	0.688	<b>0.491</b>	<b>0.511</b>	<b>0.531</b>
Stornoway	0.367	<b>0.301</b>	<b>0.321</b>	<b>0.342</b>
Kinlochbervie	0.464	<b>0.374</b>	<b>0.393</b>	<b>0.412</b>
Lerwick	0.261	<b>0.260</b>	0.279	0.299
Aberdeen	0.360	<b>0.302</b>	<b>0.322</b>	<b>0.342</b>
Leith	0.563	0.782	0.761	0.739
North Shields	0.319	0.374	0.354	0.334
Whitby	0.597	0.766	0.746	0.726
Immingham	0.675	1.406	1.378	1.349
Cromer	1.048	1.067	1.085	1.103
Lowestoft	0.499	0.531	0.511	<b>0.491</b>
Harwich	0.564	0.654	0.633	0.613
Sheerness	0.886	<b>0.851</b>	<b>0.831</b>	<b>0.810</b>
Jersey	0.374	0.403	0.379	<b>0.356</b>
St Marys	0.283	<b>0.260</b>	<b>0.276</b>	0.296
Newlyn	0.264	0.283	<b>0.262</b>	<b>0.241</b>
Plymouth	0.270	0.297	0.278	<b>0.258</b>
Weymouth	0.316	<b>0.304</b>	0.324	0.343
Bournemouth	0.235	0.256	0.237	<b>0.218</b>
Portsmouth	0.640	<b>0.549</b>	<b>0.529</b>	<b>0.509</b>
Newhaven	0.313	0.466	0.445	0.424
Dover	0.665	<b>0.656</b>	0.674	0.691
Mean	0.502	0.513	0.511	0.510

**Table B3:** Max |error| for residual water level for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Residual: Scatter index

Port	CS3X	P1010	P1012	P1014
Ilfracombe	0.417	<b>0.386</b>	<b>0.387</b>	<b>0.388</b>
Hinkley Point	0.650	<b>0.609</b>	<b>0.617</b>	<b>0.626</b>
Avonmouth	0.787	0.792	0.793	0.796
Newport	0.669	<b>0.640</b>	<b>0.640</b>	<b>0.641</b>
Mumbles	0.446	<b>0.397</b>	<b>0.401</b>	<b>0.404</b>
Milford Haven	0.333	<b>0.322</b>	<b>0.322</b>	<b>0.322</b>
Fishguard	0.331	<b>0.321</b>	<b>0.321</b>	<b>0.321</b>
Barmouth	0.386	<b>0.360</b>	<b>0.360</b>	<b>0.360</b>
Holyhead	0.302	<b>0.278</b>	<b>0.278</b>	<b>0.278</b>
Llandudno	0.372	<b>0.364</b>	<b>0.365</b>	<b>0.365</b>
Liverpool	0.407	<b>0.388</b>	<b>0.388</b>	<b>0.387</b>
Heysham	0.362	0.369	0.367	0.366
Port Erin	0.258	<b>0.250</b>	<b>0.250</b>	<b>0.250</b>
Workington	0.311	<b>0.311</b>	<b>0.310</b>	<b>0.310</b>
Portpatrick	0.318	<b>0.295</b>	<b>0.295</b>	<b>0.295</b>
Millport	0.335	<b>0.329</b>	<b>0.329</b>	<b>0.329</b>
Tobermory	0.344	<b>0.304</b>	<b>0.304</b>	<b>0.304</b>
Ullapool	0.400	<b>0.375</b>	<b>0.376</b>	<b>0.376</b>
Stornoway	0.366	<b>0.358</b>	<b>0.358</b>	<b>0.358</b>
Kinlochbervie	0.374	<b>0.348</b>	<b>0.348</b>	<b>0.348</b>
Lerwick	0.381	0.382	0.382	0.382
Aberdeen	0.393	<b>0.387</b>	<b>0.387</b>	<b>0.387</b>
Leith	0.514	0.515	0.515	0.515
North Shields	0.381	<b>0.365</b>	<b>0.365</b>	<b>0.365</b>
Whitby	0.394	0.394	0.395	0.396
Immingham	0.501	0.584	0.579	0.575
Cromer	0.407	<b>0.405</b>	<b>0.406</b>	<b>0.406</b>
Lowestoft	0.314	<b>0.298</b>	<b>0.297</b>	<b>0.297</b>
Harwich	0.402	<b>0.392</b>	<b>0.392</b>	<b>0.393</b>
Sheerness	0.398	0.435	0.435	0.435
Jersey	0.531	<b>0.496</b>	<b>0.504</b>	<b>0.511</b>
St Marys	0.410	<b>0.405</b>	<b>0.406</b>	<b>0.407</b>
Newlyn	0.338	<b>0.327</b>	<b>0.328</b>	<b>0.328</b>
Plymouth	0.358	<b>0.346</b>	<b>0.347</b>	<b>0.347</b>
Weymouth	0.376	<b>0.362</b>	<b>0.363</b>	<b>0.363</b>
Bournemouth	0.418	<b>0.402</b>	<b>0.403</b>	<b>0.404</b>
Portsmouth	0.449	<b>0.417</b>	<b>0.417</b>	<b>0.418</b>
Newhaven	0.426	<b>0.396</b>	<b>0.400</b>	<b>0.403</b>
Dover	0.473	<b>0.455</b>	<b>0.455</b>	<b>0.457</b>
Mean	0.411	<b>0.399</b>	<b>0.400</b>	<b>0.400</b>

**Table B4:** Scatter index for residual water level for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Residual: Normalised standard deviation

Port	CS3X	P1010	P1012	P1014
Ilfracombe	0.960	0.930	0.929	0.928
Hinkley Point	0.790	0.756	0.753	0.749
Avonmouth	0.578	<b>0.664</b>	<b>0.655</b>	<b>0.648</b>
Newport	0.744	<b>0.768</b>	<b>0.761</b>	<b>0.756</b>
Mumbles	0.966	0.900	0.899	0.898
Milford Haven	0.948	0.931	0.931	0.930
Fishguard	1.000	0.968	0.968	0.968
Barmouth	0.972	0.911	0.910	0.910
Holyhead	1.037	<b>1.003</b>	<b>1.003</b>	<b>1.002</b>
Llandudno	0.995	0.947	0.946	0.946
Liverpool	1.003	0.949	0.948	0.948
Heysham	0.996	0.955	0.955	0.954
Port Erin	0.991	0.983	0.982	0.982
Workington	1.018	<b>0.997</b>	<b>0.997</b>	<b>0.996</b>
Portpatrick	1.028	0.961	0.961	0.961
Millport	1.050	<b>0.994</b>	<b>0.994</b>	<b>0.993</b>
Tobermory	1.145	<b>1.026</b>	<b>1.026</b>	<b>1.026</b>
Ullapool	1.127	<b>1.069</b>	<b>1.069</b>	<b>1.069</b>
Stornoway	1.070	<b>1.034</b>	<b>1.034</b>	<b>1.034</b>
Kinlochbervie	1.124	<b>1.066</b>	<b>1.066</b>	<b>1.066</b>
Lerwick	0.991	0.973	0.973	0.973
Aberdeen	0.976	<b>1.016</b>	<b>1.015</b>	<b>1.015</b>
Leith	0.959	<b>0.996</b>	<b>0.996</b>	<b>0.996</b>
North Shields	0.930	<b>0.969</b>	<b>0.969</b>	<b>0.969</b>
Whitby	0.900	<b>0.940</b>	<b>0.940</b>	<b>0.940</b>
Immingham	0.966	<b>1.025</b>	<b>1.025</b>	<b>1.025</b>
Cromer	1.018	<b>1.012</b>	<b>1.012</b>	<b>1.012</b>
Lowestoft	1.014	<b>1.006</b>	<b>1.006</b>	<b>1.006</b>
Harwich	0.981	<b>0.985</b>	<b>0.985</b>	<b>0.985</b>
Sheerness	1.051	1.056	1.056	1.055
Jersey	0.855	0.837	0.836	0.835
St Marys	0.955	0.934	0.934	0.934
Newlyn	0.931	0.911	0.911	0.911
Plymouth	0.913	0.890	0.889	0.889
Weymouth	0.970	0.941	0.941	0.941
Bournemouth	0.962	0.951	0.951	0.951
Portsmouth	0.905	0.897	0.897	0.896
Newhaven	0.932	0.926	0.925	0.924
Dover	0.899	<b>0.899</b>	0.899	0.898
Mean	0.965	0.948	0.947	0.947

**Table B5:** Normalised STD for residual water level for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Residual: Correlation

Port	CS3X	P1010	P1012	P1014
Ilfracombe	0.910	<b>0.923</b>	<b>0.922</b>	<b>0.922</b>
Hinkley Point	0.760	<b>0.794</b>	<b>0.787</b>	<b>0.781</b>
Avonmouth	0.618	0.613	0.611	0.607
Newport	0.743	<b>0.769</b>	<b>0.769</b>	<b>0.767</b>
Mumbles	0.898	<b>0.918</b>	<b>0.916</b>	<b>0.915</b>
Milford Haven	0.943	<b>0.947</b>	<b>0.947</b>	<b>0.947</b>
Fishguard	0.945	<b>0.947</b>	<b>0.947</b>	<b>0.947</b>
Barmouth	0.924	<b>0.933</b>	<b>0.933</b>	<b>0.933</b>
Holyhead	0.957	<b>0.961</b>	<b>0.961</b>	<b>0.961</b>
Llandudno	0.930	<b>0.931</b>	<b>0.931</b>	<b>0.931</b>
Liverpool	0.918	<b>0.922</b>	<b>0.922</b>	<b>0.922</b>
Heysham	0.934	0.930	0.930	0.931
Port Erin	0.967	<b>0.968</b>	<b>0.968</b>	<b>0.968</b>
Workington	0.953	0.952	0.952	0.952
Portpatrick	0.951	<b>0.956</b>	<b>0.956</b>	<b>0.956</b>
Millport	0.948	0.946	0.946	0.946
Tobermory	0.957	0.955	0.955	0.955
Ullapool	0.936	<b>0.936</b>	<b>0.936</b>	<b>0.936</b>
Stornoway	0.940	0.939	0.939	0.939
Kinlochbervie	0.945	<b>0.945</b>	<b>0.945</b>	<b>0.945</b>
Lerwick	0.927	0.925	0.925	0.926
Aberdeen	0.921	<b>0.926</b>	<b>0.926</b>	<b>0.926</b>
Leith	0.863	<b>0.867</b>	<b>0.867</b>	<b>0.867</b>
North Shields	0.925	<b>0.932</b>	<b>0.932</b>	<b>0.932</b>
Whitby	0.919	0.919	0.919	0.918
Immingham	0.870	0.834	0.837	0.839
Cromer	0.919	<b>0.919</b>	<b>0.919</b>	<b>0.919</b>
Lowestoft	0.951	<b>0.956</b>	<b>0.956</b>	<b>0.956</b>
Harwich	0.918	<b>0.922</b>	<b>0.922</b>	<b>0.922</b>
Sheerness	0.926	0.912	0.912	0.912
Jersey	0.847	<b>0.869</b>	<b>0.864</b>	<b>0.860</b>
St Marys	0.913	<b>0.914</b>	<b>0.914</b>	<b>0.914</b>
Newlyn	0.941	<b>0.946</b>	<b>0.945</b>	<b>0.945</b>
Plymouth	0.934	<b>0.940</b>	<b>0.939</b>	<b>0.939</b>
Weymouth	0.927	<b>0.932</b>	<b>0.932</b>	<b>0.932</b>
Bournemouth	0.910	<b>0.916</b>	<b>0.916</b>	<b>0.915</b>
Portsmouth	0.894	<b>0.909</b>	<b>0.909</b>	<b>0.909</b>
Newhaven	0.905	<b>0.918</b>	<b>0.917</b>	<b>0.915</b>
Dover	0.881	<b>0.891</b>	<b>0.890</b>	<b>0.890</b>
Mean	0.907	<b>0.911</b>	<b>0.911</b>	<b>0.910</b>

**Table B6:** Correlation for residual water level for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The **green** (**pink**) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

## B.2 Skew surge

### Skew surge: RMS error

Port	CS3X	P1010	P1012	P1014
Ilfracombe	0.101	0.124	0.107	0.091
Hinkley Point	0.116	0.134	0.122	0.112
Avonmouth	0.195	0.190	0.186	0.183
Newport	0.201	0.202	0.186	0.171
Mumbles	0.068	0.074	0.065	0.062
Milford Haven	0.106	0.125	0.108	0.091
Fishguard	0.084	0.099	0.083	0.069
Barmouth	0.081	0.075	0.071	0.072
Holyhead	0.057	0.057	0.050	0.052
Llandudno	0.077	0.076	0.071	0.071
Liverpool	0.108	0.128	0.111	0.095
Heysham	0.083	0.079	0.075	0.075
Port Erin	-	-	-	-
Workington	0.111	0.085	0.097	0.113
Portpatrick	0.071	0.072	0.065	0.064
Millport	0.083	0.072	0.074	0.082
Tobermory	0.068	0.059	0.057	0.061
Ullapool	0.083	0.070	0.075	0.085
Stornoway	0.066	0.065	0.063	0.066
Kinlochbervie	0.077	0.067	0.070	0.078
Lerwick	0.054	0.053	0.055	0.062
Aberdeen	0.068	0.058	0.068	0.082
Leith	0.072	0.088	0.079	0.073
North Shields	0.062	0.069	0.059	0.054
Whitby	0.138	0.154	0.136	0.118
Immingham	0.128	0.111	0.121	0.133
Cromer	0.115	0.115	0.112	0.111
Lowestoft	0.069	0.078	0.068	0.063
Harwich	0.116	0.151	0.138	0.127
Sheerness	0.087	0.137	0.130	0.124
Jersey	-	-	-	-
St Marys	0.082	0.098	0.083	0.070
Newlyn	0.090	0.110	0.092	0.076
Plymouth	0.075	0.094	0.078	0.064
Weymouth	0.048	0.055	0.046	0.045
Bournemouth	0.077	0.089	0.072	0.057
Portsmouth	0.083	0.100	0.083	0.069
Newhaven	0.071	0.076	0.066	0.061
Dover	0.106	0.121	0.109	0.099
Mean	0.091	0.098	0.090	0.086

**Table B7:** RMS error for skew surge for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Skew surge: Mean error

Port	CS3X	P1010	P1012	P1014
Ilfracombe	-0.076	<b>-0.107</b>	-0.087	<b>-0.067</b>
Hinkley Point	<b>-0.044</b>	<b>-0.087</b>	-0.066	-0.045
Avonmouth	-0.039	<b>-0.062</b>	-0.043	<b>-0.024</b>
Newport	-0.148	<b>-0.168</b>	-0.148	<b>-0.129</b>
Mumbles	-0.009	<b>-0.042</b>	-0.022	<b>-0.002</b>
Milford Haven	-0.086	<b>-0.111</b>	-0.092	<b>-0.072</b>
Fishguard	-0.063	<b>-0.084</b>	-0.064	<b>-0.045</b>
Barmouth	<b>0.004</b>	<b>-0.025</b>	-0.006	0.014
Holyhead	<b>-0.001</b>	<b>-0.027</b>	-0.007	0.013
Llandudno	<b>0.001</b>	<b>-0.030</b>	-0.010	0.011
Liverpool	-0.076	<b>-0.109</b>	-0.088	<b>-0.068</b>
Heysham	0.010	<b>-0.027</b>	<b>-0.008</b>	0.011
Port Erin	-	-	-	-
Workington	0.075	<b>0.038</b>	<b>0.061</b>	<b>0.083</b>
Portpatrick	<b>-0.001</b>	<b>-0.034</b>	-0.013	0.007
Millport	0.029	<b>-0.002</b>	<b>0.018</b>	<b>0.039</b>
Tobermory	0.003	-0.017	<b>0.003</b>	<b>0.022</b>
Ullapool	0.031	<b>0.009</b>	<b>0.028</b>	<b>0.047</b>
Stornoway	0.003	-0.017	<b>0.003</b>	<b>0.022</b>
Kinlochbervie	0.023	<b>0.001</b>	<b>0.020</b>	<b>0.040</b>
Lerwick	0.010	<b>-0.006</b>	0.014	<b>0.033</b>
Aberdeen	0.037	<b>0.023</b>	0.043	<b>0.063</b>
Leith	-0.024	<b>-0.050</b>	-0.030	<b>-0.010</b>
North Shields	-0.022	<b>-0.042</b>	<b>-0.022</b>	<b>-0.002</b>
Whitby	-0.124	<b>-0.143</b>	<b>-0.123</b>	<b>-0.103</b>
Immingham	0.087	<b>0.063</b>	<b>0.080</b>	<b>0.097</b>
Cromer	-0.016	<b>-0.030</b>	<b>-0.011</b>	<b>0.009</b>
Lowestoft	-0.026	<b>-0.046</b>	<b>-0.025</b>	<b>-0.005</b>
Harwich	-0.065	<b>-0.104</b>	-0.084	<b>-0.064</b>
Sheerness	<b>-0.020</b>	<b>-0.064</b>	-0.045	-0.027
Jersey	-	-	-	-
St Marys	-0.056	<b>-0.080</b>	-0.060	<b>-0.040</b>
Newlyn	-0.075	<b>-0.099</b>	-0.079	<b>-0.059</b>
Plymouth	-0.054	<b>-0.081</b>	-0.061	<b>-0.042</b>
Weymouth	-0.007	<b>-0.032</b>	-0.014	<b>0.005</b>
Bournemouth	-0.064	<b>-0.079</b>	<b>-0.060</b>	<b>-0.040</b>
Portsmouth	-0.059	<b>-0.083</b>	-0.063	<b>-0.042</b>
Newhaven	-0.025	<b>-0.047</b>	-0.027	<b>-0.007</b>
Dover	-0.050	<b>-0.079</b>	-0.059	<b>-0.039</b>
Mean	-0.025	<b>-0.051</b>	-0.031	<b>-0.011</b>

**Table B8:** Mean error for skew surge for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The **green** (**pink**) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

Skew surge: Max |error|

Port	CS3X	P1010	P1012	P1014
Ilfracombe	0.277	0.325	0.306	0.287
Hinkley Point	0.396	0.422	0.404	0.385
Avonmouth	0.566	0.567	0.549	0.531
Newport	0.602	0.559	0.541	0.523
Mumbles	0.310	0.386	0.366	0.346
Milford Haven	0.268	0.273	0.254	0.234
Fishguard	0.218	0.254	0.235	0.215
Barmouth	0.388	0.236	0.246	0.265
Holyhead	0.315	0.246	0.266	0.286
Llandudno	0.457	0.486	0.506	0.527
Liverpool	0.322	0.285	0.264	0.250
Heysham	0.399	0.266	0.286	0.305
Port Erin	-	-	-	-
Workington	0.571	0.427	0.450	0.473
Portpatrick	0.410	0.310	0.331	0.351
Millport	0.520	0.382	0.403	0.423
Tobermory	0.401	0.222	0.205	0.224
Ullapool	0.337	0.322	0.342	0.361
Stornoway	0.226	0.178	0.197	0.216
Kinlochbervie	0.326	0.374	0.393	0.412
Lerwick	0.223	0.249	0.269	0.288
Aberdeen	0.235	0.227	0.247	0.267
Leith	0.259	0.308	0.306	0.327
North Shields	0.245	0.222	0.202	0.218
Whitby	0.387	0.414	0.394	0.373
Immingham	0.409	0.359	0.375	0.391
Cromer	1.015	1.017	1.035	1.053
Lowestoft	0.292	0.391	0.371	0.352
Harwich	0.485	0.563	0.542	0.521
Sheerness	0.394	0.502	0.481	0.460
Jersey	-	-	-	-
St Marys	0.280	0.257	0.276	0.296
Newlyn	0.216	0.228	0.208	0.189
Plymouth	0.201	0.297	0.278	0.258
Weymouth	0.180	0.189	0.170	0.172
Bournemouth	0.217	0.226	0.206	0.185
Portsmouth	0.307	0.243	0.224	0.204
Newhaven	0.270	0.269	0.250	0.230
Dover	0.322	0.427	0.407	0.387
Mean	0.358	0.349	0.345	0.346

**Table B9:** Max |error| for skew surge for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).



### Skew surge: Scatter index

Port	CS3X	P1010	P1012	P1014
Ilfracombe	0.433	<b>0.397</b>	<b>0.397</b>	<b>0.398</b>
Hinkley Point	0.607	<b>0.576</b>	<b>0.579</b>	<b>0.581</b>
Avonmouth	0.860	<b>0.810</b>	<b>0.812</b>	<b>0.815</b>
Newport	0.689	<b>0.573</b>	<b>0.575</b>	<b>0.576</b>
Mumbles	0.414	<b>0.375</b>	<b>0.376</b>	<b>0.377</b>
Milford Haven	0.374	<b>0.341</b>	<b>0.342</b>	<b>0.342</b>
Fishguard	0.352	<b>0.330</b>	<b>0.330</b>	<b>0.330</b>
Barmouth	0.397	<b>0.347</b>	<b>0.347</b>	<b>0.347</b>
Holyhead	0.318	<b>0.281</b>	<b>0.281</b>	<b>0.281</b>
Llandudno	0.412	<b>0.377</b>	<b>0.377</b>	<b>0.377</b>
Liverpool	0.397	<b>0.346</b>	<b>0.346</b>	<b>0.346</b>
Heysham	0.381	<b>0.346</b>	<b>0.345</b>	<b>0.345</b>
Port Erin	-	-	-	-
Workington	0.384	<b>0.353</b>	<b>0.354</b>	<b>0.354</b>
Portpatrick	0.347	<b>0.307</b>	<b>0.307</b>	<b>0.307</b>
Millport	0.344	<b>0.315</b>	<b>0.315</b>	<b>0.315</b>
Tobermory	0.344	<b>0.285</b>	<b>0.285</b>	<b>0.285</b>
Ullapool	0.412	<b>0.376</b>	<b>0.376</b>	<b>0.376</b>
Stornoway	0.381	<b>0.360</b>	<b>0.361</b>	<b>0.361</b>
Kinlochbervie	0.376	<b>0.342</b>	<b>0.342</b>	<b>0.342</b>
Lerwick	0.359	0.359	0.359	0.359
Aberdeen	0.378	<b>0.355</b>	<b>0.355</b>	<b>0.355</b>
Leith	0.456	0.494	0.493	0.493
North Shields	0.385	<b>0.358</b>	<b>0.358</b>	<b>0.358</b>
Whitby	0.367	<b>0.348</b>	<b>0.348</b>	<b>0.348</b>
Immingham	0.484	<b>0.474</b>	<b>0.473</b>	<b>0.472</b>
Cromer	0.590	<b>0.574</b>	<b>0.574</b>	<b>0.574</b>
Lowestoft	0.311	<b>0.305</b>	<b>0.305</b>	<b>0.305</b>
Harwich	0.508	0.580	0.580	0.580
Sheerness	0.429	0.614	0.613	0.613
Jersey	-	-	-	-
St Marys	0.451	<b>0.426</b>	<b>0.426</b>	<b>0.426</b>
Newlyn	0.350	<b>0.334</b>	<b>0.334</b>	<b>0.334</b>
Plymouth	0.354	<b>0.340</b>	<b>0.340</b>	<b>0.340</b>
Weymouth	0.356	<b>0.335</b>	<b>0.335</b>	<b>0.334</b>
Bournemouth	0.385	<b>0.375</b>	<b>0.375</b>	<b>0.376</b>
Portsmouth	0.379	<b>0.356</b>	<b>0.357</b>	<b>0.358</b>
Newhaven	0.455	<b>0.410</b>	<b>0.411</b>	<b>0.412</b>
Dover	0.482	<b>0.472</b>	<b>0.472</b>	<b>0.472</b>
Mean	0.424	<b>0.404</b>	<b>0.404</b>	<b>0.405</b>

**Table B10:** Scatter index for skew surge for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).



### Skew surge: Normalised standard deviation

Port	CS3X	P1010	P1012	P1014
Ilfracombe	1.003	0.924	0.924	0.924
Hinkley Point	0.952	0.890	0.888	0.886
Avonmouth	0.676	0.606	0.604	0.603
Newport	1.116	0.792	0.790	0.789
Mumbles	1.016	0.920	0.920	0.920
Milford Haven	0.988	0.930	0.930	0.929
Fishguard	1.016	0.963	0.963	0.963
Barmouth	0.913	0.915	0.914	0.914
Holyhead	1.045	1.018	1.018	1.018
Llandudno	1.046	0.975	0.976	0.976
Liverpool	1.081	1.009	1.008	1.008
Heysham	0.957	0.878	0.878	0.878
Port Erin	-	-	-	-
Workington	1.139	1.109	1.108	1.107
Portpatrick	1.076	0.991	0.991	0.991
Millport	1.077	1.010	1.010	1.010
Tobermory	1.137	1.006	1.006	1.006
Ullapool	1.140	1.083	1.083	1.084
Stornoway	1.072	1.034	1.035	1.035
Kinlochbervie	1.125	1.073	1.073	1.074
Lerwick	0.989	0.967	0.967	0.967
Aberdeen	0.947	0.981	0.981	0.981
Leith	0.908	0.909	0.908	0.908
North Shields	0.865	0.925	0.925	0.925
Whitby	0.866	0.911	0.910	0.910
Immingham	0.862	0.844	0.845	0.845
Cromer	1.053	1.060	1.060	1.059
Lowestoft	1.006	1.006	1.006	1.005
Harwich	0.967	0.977	0.976	0.976
Sheerness	0.943	1.015	1.015	1.014
Jersey	-	-	-	-
St Marys	0.975	0.930	0.930	0.930
Newlyn	0.936	0.906	0.906	0.906
Plymouth	0.914	0.905	0.904	0.904
Weymouth	0.987	0.914	0.914	0.914
Bournemouth	0.990	0.939	0.939	0.940
Portsmouth	0.973	0.908	0.908	0.908
Newhaven	0.943	0.917	0.917	0.917
Dover	0.932	0.896	0.896	0.896
Mean	0.990	0.947	0.947	0.946

**Table B11:** Normalised STD for skew surge for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

### Skew surge: Correlation

Port	CS3X	P1010	P1012	P1014
Ilfracombe	0.906	<b>0.918</b>	<b>0.918</b>	<b>0.917</b>
Hinkley Point	0.808	<b>0.820</b>	<b>0.819</b>	<b>0.817</b>
Avonmouth	0.530	<b>0.587</b>	<b>0.583</b>	<b>0.579</b>
Newport	0.793	<b>0.820</b>	<b>0.819</b>	<b>0.818</b>
Mumbles	0.916	<b>0.927</b>	<b>0.927</b>	<b>0.926</b>
Milford Haven	0.929	<b>0.940</b>	<b>0.940</b>	<b>0.940</b>
Fishguard	0.939	<b>0.944</b>	<b>0.944</b>	<b>0.944</b>
Barmouth	0.918	<b>0.938</b>	<b>0.938</b>	<b>0.938</b>
Holyhead	0.952	<b>0.961</b>	<b>0.961</b>	<b>0.961</b>
Llandudno	0.920	<b>0.928</b>	<b>0.928</b>	<b>0.928</b>
Liverpool	0.930	<b>0.941</b>	<b>0.941</b>	<b>0.941</b>
Heysham	0.925	<b>0.940</b>	<b>0.941</b>	<b>0.941</b>
Port Erin	-	-	-	-
Workington	0.944	<b>0.949</b>	<b>0.949</b>	<b>0.948</b>
Portpatrick	0.947	<b>0.952</b>	<b>0.952</b>	<b>0.952</b>
Millport	0.948	<b>0.951</b>	<b>0.951</b>	<b>0.951</b>
Tobermory	0.956	<b>0.960</b>	<b>0.960</b>	<b>0.960</b>
Ullapool	0.934	<b>0.938</b>	<b>0.938</b>	<b>0.938</b>
Stornoway	0.935	<b>0.938</b>	<b>0.938</b>	<b>0.938</b>
Kinlochbervie	0.944	<b>0.948</b>	<b>0.948</b>	<b>0.948</b>
Lerwick	0.935	0.934	0.934	0.934
Aberdeen	0.926	<b>0.936</b>	<b>0.936</b>	<b>0.936</b>
Leith	0.890	0.871	0.871	0.871
North Shields	0.925	<b>0.934</b>	<b>0.934</b>	<b>0.934</b>
Whitby	0.933	<b>0.938</b>	<b>0.938</b>	<b>0.938</b>
Immingham	0.875	<b>0.881</b>	<b>0.882</b>	<b>0.882</b>
Cromer	0.836	<b>0.846</b>	<b>0.846</b>	<b>0.846</b>
Lowestoft	0.952	<b>0.954</b>	<b>0.954</b>	<b>0.954</b>
Harwich	0.867	0.828	0.828	0.828
Sheerness	0.904	0.814	0.815	0.815
Jersey	-	-	-	-
St Marys	0.896	<b>0.905</b>	<b>0.905</b>	<b>0.905</b>
Newlyn	0.937	<b>0.943</b>	<b>0.943</b>	<b>0.943</b>
Plymouth	0.935	<b>0.941</b>	<b>0.941</b>	<b>0.941</b>
Weymouth	0.936	<b>0.943</b>	<b>0.943</b>	<b>0.943</b>
Bournemouth	0.925	<b>0.927</b>	<b>0.927</b>	<b>0.927</b>
Portsmouth	0.926	<b>0.935</b>	<b>0.935</b>	<b>0.934</b>
Newhaven	0.892	<b>0.912</b>	<b>0.912</b>	<b>0.911</b>
Dover	0.878	<b>0.882</b>	<b>0.882</b>	<b>0.882</b>
Mean	0.904	<b>0.909</b>	<b>0.909</b>	<b>0.908</b>

**Table B12:** Correlation for skew surge for the reference pressure tests. Ports are grouped into 'West English & Welsh coast', 'West Scottish coast', 'East coast' and 'South coast' sectors. Results in **bold** are better than the CS3X run. The green (pink) figure shows the best (worst) value at each location (calculated using higher precision figures than are printed here).

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