Modelling Storm Surges in Irish and Celtic Seas using a Finite Element Model (TELEMAC)

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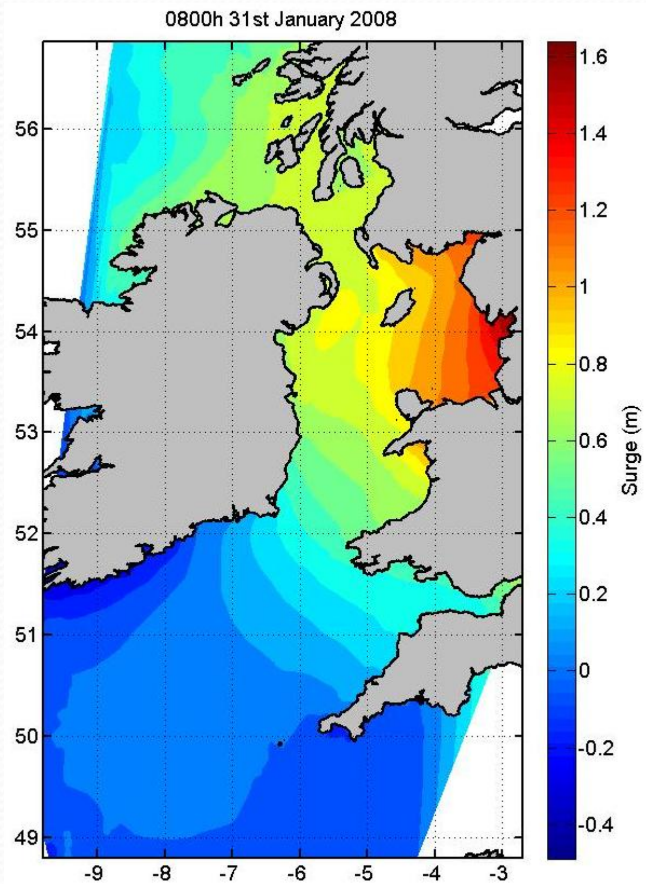
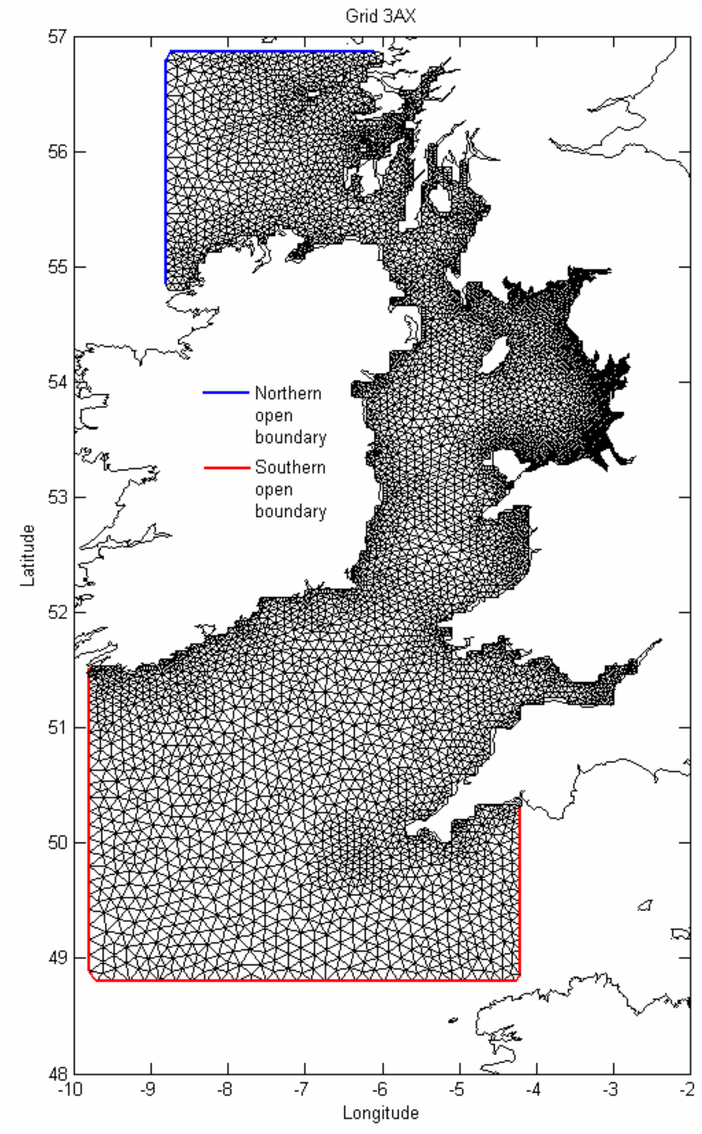


TELEMAC-2D

- Numerical modelling system developed by EDF and the National Hydraulics and Environment Laboratory.
- TELEMAC-2D is the hydrodynamic module: horizontal depth averaged velocities and water depth.
- Solves the depth-averaged (Saint-Venant) free surface flow equations on an irregular grid.
- Used for a range of maritime and fluvial applications and takes into account many physical phenomena including friction, turbulence, wind velocity, variations in atmospheric pressure and lunar and solar tide generating forces.

The Irish Sea tidal model (3AX) (Jones and Davies, 2005)



- Irregular grid with triangular elements.
- Ratio between the triangular element size and $(gh)^{1/2}$ is constant.
- 2d vertically integrated hydrodynamic equations (elevation and two components of velocity) solved at each triangle point (node).
- Equations solved in spherical coordinates:

Surface elevation

$$\frac{\partial \eta}{\partial t} + \frac{1}{R\cos\varphi}\frac{\partial}{\partial \varphi} V\cos\varphi + \frac{1}{R\cos\varphi}\frac{\partial}{\partial \chi} U = 0$$

U-Velocity

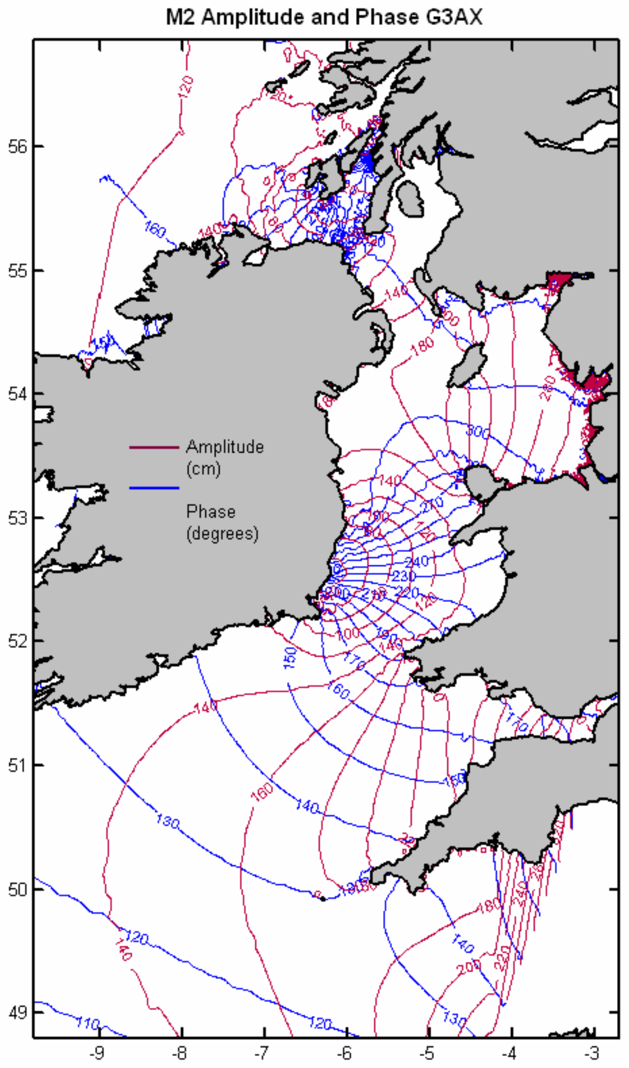
$$\frac{\partial U}{\partial t} + S_u - 2\omega\sin\varphi V = \frac{-g}{R\cos\varphi}\frac{\partial \eta}{\partial \chi} + \frac{\tau_\chi}{\rho(h+\eta)}$$

V-Velocity

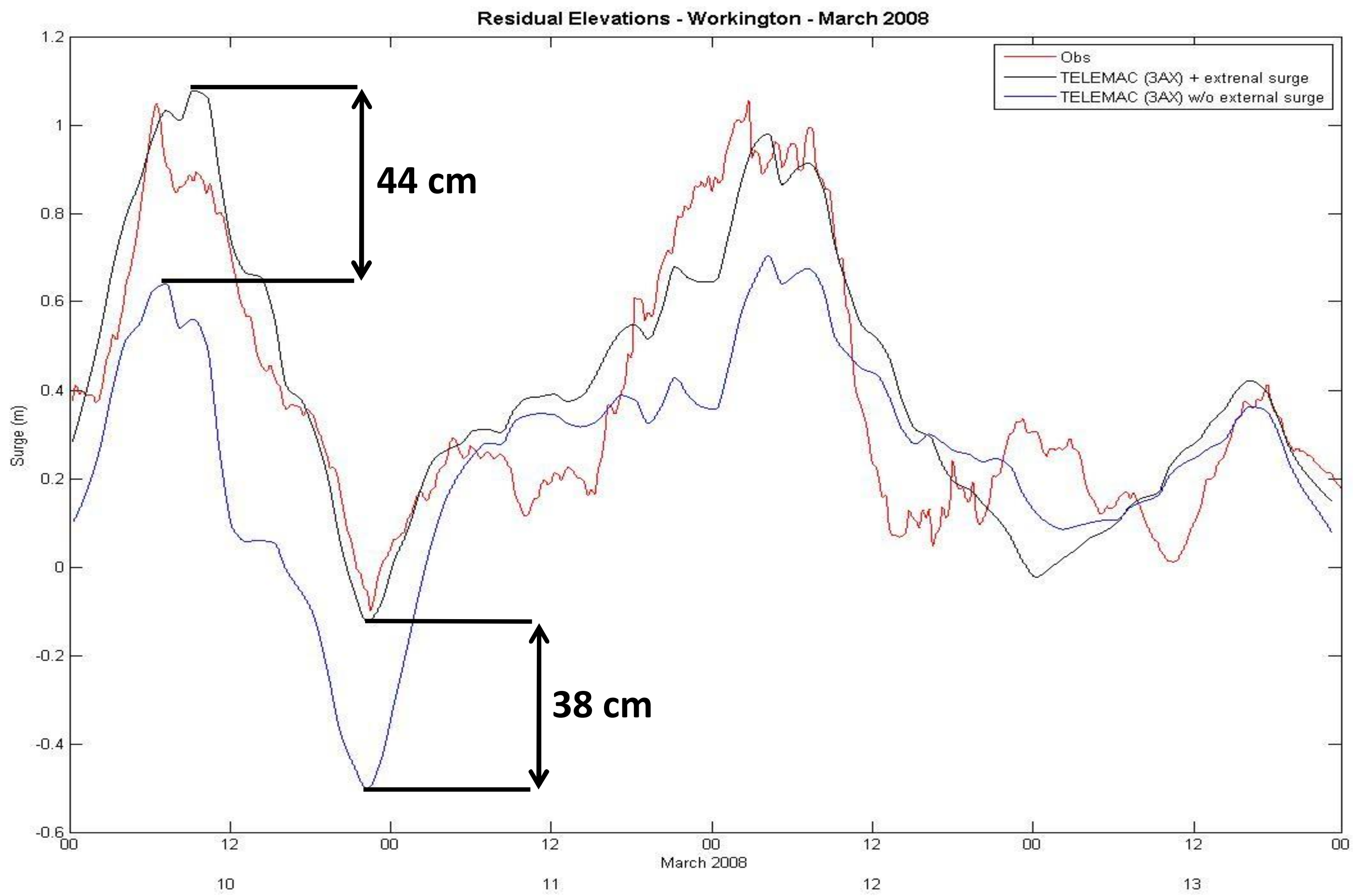
$$\frac{\partial V}{\partial t} + S_v + 2\omega\sin\varphi U = \frac{-g}{R}\frac{\partial \eta}{\partial \varphi} + \frac{\tau_\varphi}{\rho(h+\eta)}$$

Modelling the tides

- Spatial distribution of co-phase and co-amplitude lines in good agreement with co-tidal charts based on observations.
- Increasing tidal amplitudes in Liverpool Bay and the Bristol Channel as water depths decrease.
- Bias in elevation amplitude in finite difference solution is removed in finite element calculation.
- Average deviation in amplitude and phase from observations is 7.51 cm and 2.14^{o}.



External Surge



Disadvantages of finite difference models

Finite difference models use a uniform grid therefore:

- Resolution of near shore points is the same as for those in deep water.
- Need a nested model with higher resolution to cover shallow areas requiring information of tide and surge propagation.
- Poor representation of the coastline leads to a 'stair casing' effect that corrupts the near shore tidal signal and causes artificial vorticity.
- Cannot resolve small scale flow features such as gyres and eddies.

Advantages of finite element models

- Higher resolution in shallow areas where tide shows greatest spatial variability over rapidly changing bathymetry.

- Can resolve offshore features with rapidly changing bathymetry such as the North Channel.

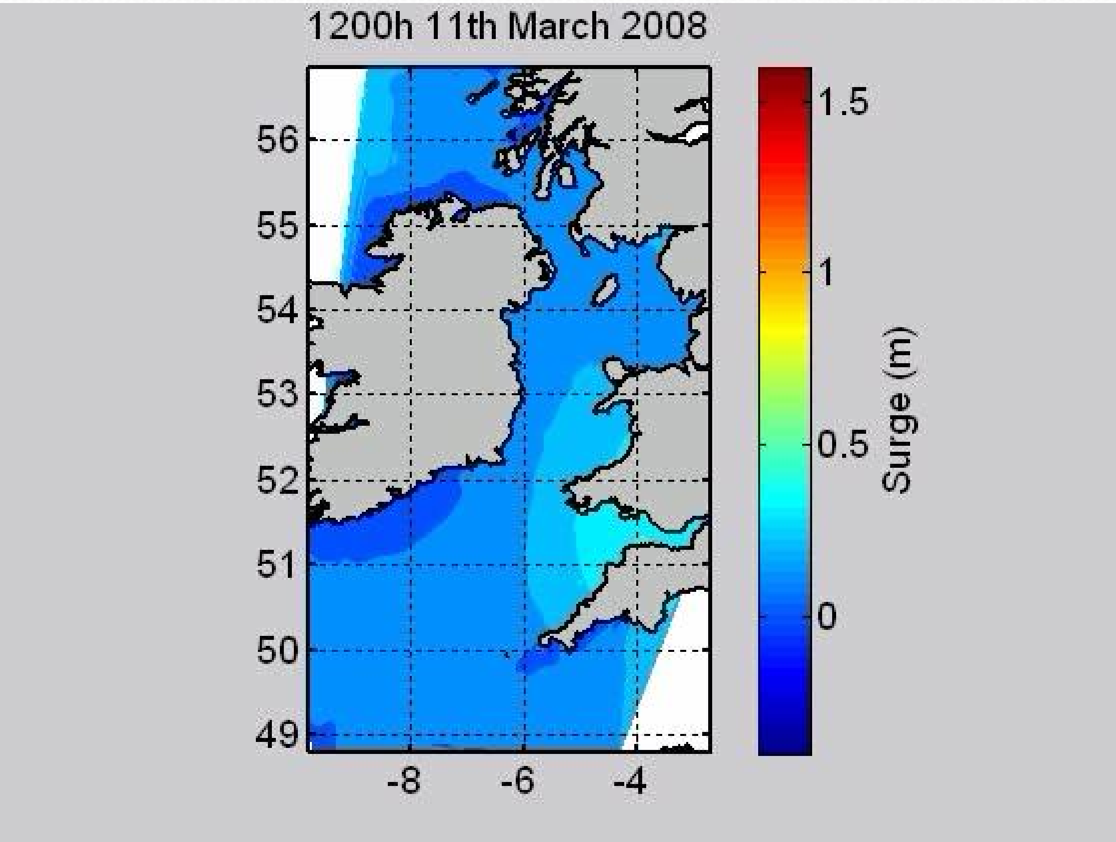
- Better representation of surface wind stress in shallow water giving more accurate surge predictions.

- Can represent areas of ‘wetting and drying’ more accurately and the effect this has on the tide.

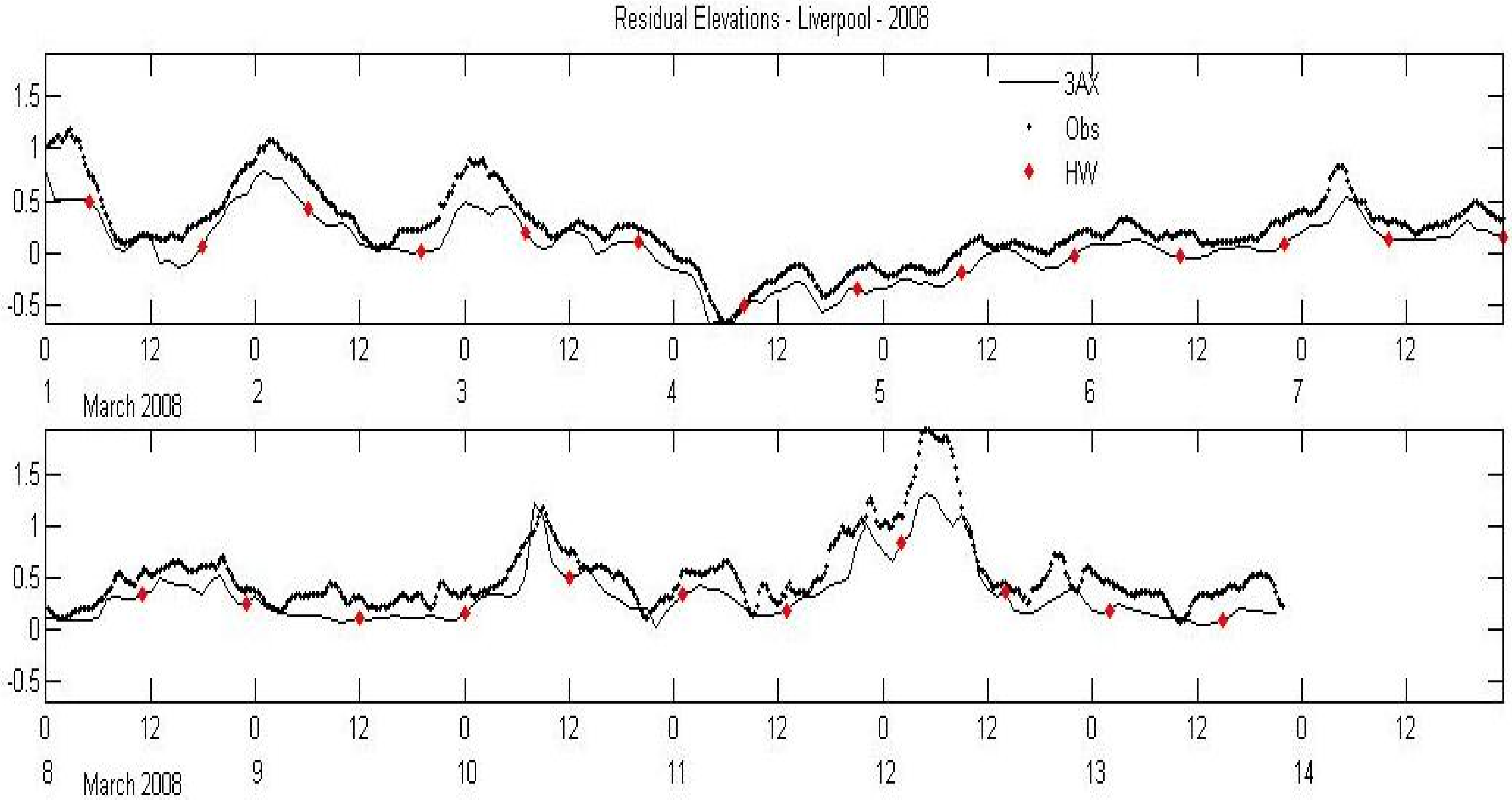
Carrying out a season simulation

- Tide only simulation carried out.
- Tidal simulation with met forcing from Met Office ‘mesoscale’ weather forecast model interpolated onto the operational grid (CS3X) and applied in the simulation using a nearest node look-up table.
- External surge added to boundary points as residual elevations from nearest nodes on CS3X.
- Tide only solution taken away from the tide + surge solution to give the residual currents and elevations.

March 2008 Event

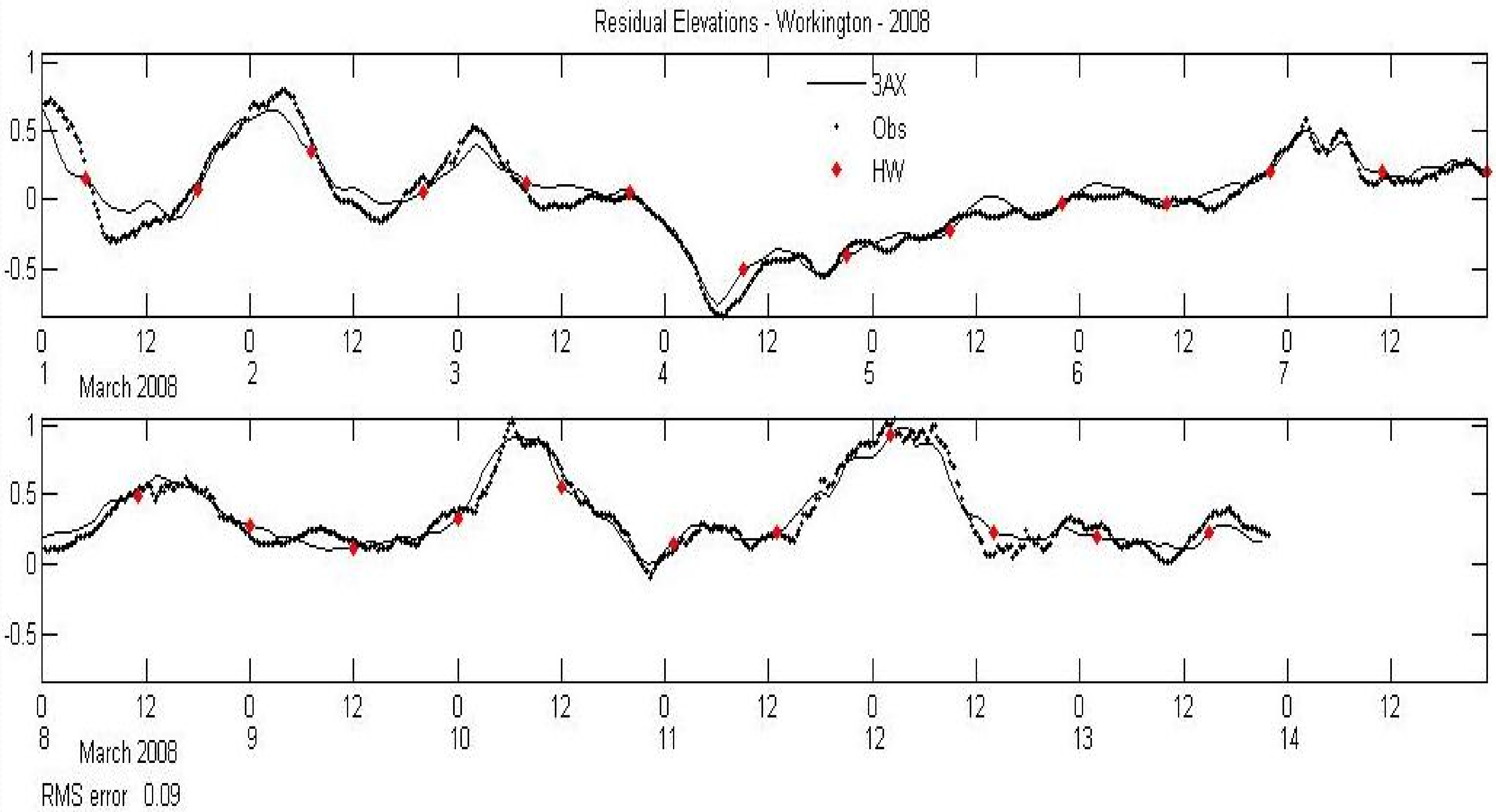


March 2008 Event

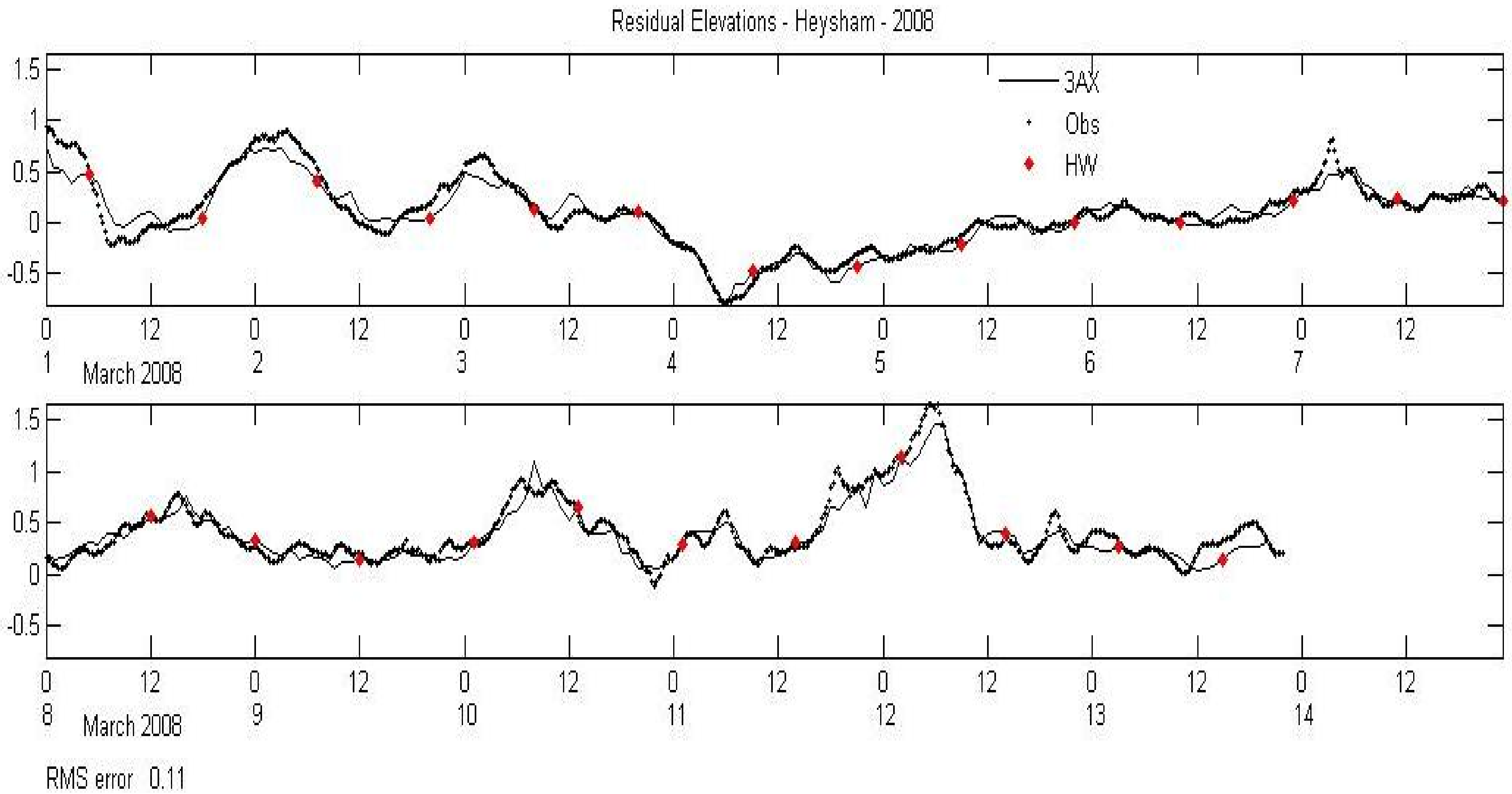


RMS error 0.22

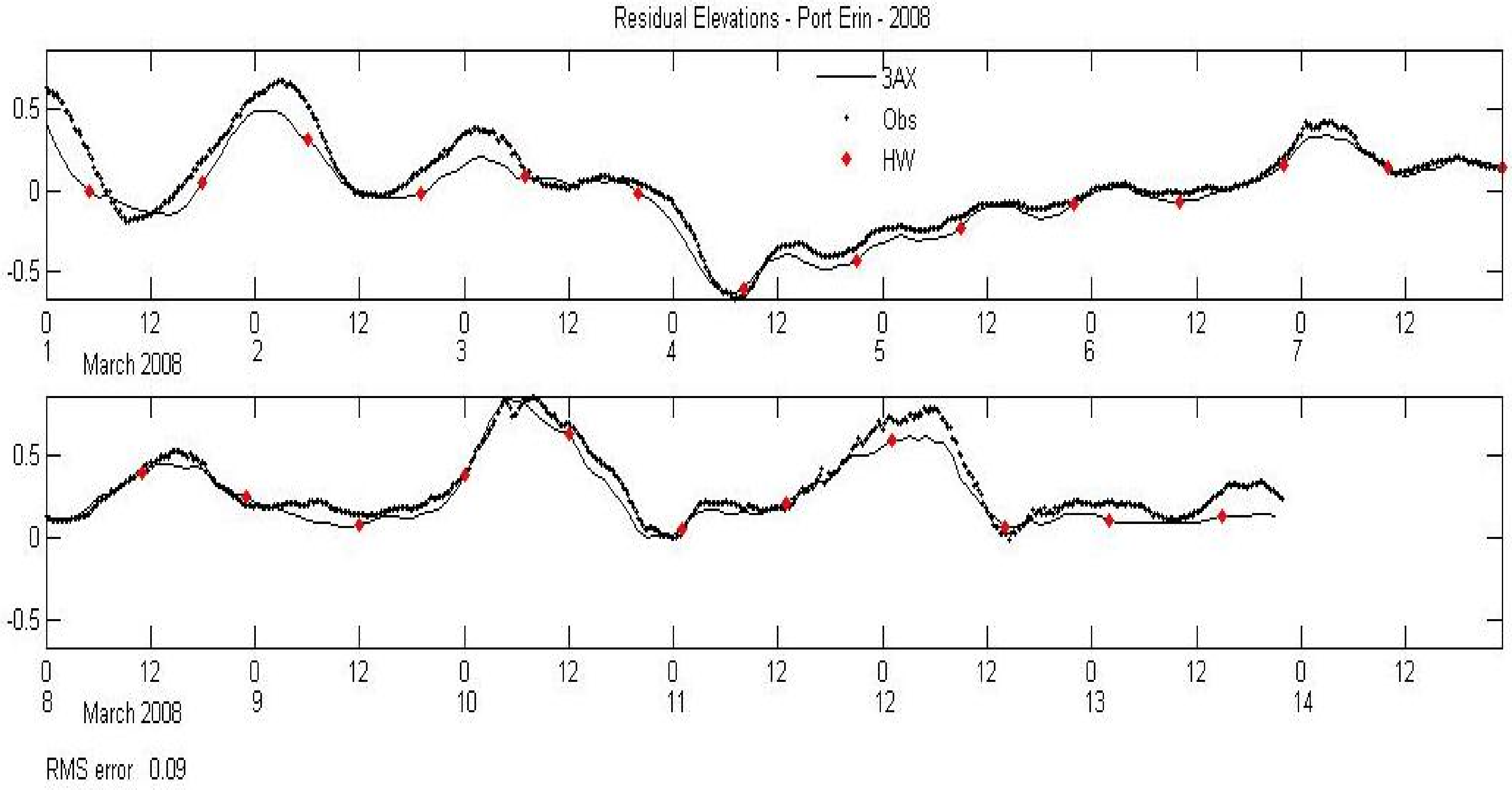
March 2008 Event



March 2008 Event

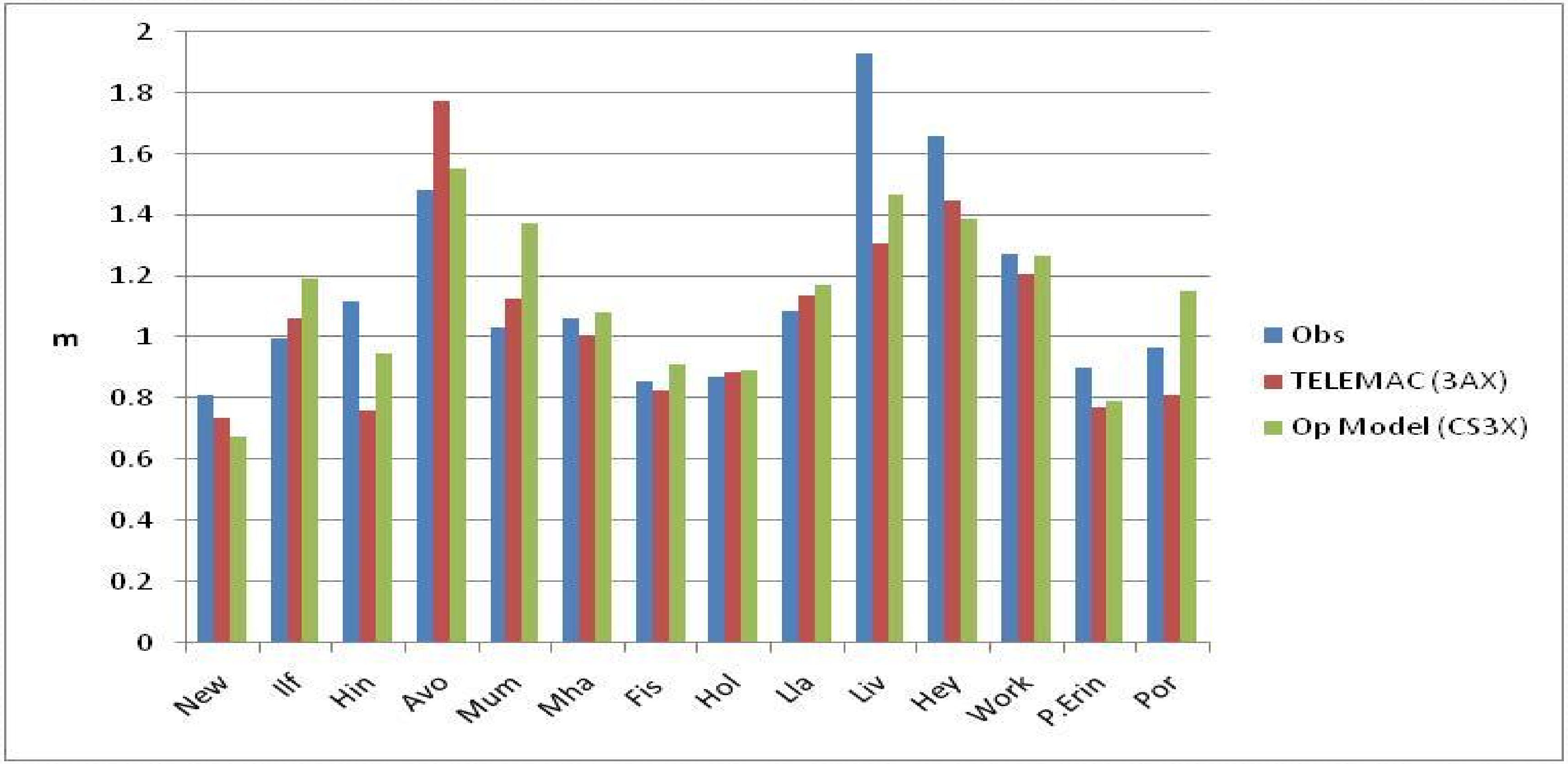


March 2008 Event



RMS Errors Oct 07 – Mar 08 (Simulated residual vs. obs residual)		
Port	**TELEMAC (3AX)**	**Operational Model (CS3X)**
Newlyn	0.11	0.11
Ilfracombe	0.12	0.12
Hinkley Point	0.16	0.15
Avonmouth	0.24	0.23
Mumbles	0.22	0.22
Milford Haven	0.11	0.13
Fishguard	0.07	0.06
Holyhead	0.07	0.07
Llandudno	0.09	0.09
Liverpool	0.14	0.14
Heysham	0.1	0.1
Workington	0.12	0.11
Port Erin	0.07	0.07
Portpatrick	0.08	0.08
Average RMS error	0.12	0.12

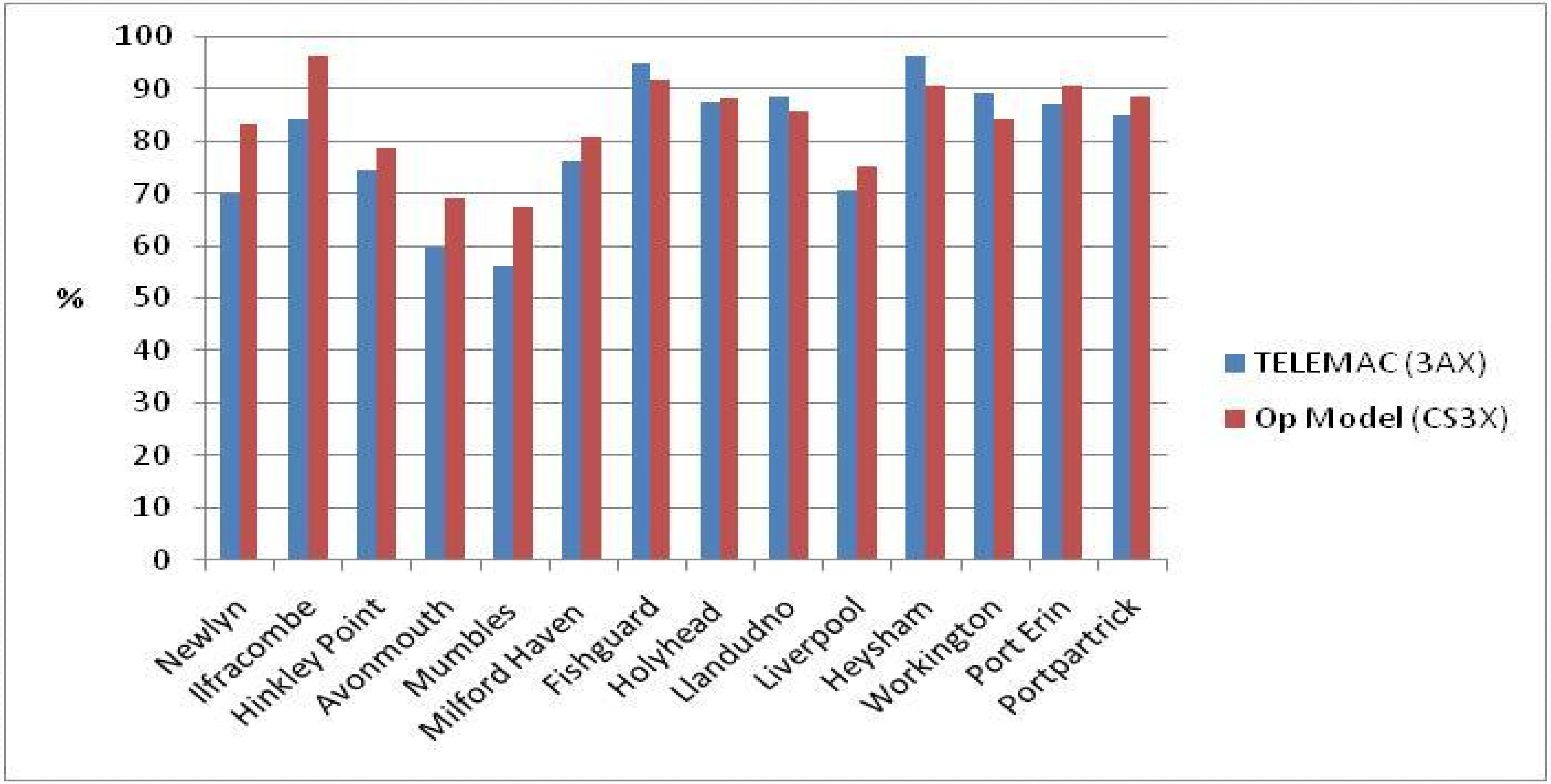
Peak Residuals



• Average difference between the highest observed residual and the simulated residual is approximately 15cm for both models.

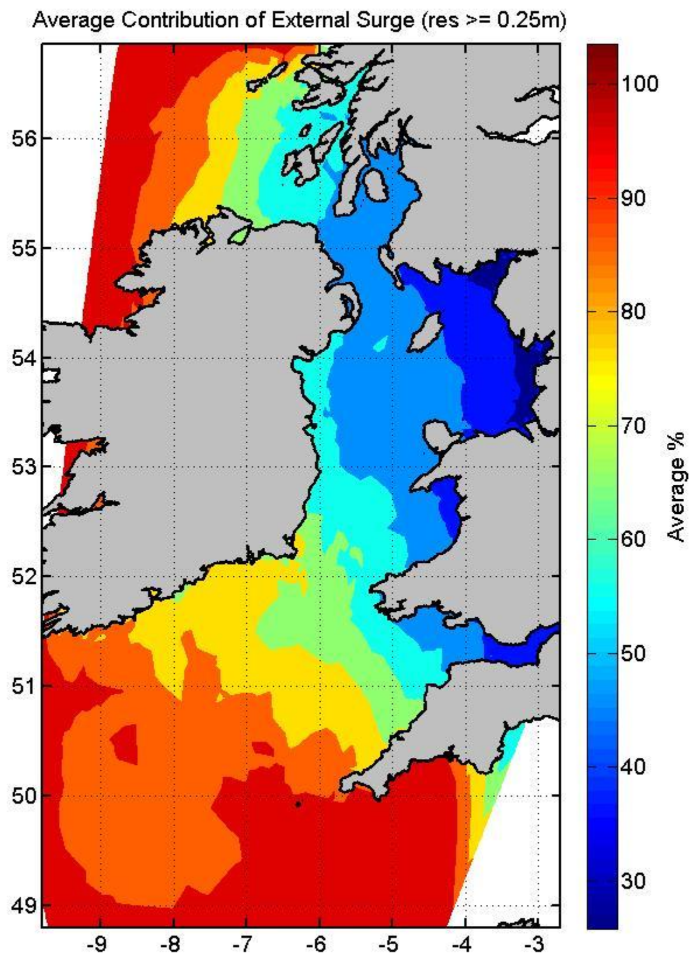
•Both models simulated an average of 87% of highest observed residual.

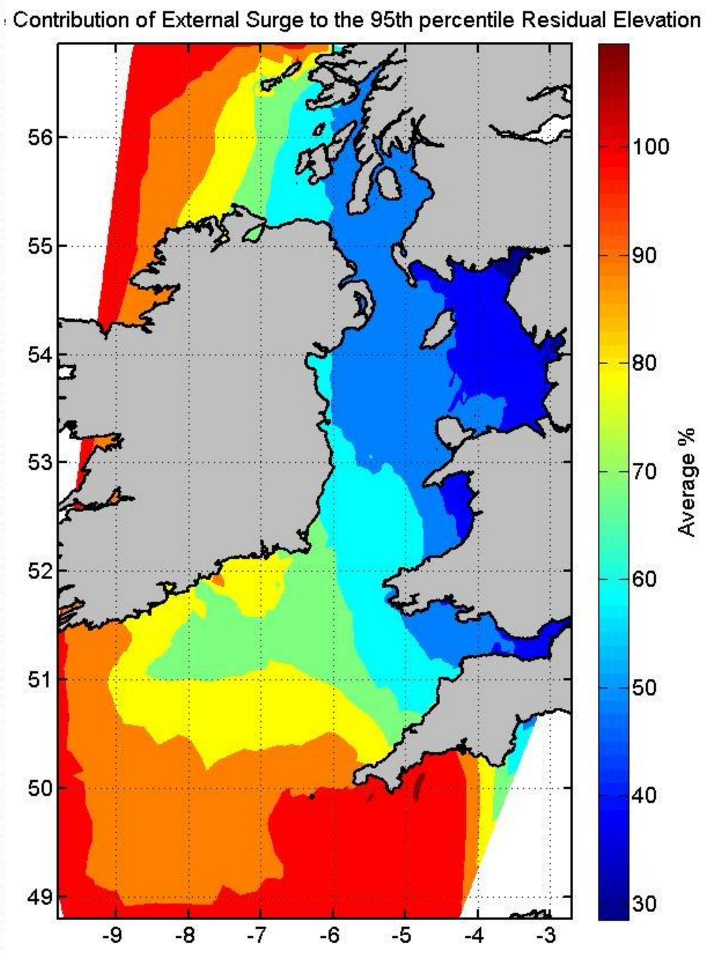
Skew Surge



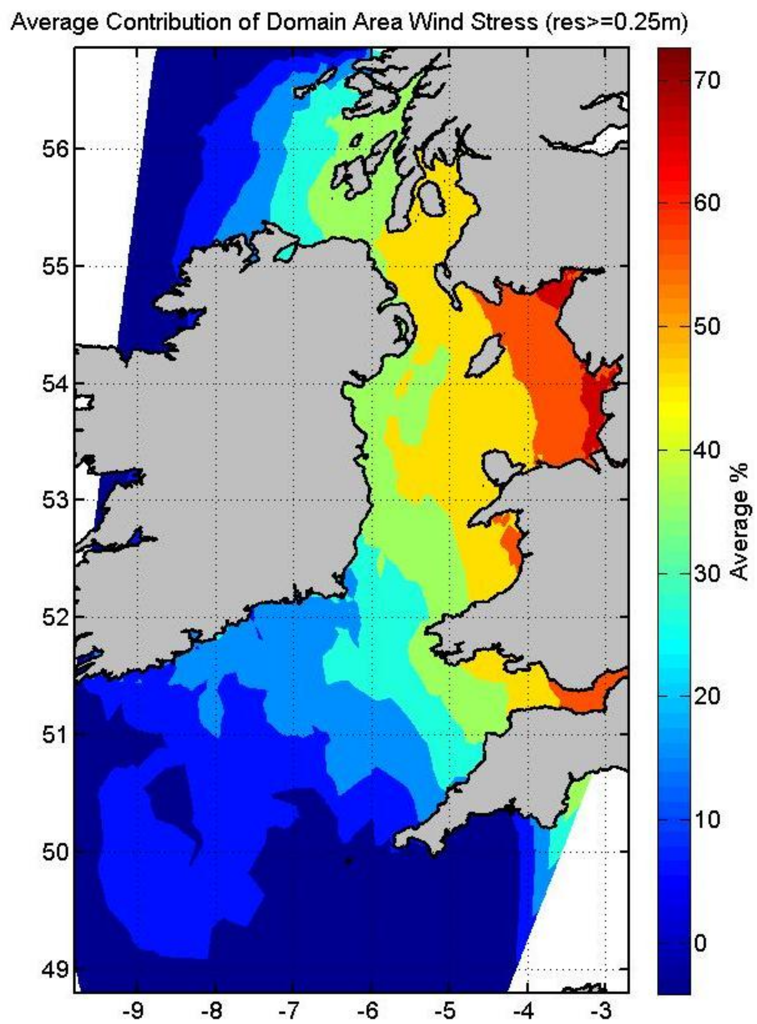
•TELEMAC and the operational model simulated an average of 80% and 83% of the observed skew surge height respectively.

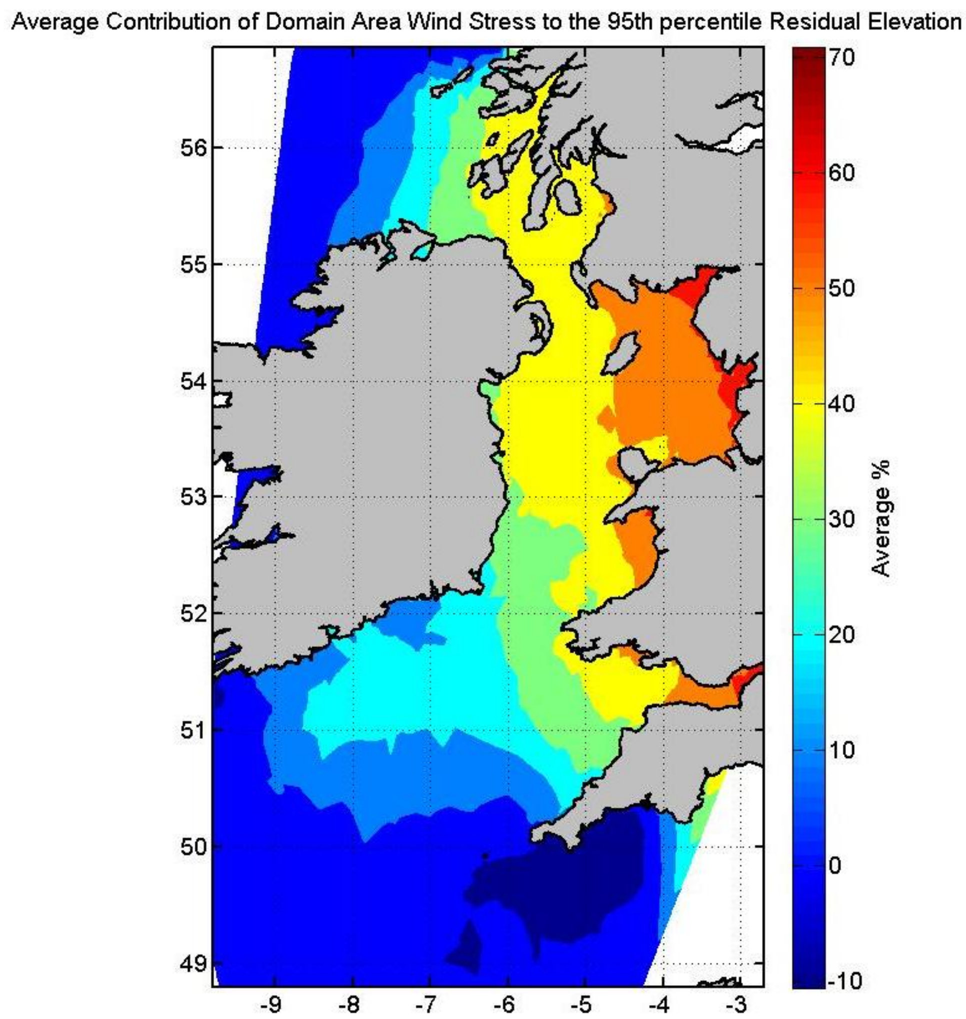
Surge components – External Surge



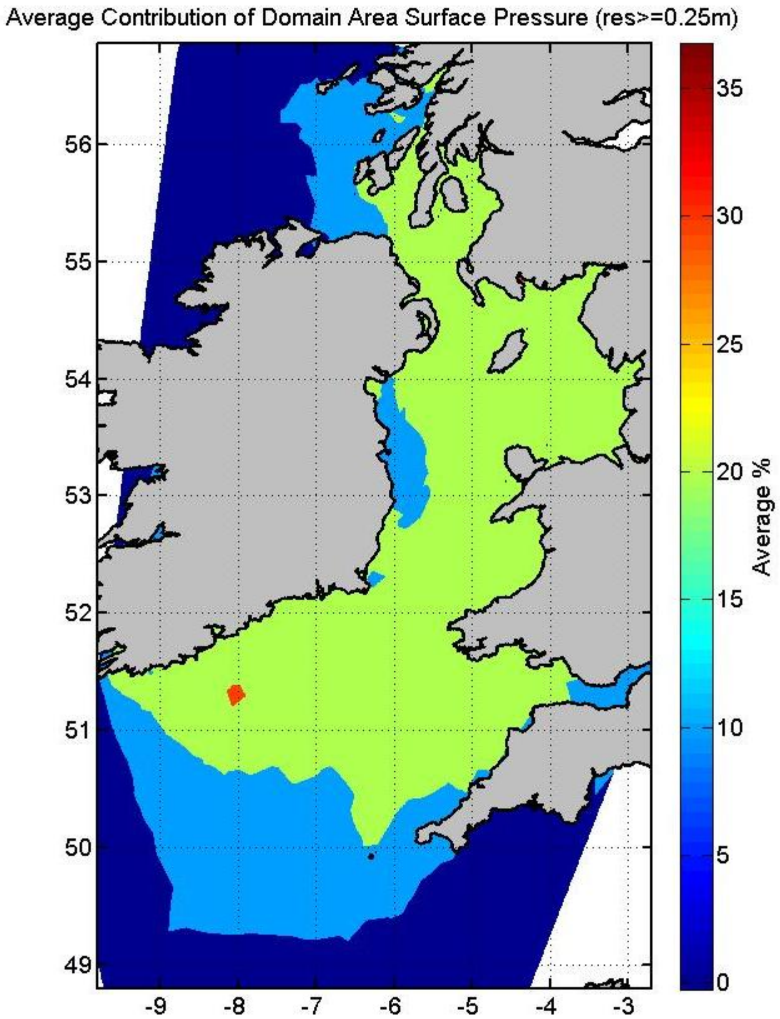


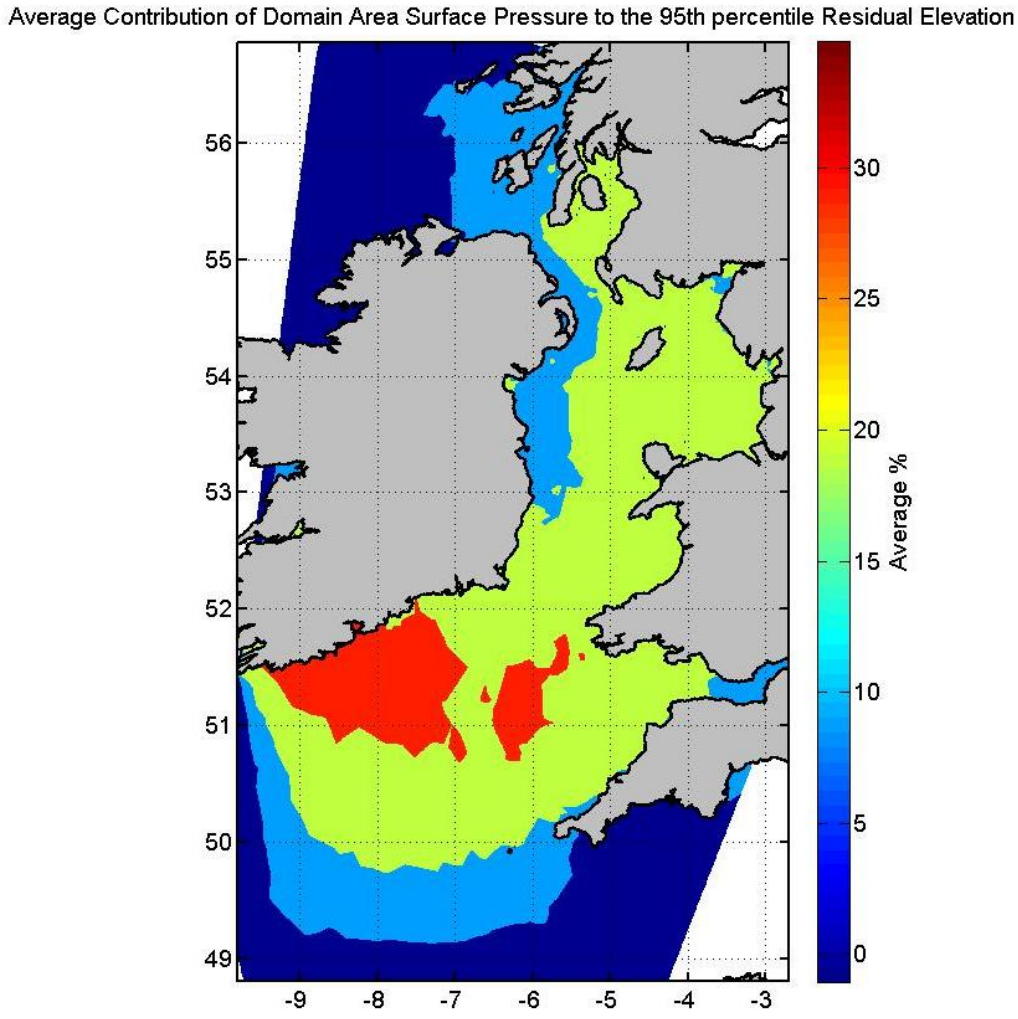
Surge components – Wind Stress





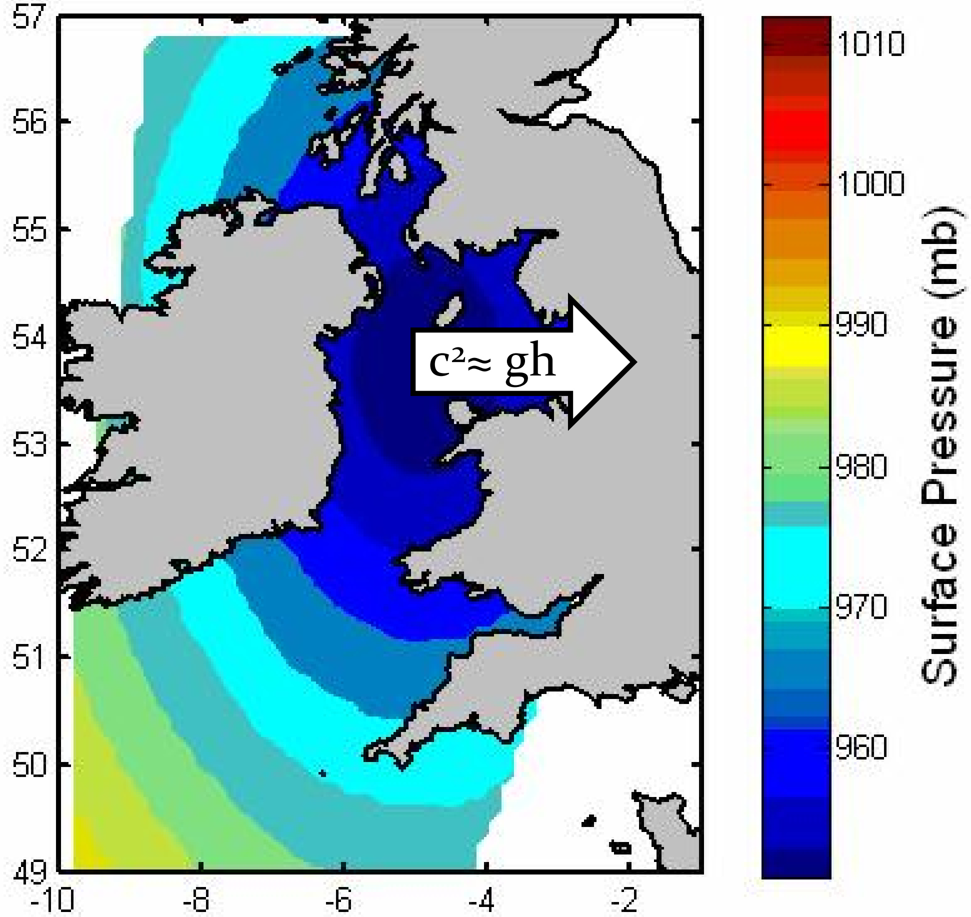
Surge Components - Pressure



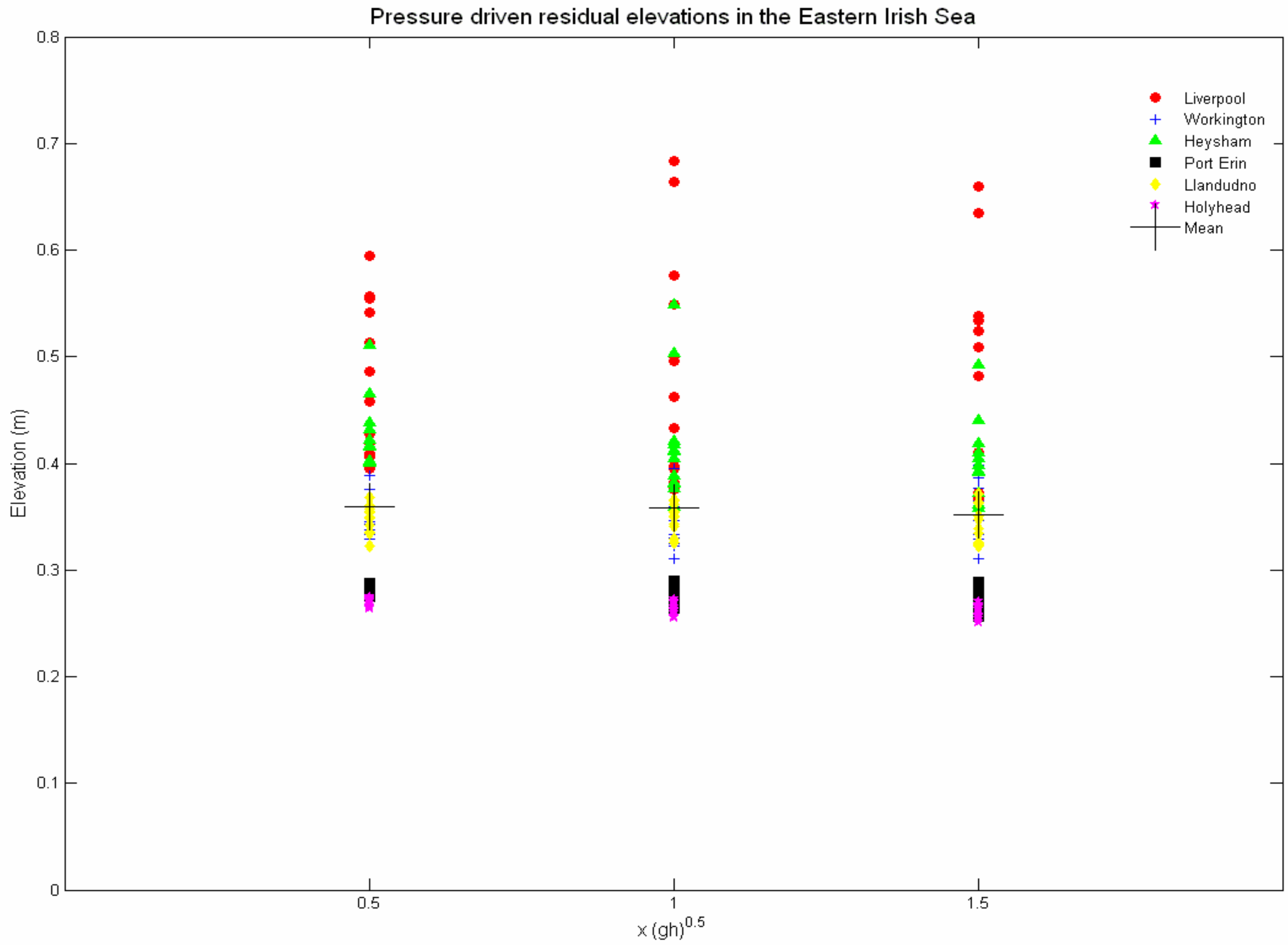


Larger pressure induced surges?

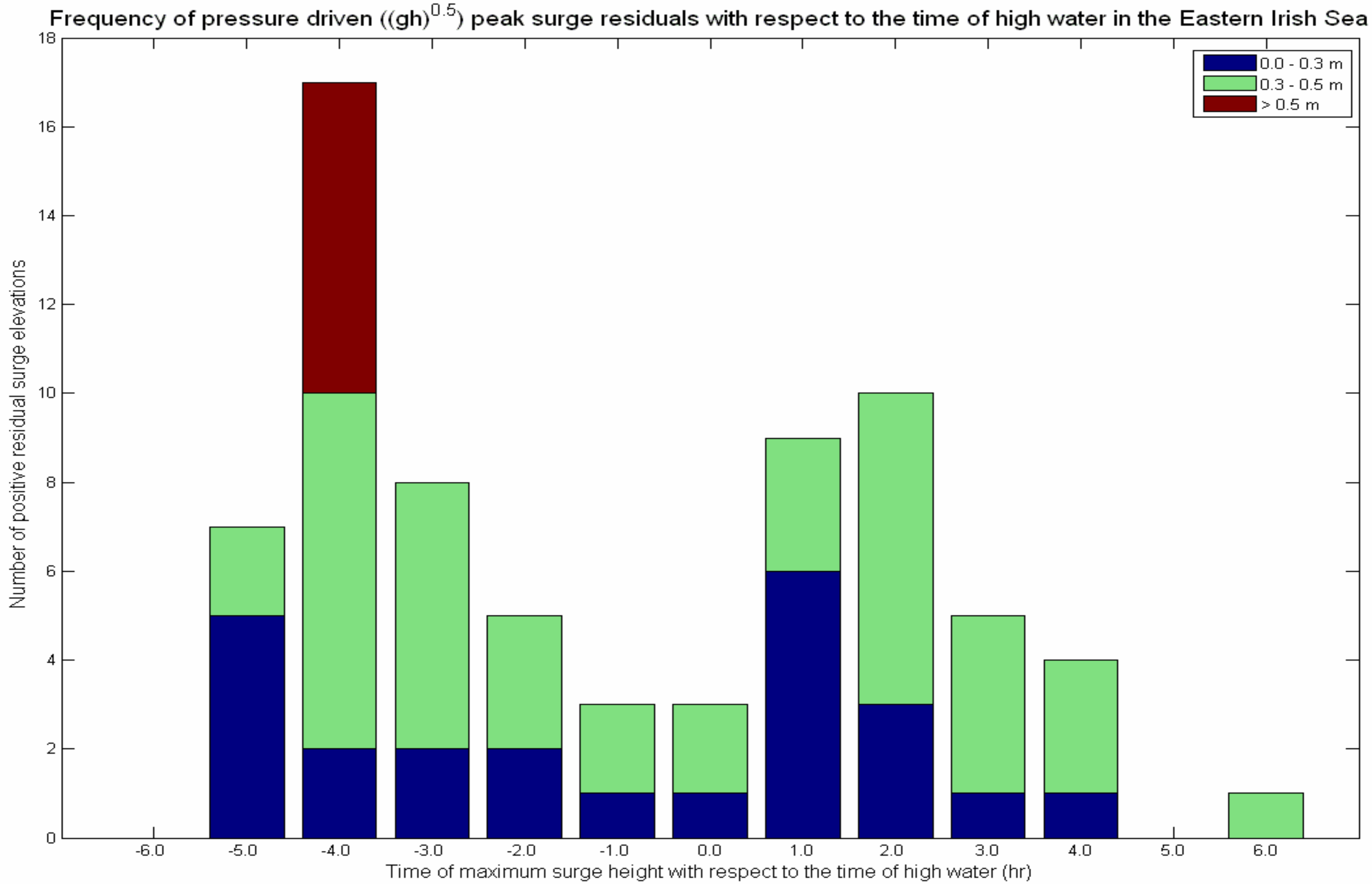
- Dynamic factor = $1/(1-c^2/gh)$ Proudman (1953)
- Idealised pressure system where $c^2 \approx gh$
- Possibility of larger pressure induced surges?



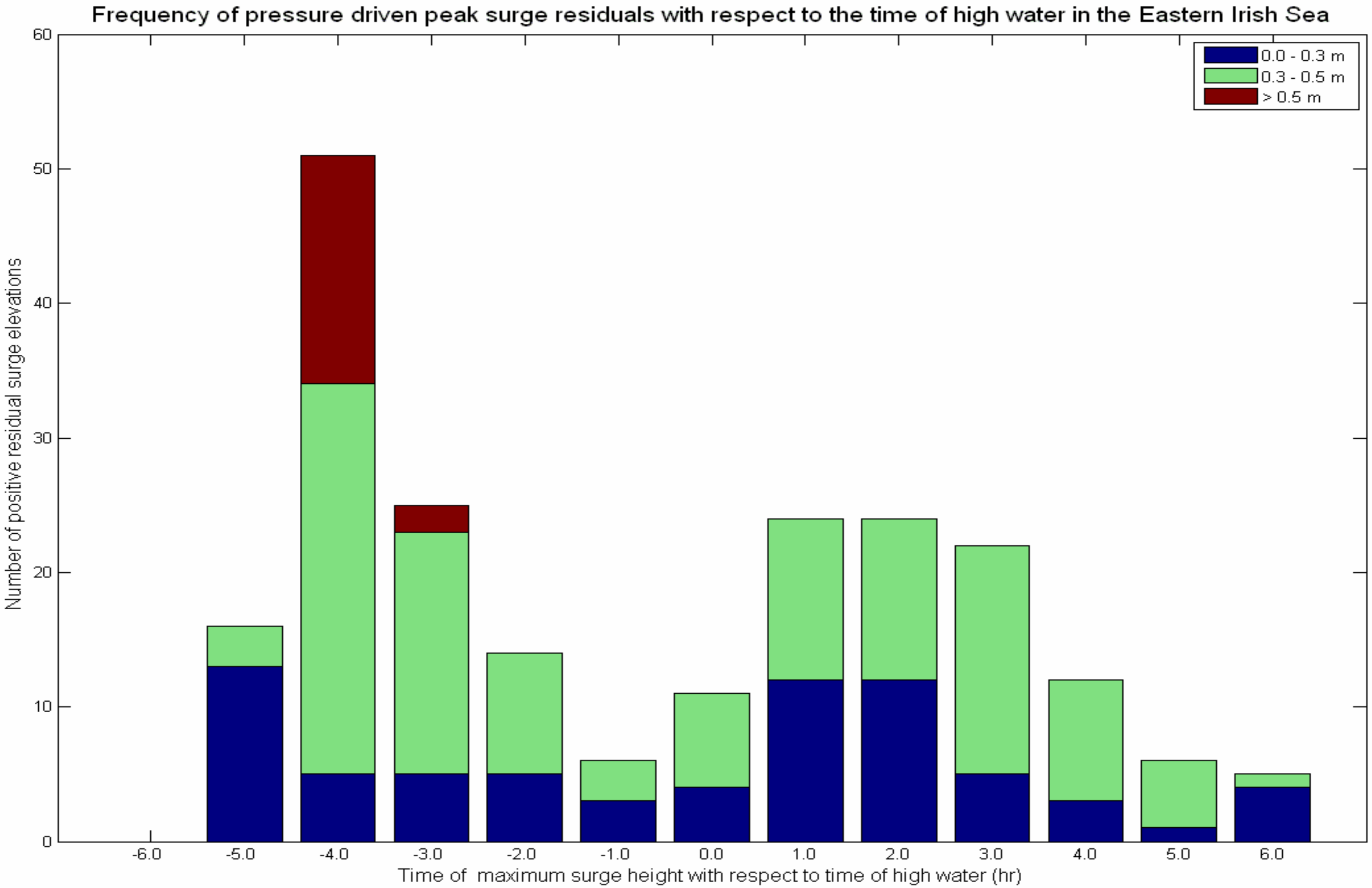
Pressure driven residual elevations



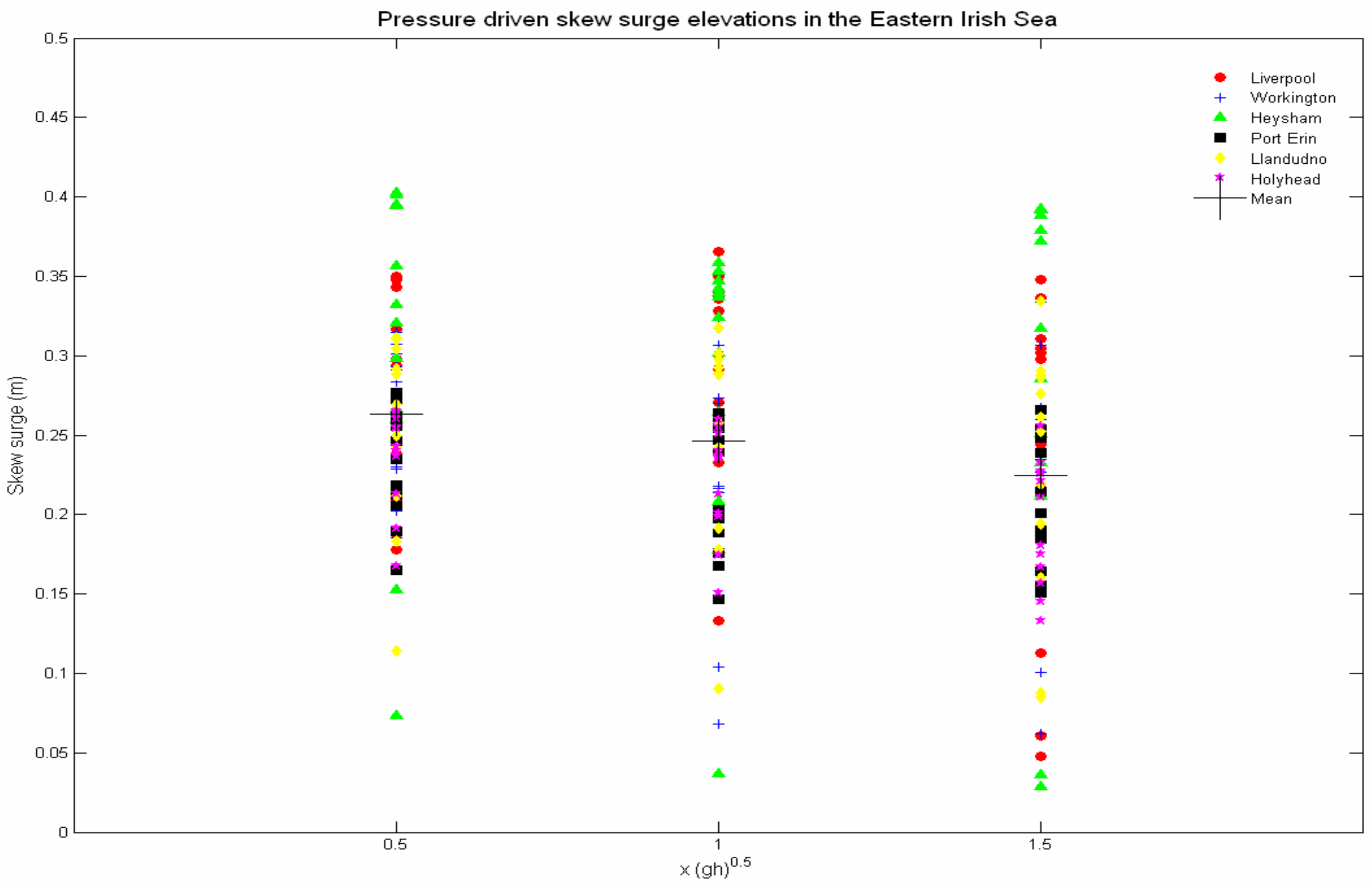
Timing of peak surge



Timing of peak surge

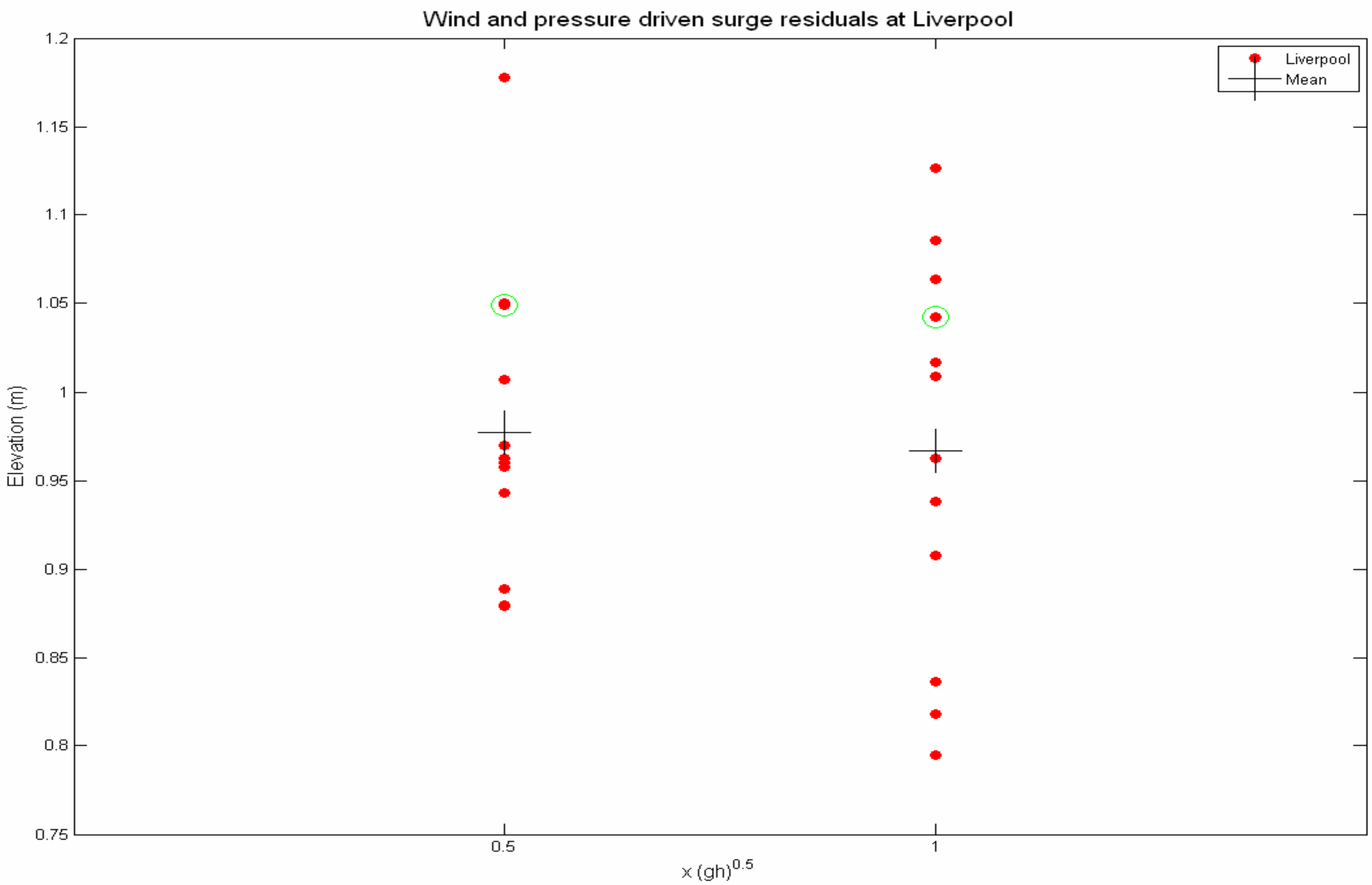


Skew surge



Pressure driven skew surge elevations in the Eastern Irish Sea
Skew surge (m)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.5
1
1.5
x (gh)^0.5
Liverpool
Workington
Heysham
Port Erin
Llandudno
Holyhead
Mean

Wind and pressure driven residuals



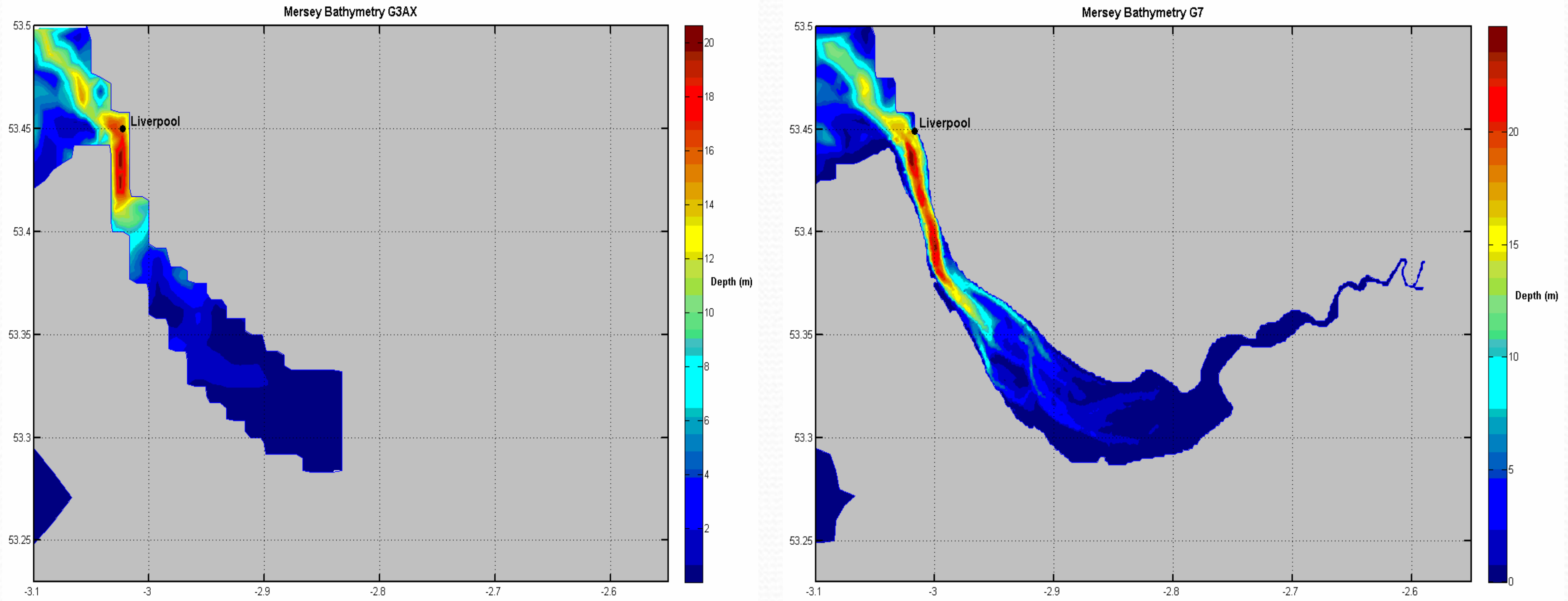
Conclusions

- TELEMAC performs as well as the operational model (CS3X) based on RMS errors and the predicted peak surge residuals.
- TELEMAC simulates on average over 80% of the observed peak residuals and skew surges.
- No evidence that increasing resolution in shallow water improves surge predictions.
- Increasing the resolution of the model grid eventually becomes limited by the resolution of the met forcing and/or the bathymetry.

Conclusions

- Pressure induced surge residuals may be larger at certain locations when the propagation speed of the depression ≈ $\sqrt{gh}$
- However, tide-surge interaction prevents larger pressure induced residuals occurring near high water.
- No significant increase in pressure induced skew surge heights.
- Wind dominates the surge response in a combined wind + pressure solution and is more significant than any pressure induced surge increase.

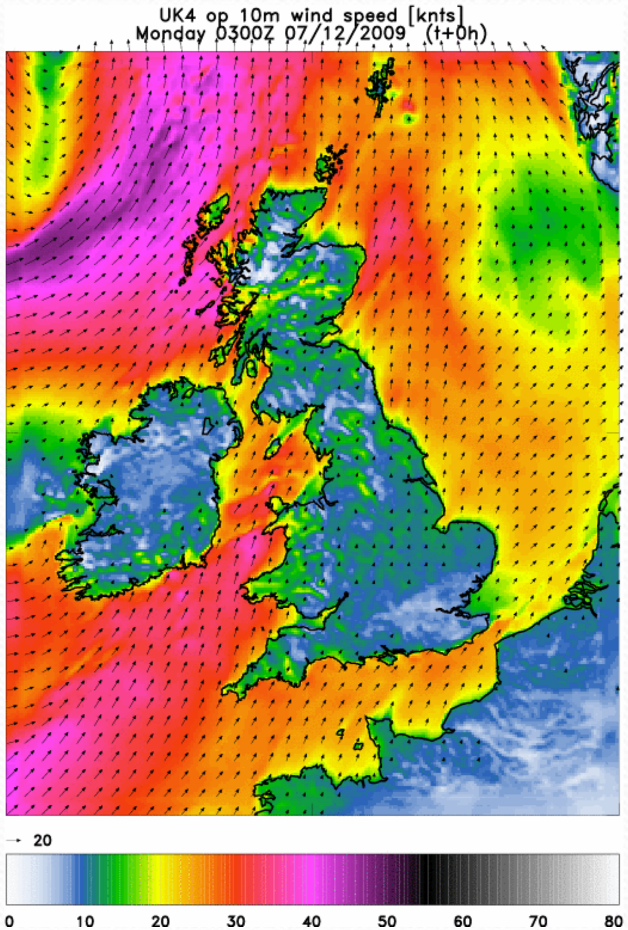
Future Work – G7



- Resolving the Mersey Estuary (G7)

UK4 – 4km winds

- Increasing the resolution of the wind stress field by three times.
- Improved surge prediction in the eastern Irish Sea?



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