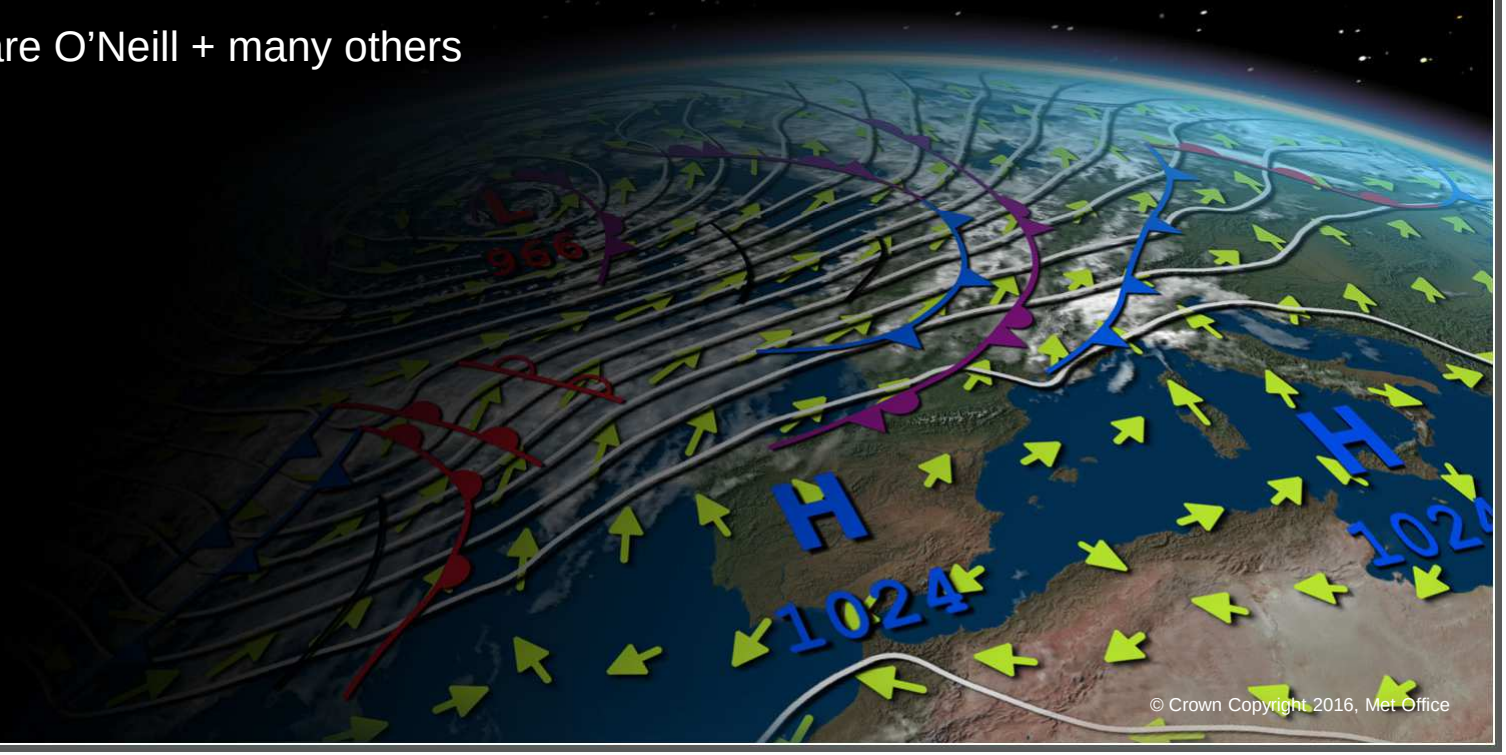
Storm surge forecasting and other Met Office ocean modelling

EMODnet stakeholder meeting

Clare O'Neill + many others



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Outline

- Ocean modelling at the Met Office
- Storm surge forecasting
  - Current operational setup
  - New surge model – setup, tests and results

Ocean modelling at the Met Office

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Oceanography in the Met Office

- ~50 ocean scientists
- Ocean Forecasting R&D
  - forecasting research and services
  - wave model and marine data assimilation development
- Oceans Cryosphere and Dangerous Climate Change
  - climate processes and services
  - ocean model development
- Marine Observations
  - Argo deployments, some marine networks
  - Collecting real-time in situ from external sources
- Applied Science
  - Utilising capability from above groups to provide services

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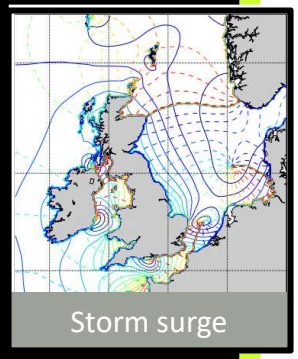
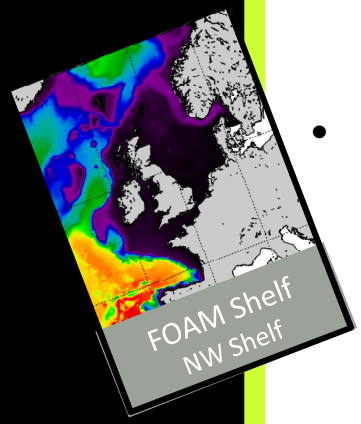
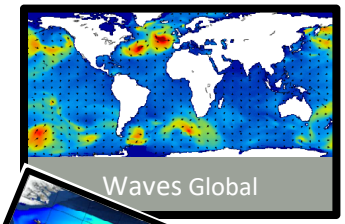
Models and Systems

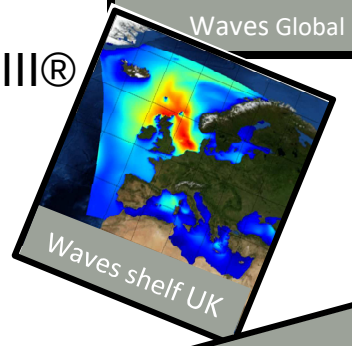


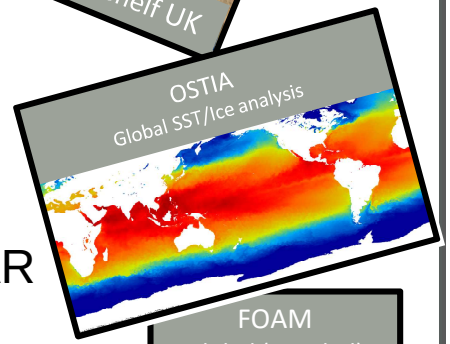


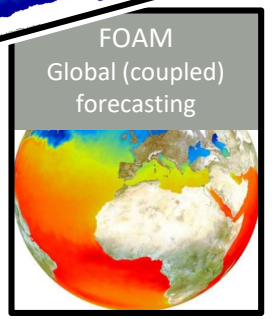
- Surface waves based on NCEP's WAVEWATCH III®
  - Runs 4 x daily, including an ensemble
- Storm surge based on CS3X (moving to NEMO)
  - Runs 4 x daily, including an ensemble
- SST & sea-ice satellite and in situ obs analysis (OSTIA)
  - foundation SST and diurnal temperature
- Ocean (FOAM) using NEMO-CICE with NEMOVAR data assimilation
  - 3D monitoring and prediction, including biogeochemistry

Coupled Atmosphere-Ocean-Wave-Ice-Land research systems



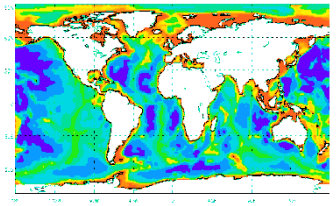




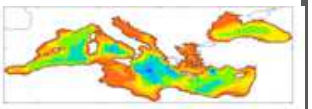


Deep ocean forecasts – FOAM-NEMO system

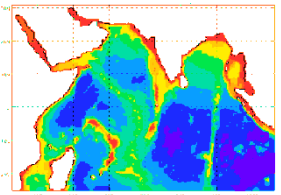
- NEMO physical model
  - Temperature, salinity & currents
  - 75 levels (1 m near surface)
- CICE sea-ice model
- NWP surface fluxes
- Climatological river inputs
- Daily 6-day forecast
- Assimilation of data using NEMOVAR
  - Argo T, S profiles
  - Surface height (satellite altimeters)
  - Sea surface temperature



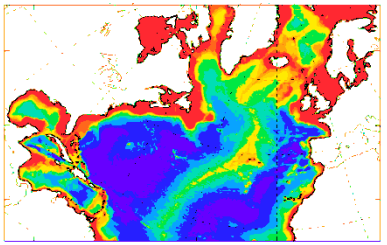
FOAM-NEMO 1/4º Global



FOAM-NEMO 1/12º Mediterranean



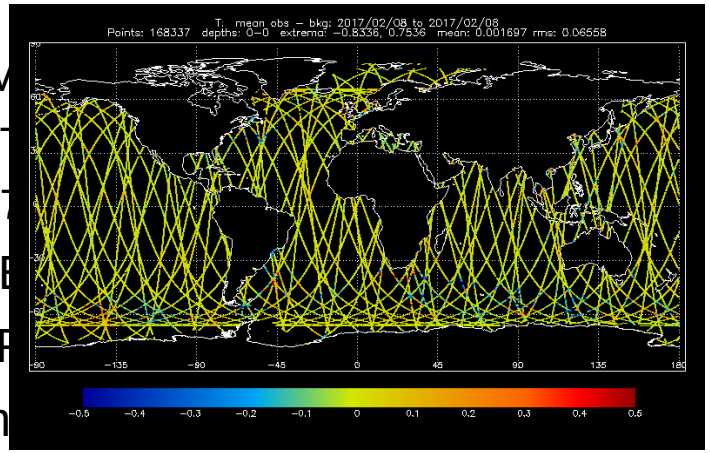
FOAM-NEMO 1/12º Indian Ocean

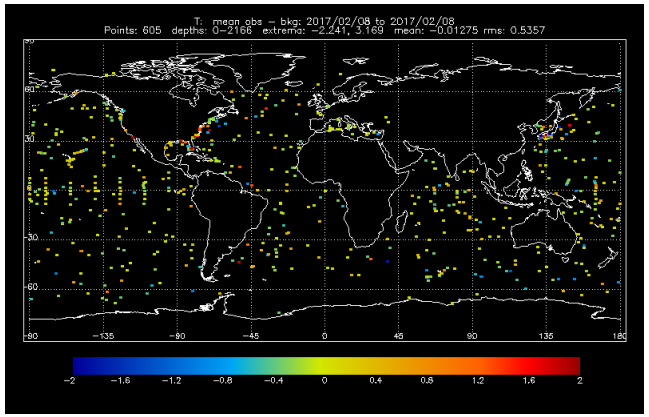


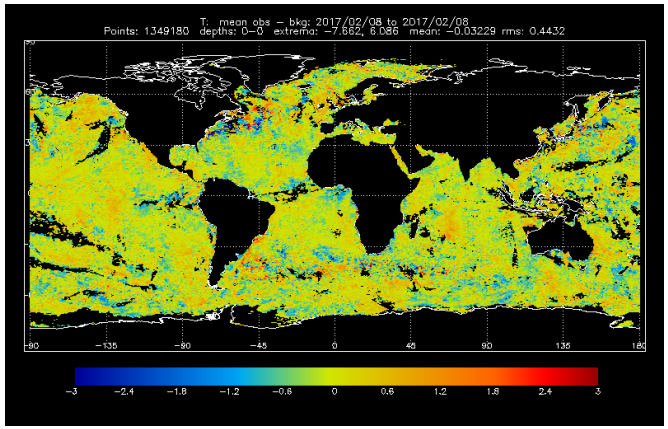
FOAM-NEMO 1/12º North Atlantic

Deep ocean forecasts – FOAM-NEMO system

- NEM
  -
  -
- CICE
- NWP
- Clim
- Daily 6-day forecast
- Assimilation of data using NEMOVar
  - Argo T, S profiles
  - Surface height (satellite altimeters)
  - Sea surface temperature

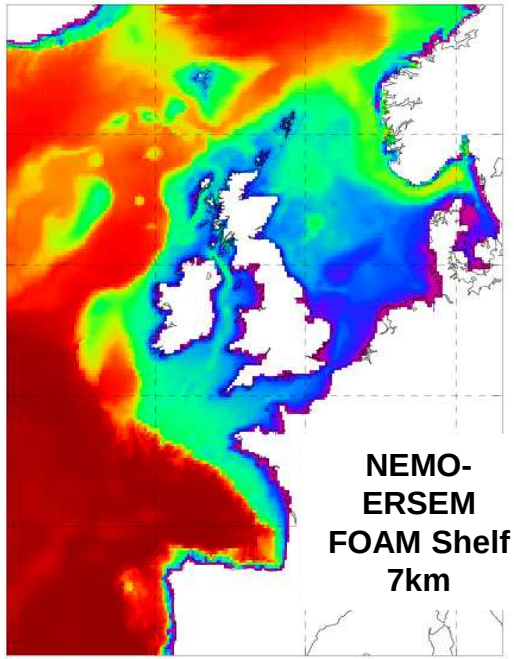






Shelf seas forecasts – NEMO/ERSEM

- FOAM-NEMO Shelf Seas model
  - Temperature, salinity, currents, sea level
  - Tides, s-coordinates
- ERSEM Ecosystem model
  - Nutrients, phytoplankton, zooplankton
  - sediments
- Driven by NWP surface fluxes, rivers & bdys
- Assimilation of SST data
- Daily 5-day forecast
- 20+ year hindcasts of physical system



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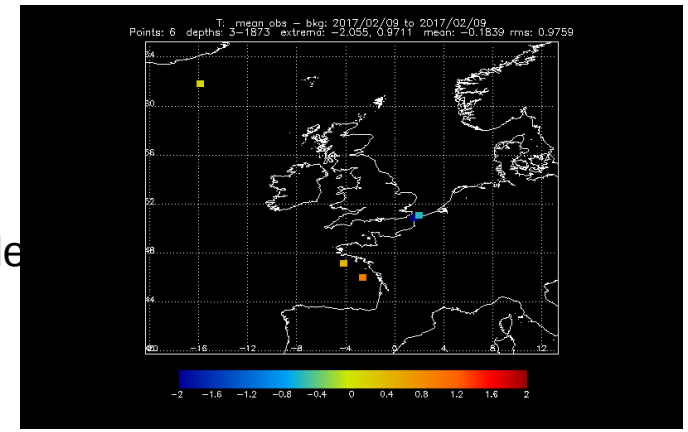
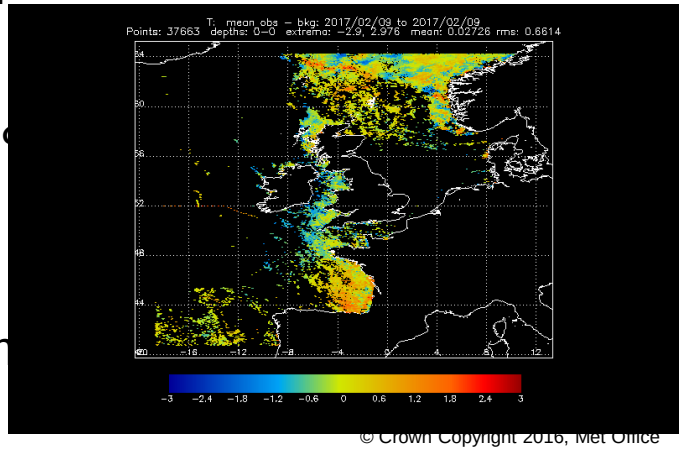
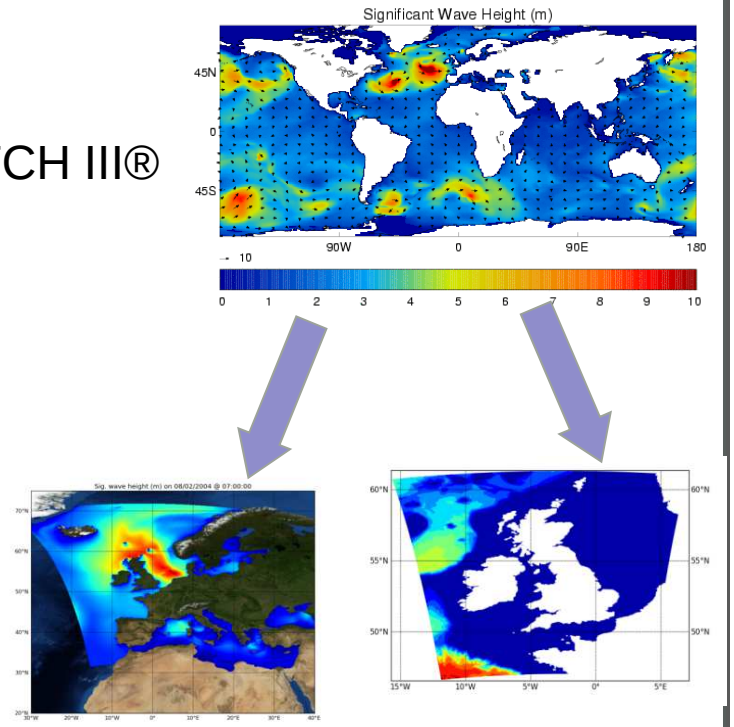




Wave forecasts

- Models based on NCEP's WAVEWATCH III®
- Forecasts based on 4 configurations
  - Global wave model 25-12-6-3 km;
    4(2) times daily to 2(5) days ahead
  - European wave model ~8km;
    4(2) times daily to 2(5) days ahead
  - UK 4km wave model;
    4 times daily to 2 days ahead
  - Atlantic model 24-member ensemble 25-12-6 km;
    4 times daily to 7 days ahead



Met Office

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

Storm surge forecasting

Storm surges

- Change in coastal sea level caused by the combined effects of surface winds and air pressure
- Potential to cause widespread coastal flooding, damage to infrastructure, and loss of life
- Met Office run an operational storm surge forecast system to mitigate risk

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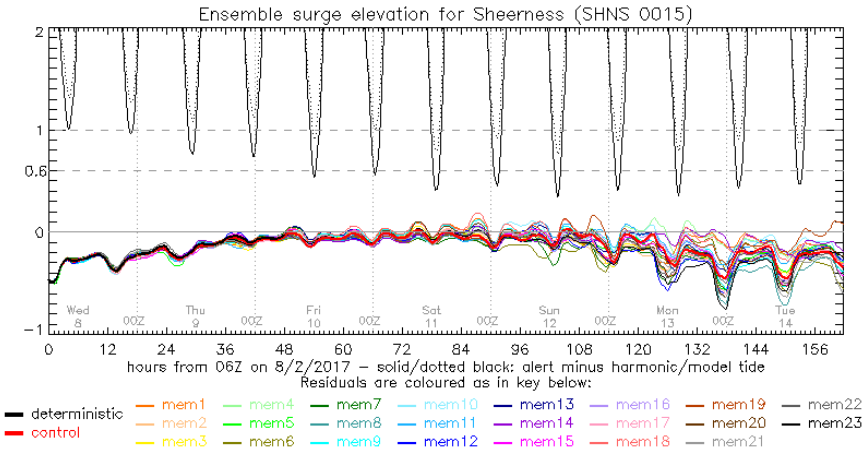
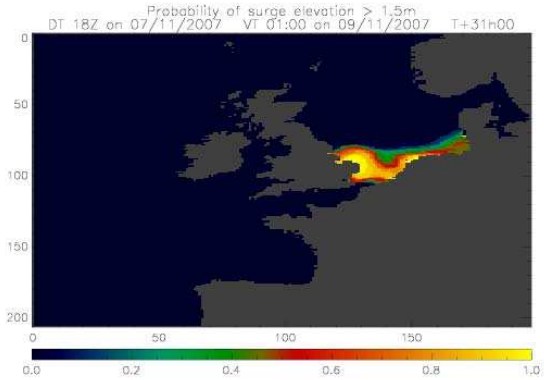
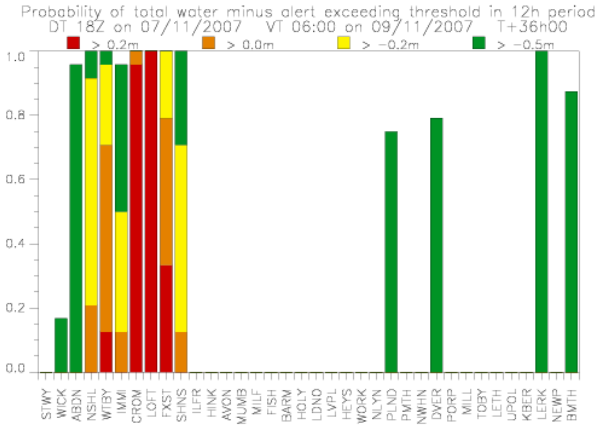
Operational system

- Barotropic, 12 km CS3X model for north-west European shelf developed by NOC
- Runs 4x per day
- 24-member ensemble predictions generated using MOGREPS-G (global atmosphere ensemble model)
- Residual surge calculated by subtracting model tides
- Focus on UK tide gauge network locations

Operational system







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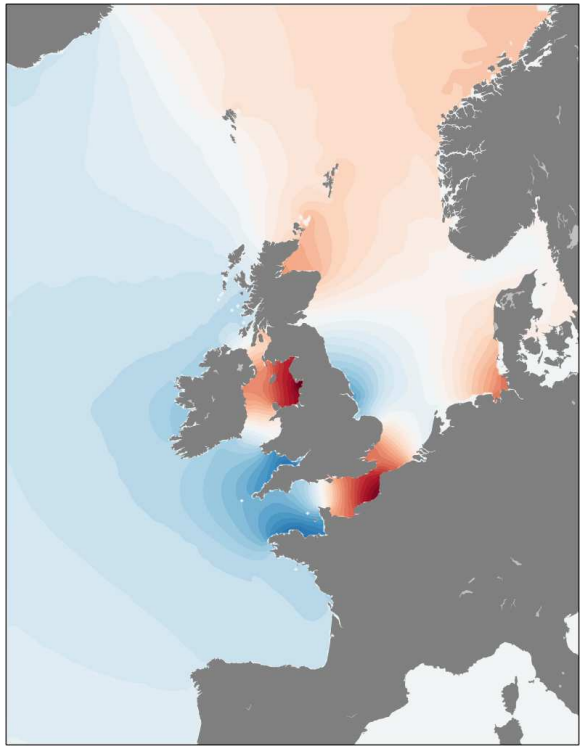
NEMO-surge project

- CS3X is becoming more difficult to maintain. Can we set up a NEMO based model to replace it?
- Easier to add future developments
- Harmonise the models run at the Met Office

NEMO-surge

- Based on AMM7 – higher resolution than CS3X (~12km vs ~7km)
- Barotropic, no temperature/salinity
- Inputs:
  - Tides at open boundaries
  - Wind and air pressure
- Testing in 2 stages: tide only, then with atmospheric forcing



Tide-only sensitivity tests

- Bathymetry – crucial for correct tidal solution
- Bottom friction coefficient
- Number of tidal constituents
- 1 year hindcast (2004)

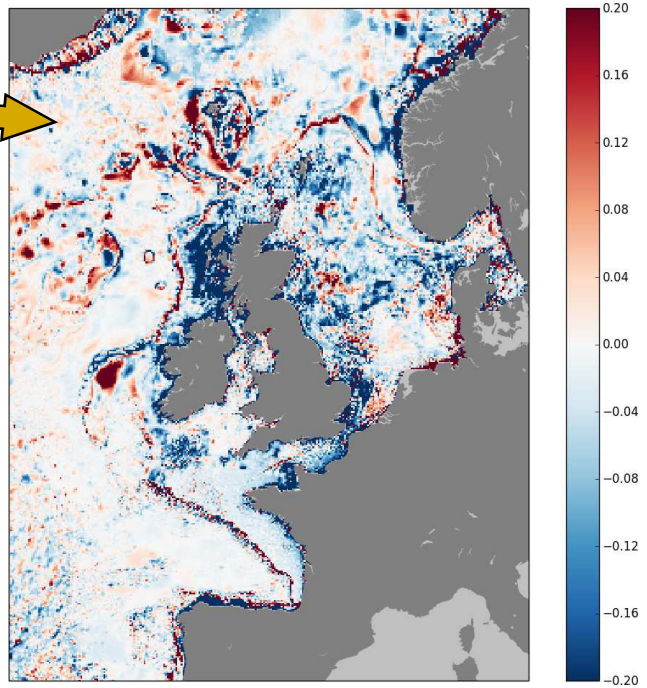
Tide sensitivity tests: bathymetry

- Default AMM7 (NOOS based) – “Control”
- Extra manual tweaks to North Sea, Fair Isle gap, Waddenzee
- EMODnet product
  - Product is referenced to LAT, but model needs MSL. Used long model run to estimate the correction
  - Minimum depth applied for model stability (6m or 10m depending on tidal range)
- Harmonic analysis on model output, compared with harmonic analysis from observed timeseries (19 years)

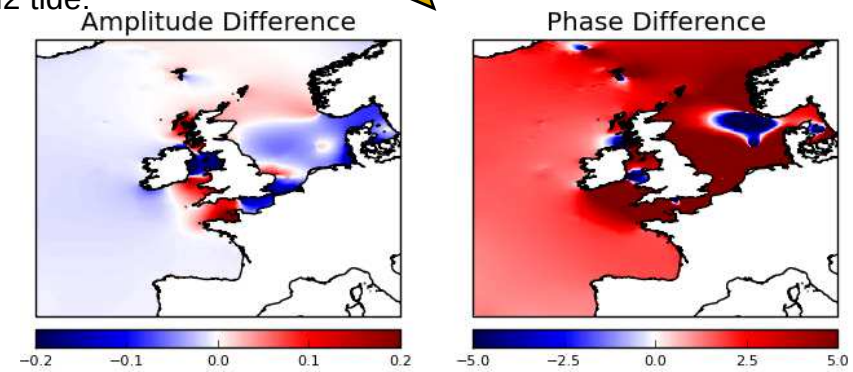
Tide sensitivity tests: bathymetry

- Control vs EMODnet bathymetry – many shelf and coastal areas 20% deeper
- Large differences in tidal phase especially (generally earlier)

(control - EMODnet) / control



M2 tide:



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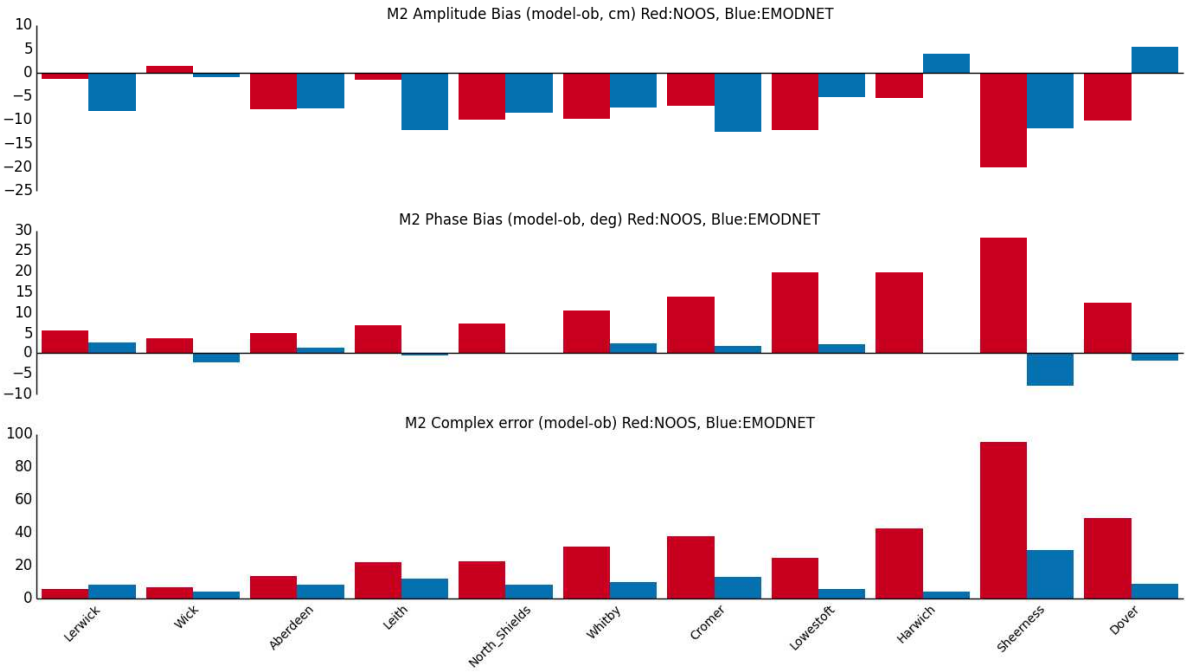
Tide sensitivity tests: bathymetry



M2 tide, East coast ports

Complex error: $Hs = \sqrt{(H_m \cos G_m - H_o \cos G_o)^2 + (H_m \sin G_m - H_o \sin G_o)^2}$

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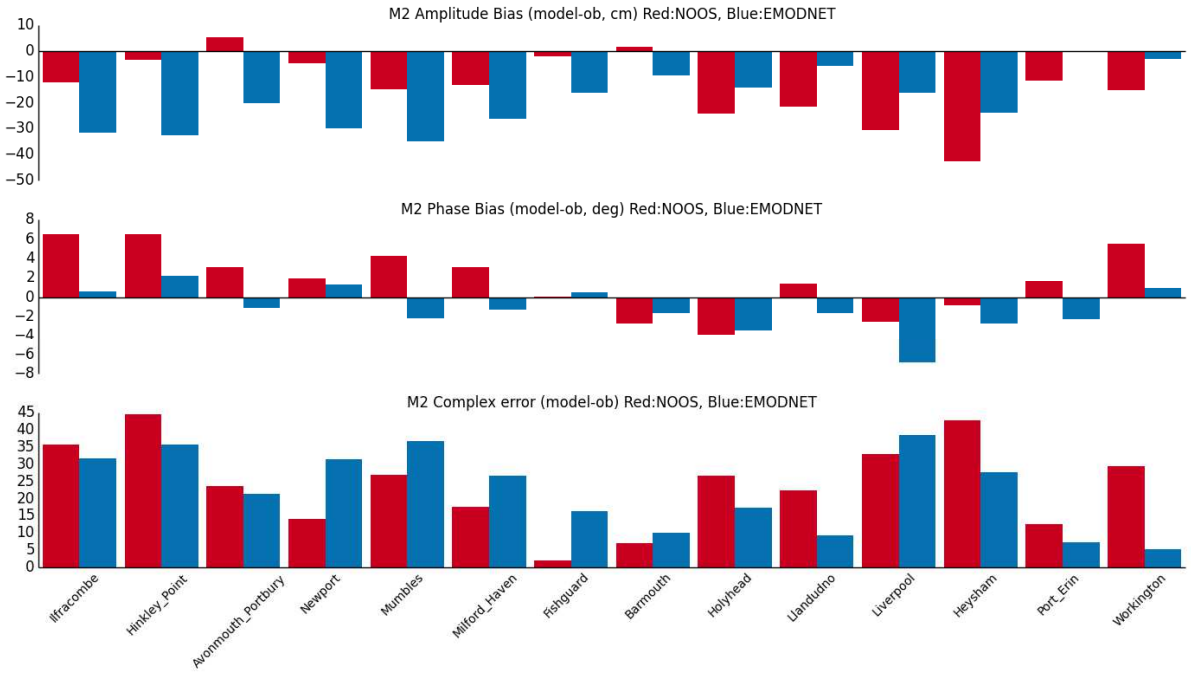
Tide sensitivity tests: bathymetry



M2 tide, west coast ports

Complex error: $Hs = \sqrt{(H_m \cos G_m - H_o \cos G_o)^2 + (H_m \sin G_m - H_o \sin G_o)^2}$

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Tide sensitivity tests: bathymetry

Tidal constituent	Mean complex Error					RMS complex error				
	Control	NS	WZ	FIG	EMODnet	Control	NS	WZ	FIG	EMODnet
Q1	0.75	0.73	0.75	0.75	0.77	0.79	0.77	0.79	0.8	0.85
O1	1.75	1.36	1.75	1.75	0.7	1.92	1.48	1.93	1.92	0.81
P1	0.76	0.68	0.77	0.77	0.92	0.86	0.76	0.87	0.86	0.98
K1	1.99	1.83	2	2	1.56	2.28	2.11	2.29	2.29	1.95
2N2	2.62	2.69	2.63	2.65	2.92	3.96	4.03	3.97	3.97	4.14
MU2	2.19	2.03	2.15	2.14	2.01	2.87	2.65	2.85	2.82	2.53
N2	5.87	4.89	5.87	5.77	3.47	6.84	5.57	6.83	6.72	4.02
NU2	1.09	1.06	1.09	1.09	1.23	1.29	1.21	1.29	1.28	1.34
M2	23.77	19.23	23.7	23.17	16.16	29.23	22.19	29.26	28.62	18.99
S2	8.95	7.42	8.93	8.75	5.07	10.96	9.01	10.91	10.72	5.86
K2	2.61	2.13	2.61	2.55	1.92	3.13	2.54	3.14	3.08	2.17
M4	7.72	7.59	8.08	7.93	5.6	9.65	9.65	10.07	9.89	7.95
MS4	5.59	5.38	5.81	5.73	3.77	7.52	7.38	7.76	7.65	5.75
M6	2.5	2.26	2.4	2.43	1.87	3.34	3.12	3.23	3.27	2.31

Complex error: $Hs = \sqrt{(H_m \cos G_m - H_o \cos G_o)^2 + (H_m \sin G_m - H_o \sin G_o)^2}$

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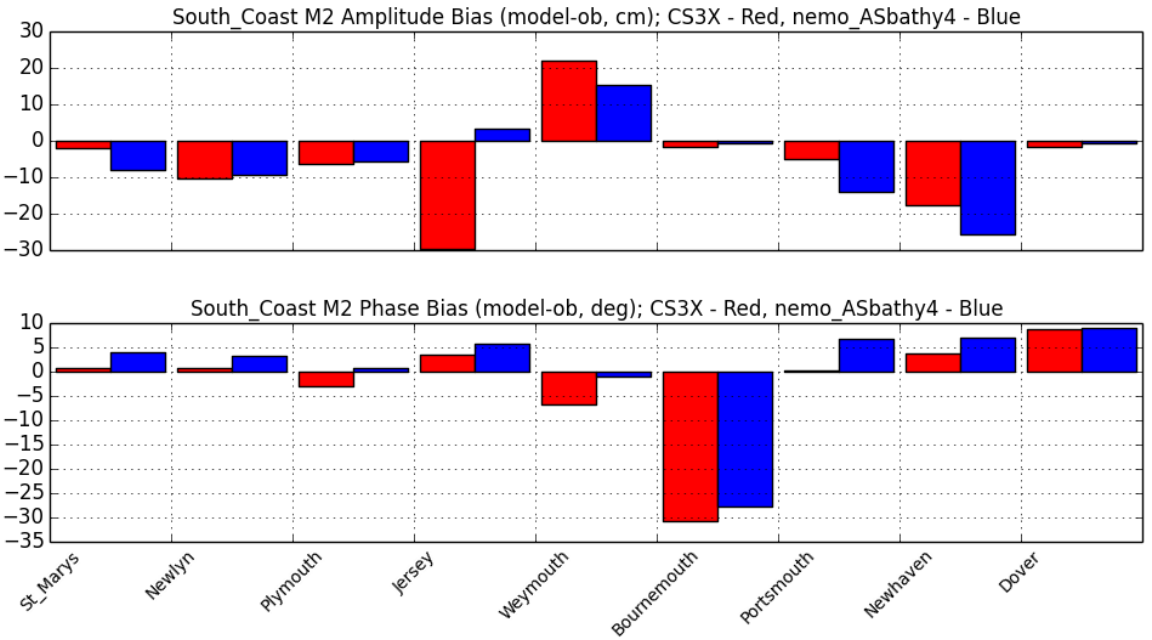
Tide-only: NEMO vs CS3X



Furner, R.; Williams, J.; Horsburgh, K.; Saulter, A., 2016: NEMO-surge: Setting up an accurate tidal model. Met Office Forecasting Research Technical Report 610, available online

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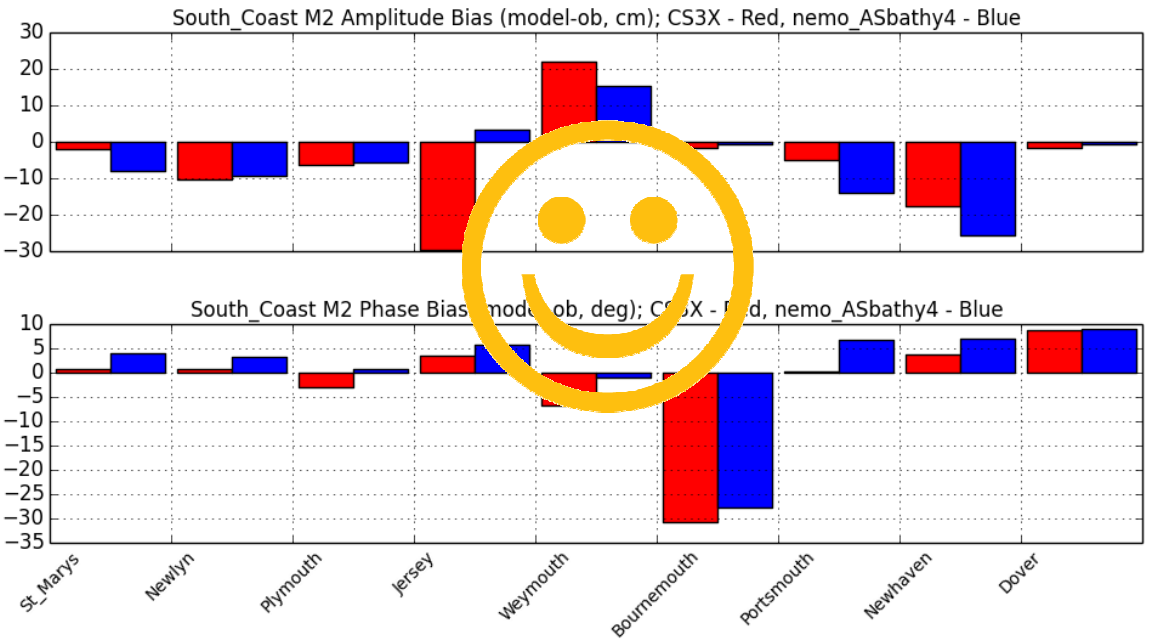

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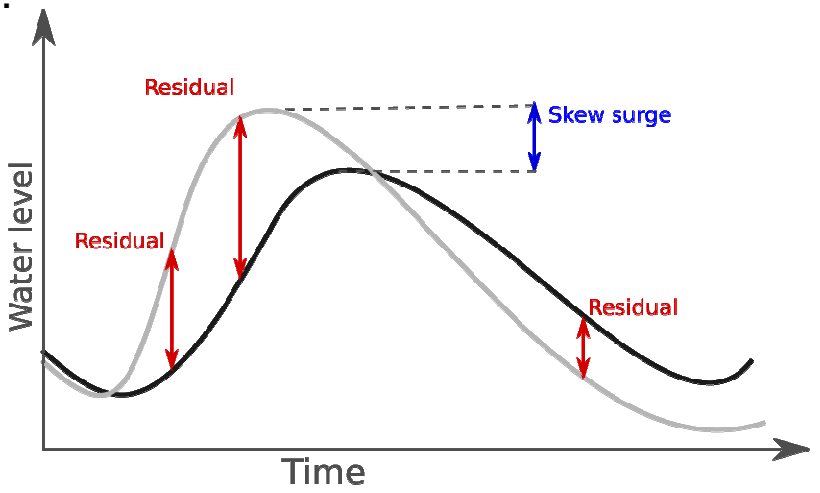
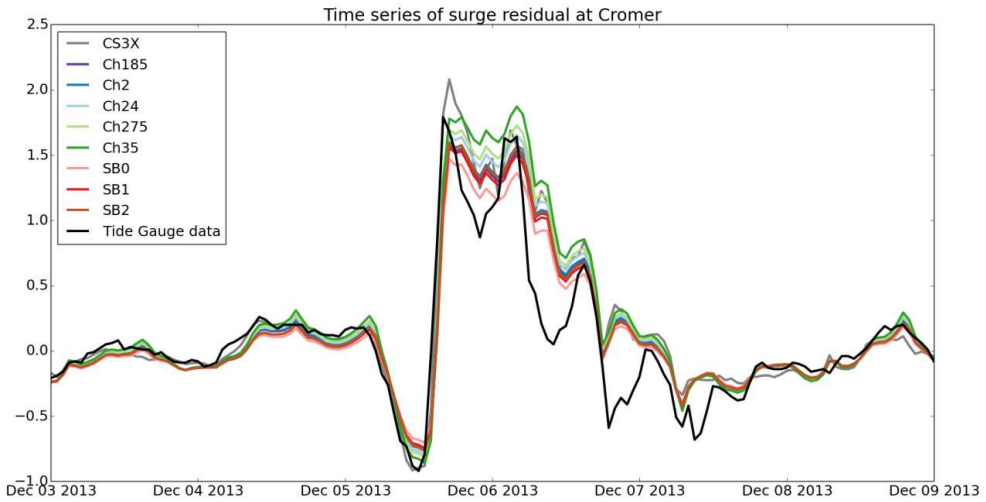
Surge sensitivity

- Wind parameterisation:
  - Charnock or Smith & Banke?
  - Sensitivity to parameters
- Reference pressure level
- Residual and skew surge compared with observations and benchmarked against CS3X
- 2 year hindcast (2013-14)



Wind parameterisation tests

- 5 runs using Charnock values 0.0185 - 0.035
- 3 runs using linear Smith and Banke type
- Not much sensitivity most of the time, more during surge events
- “Best” option different for different ports

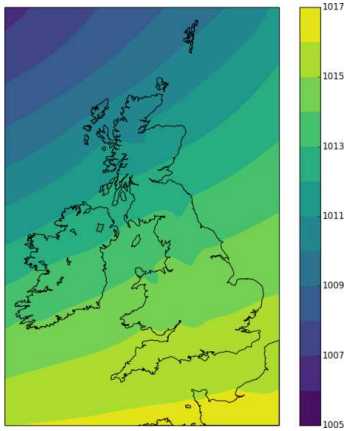


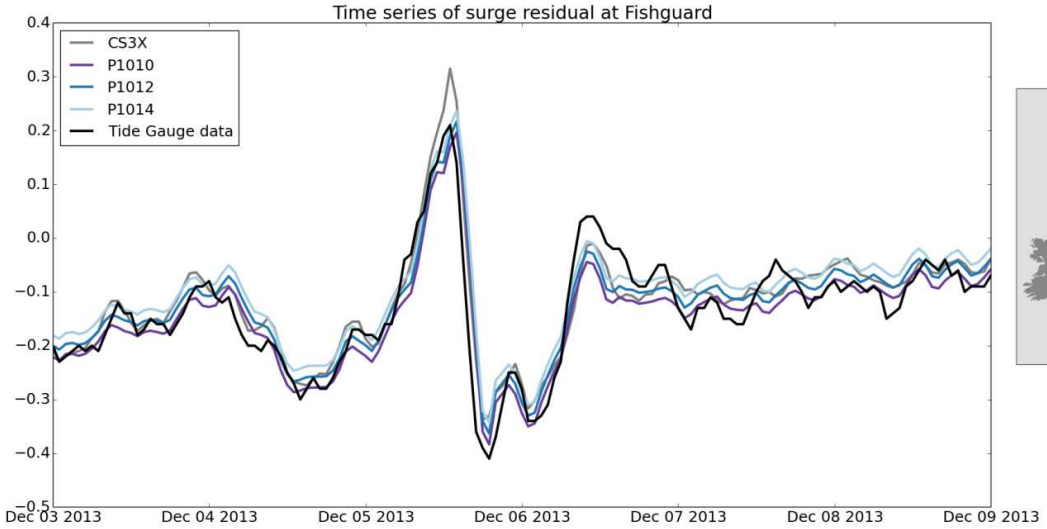
Residual: RMS error

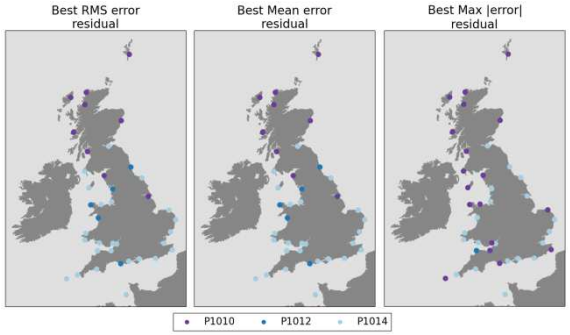
Port	CS3X	Ch185	Ch2	Ch24	Ch275	Ch35	SB0	SB1	SB2
Ilfracombe	0.114	**0.112**	**0.112**	**0.111**	**0.111**	**0.111**	**0.114**	**0.113**	**0.112**
Hinkley Point	0.148	**0.143**	**0.143**	**0.142**	**0.142**	**0.141**	**0.146**	**0.144**	**0.144**
Avonmouth	0.211	0.211	0.211	0.212	0.212	0.213	0.212	0.212	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**

Reference pressure tests

- 3 runs: 1010, 1012, 1014 hPa
- Effectively moves everything up/down
- North/South spatial pattern







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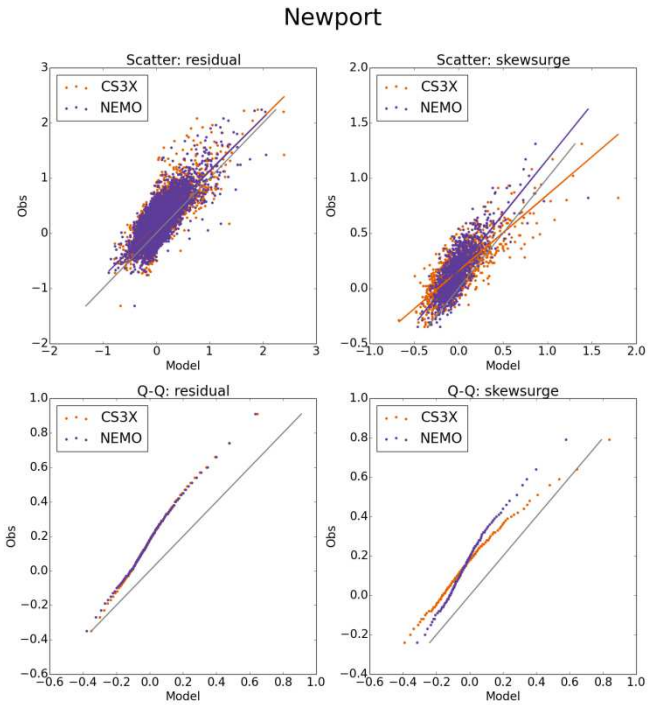
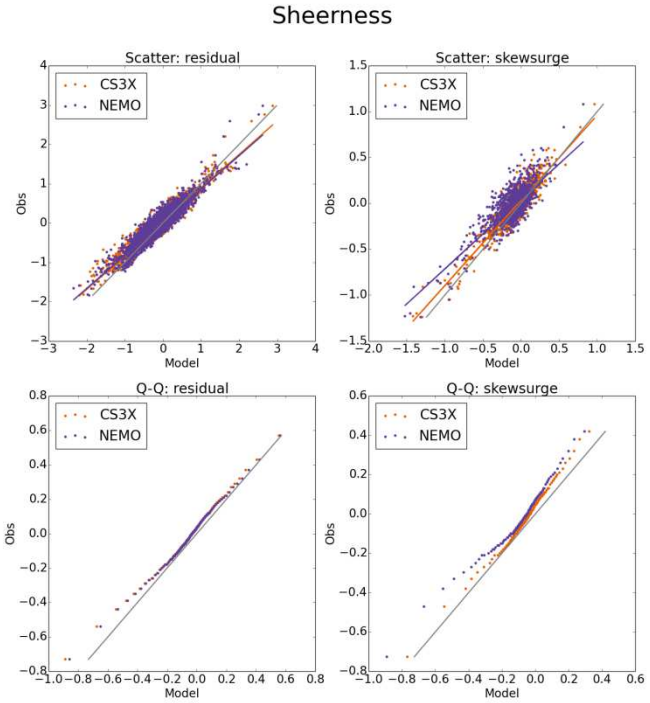
NEMO vs CS3X

- Differences from port to port





NEMO vs CS3X

- But overall statistics very similar

Residual

Metric	CS3X	NEMO-Surge	Diff
RMSE	0.098	0.096	-0.002
Mean error	-0.036	-0.036	0.000
Max |error|	0.568	0.582	0.014
SI	0.431	0.419	-0.012
N. STD	0.994	0.976	-0.018
Corr.	0.902	0.904	0.003

Skew surge

Metric	CS3X	NEMO-Surge	Diff
RMSE	0.095	0.096	0.000
Mean error	-0.036	-0.043	-0.007
Max |error|	0.401	0.401	0.000
SI	0.438	0.420	-0.018
N. STD	1.009	0.967	-0.042
Corr.	0.902	0.905	0.003

Full report: O'Neill, C.; Saulter, A.; Williams, J.; Horsburgh, K., 2016: NEMO-surge: Application of atmospheric forcing and surge evaluation Met Office Forecasting Research Technical Report 619, available online

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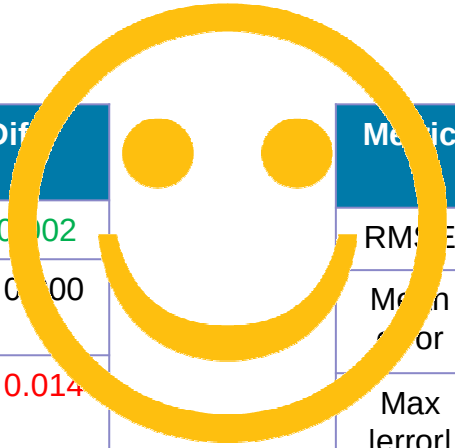

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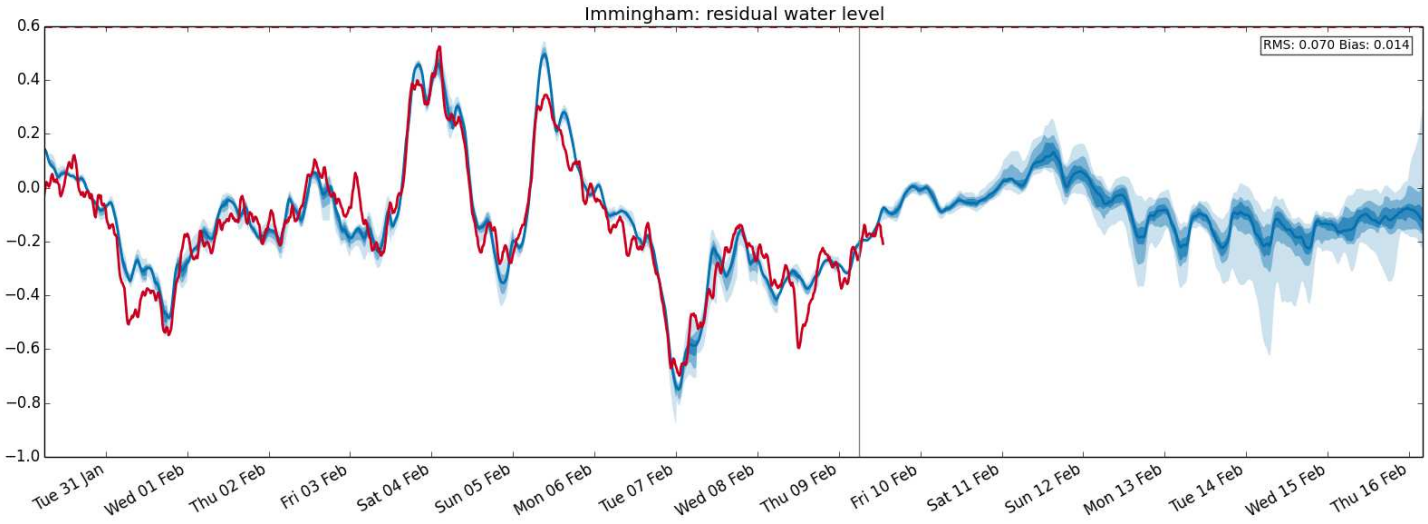
What next?

- NEMO-surge currently running operationally in parallel – winter performance will be evaluated against observations and compared with CS3X system



Longer term…

- Lots of potential for future science changes:
  - Data assimilation
  - Wave coupling
  - Higher grid resolution (eg AMM15 in development)
  - Varying bottom roughness
  - Wetting and drying
  - Density
  - …

Questions?