Application of a refined resolution global wave forecast model

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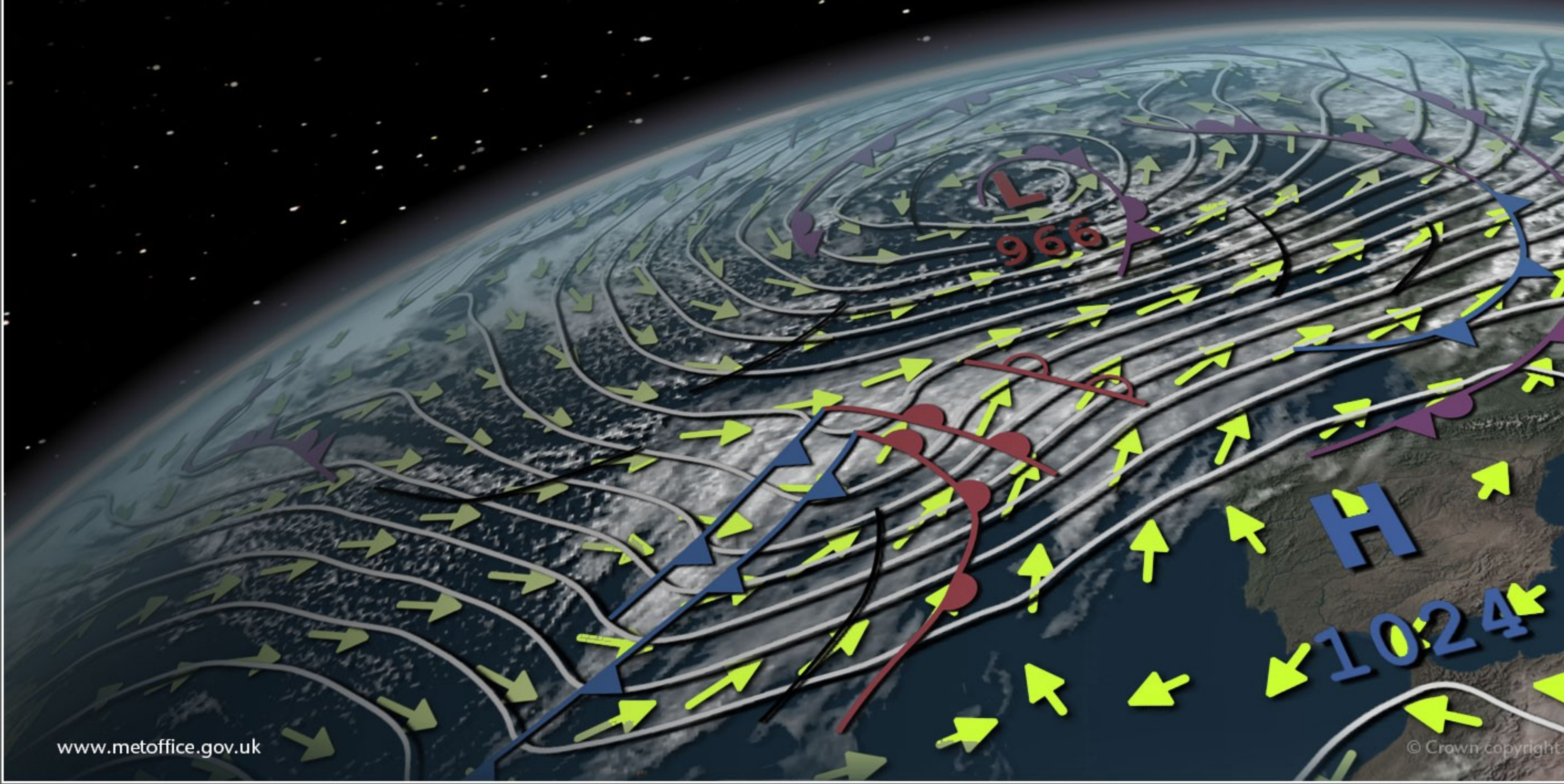
Presentation to Challenger Waves SIG, 19/10/2016



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In late 2016 (Operational Suite OS38) the Met Office will introduce a new global configuration of its operational wave forecast model. The model is based on WAVEWATCH III version 4.18. The configuration uses a Spherical Multiple-Cell (SMC) grid. This is an unstructured grid, using multiple time-steps for different resolution cells, but retains conventional latitude-longitude grid features, such as rectangular cells and finite difference schemes. Thus it is as efficient as a conventional latitude-longitude grid model at coarse resolutions.
The new global model uses refined cell scales reducing from 25km in the open ocean to up to 3km at the coastline, and source term physics based on the ST4 switch. The choice of a refined grid method has been made in order to improve overall model accuracy (through providing a better description of coastline and island masks) whilst retaining model efficiency, but has the important additional benefit of enabling good quality forecasts to be generated in coastal waters without the requirement to set up and run nested regional models. Adaptations to the WAVEWATCH III post-processing code enable model outputs to be generated in either native grid 'sea-point only' or interpolated regular grid formats.
Comparisons between the new configuration and the global model run operationally during the trials period, show a major overall improvement.
For example, significant wave height errors were reduced from 18% of the background signal in the operational model to 14% in the new configuration, representing relative change in the errors of over 20%. The model's utility for regional forecasting has also been demonstrated, with more modest improvements in performance also found versus the (8km resolved) European regional wave model. The changes in model quality result from a combination of both the grid and source term updates, with the most notable impact being a reduction in large over-prediction errors during storms.

- Why adopt a refined resolution model?
- The Spherical Multiple-Cell grid and application in the S36125 global wave model configuration
- Trials results
- Conclusions

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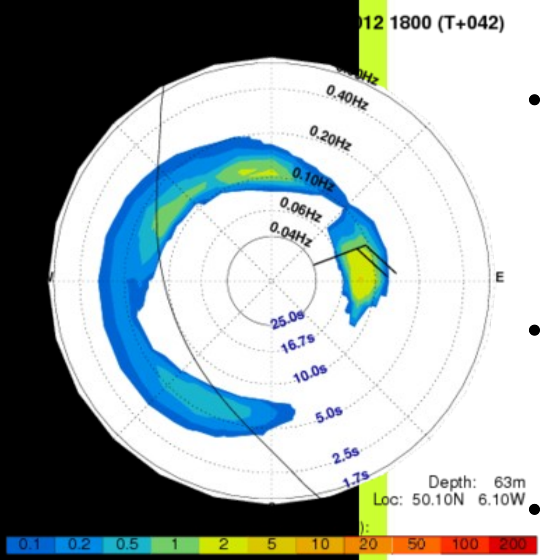
Why adopt a refined resolution model?



- The problem:
  - Wave models comprise two steps that change the wave spectrum – growth and propagation
  - In WAVEWATCH III propagation calculations are distributed so that each spectral energy bin is solved across the model grid on a single processor (e.g. 1080 separate tracers for a 30x36 spectrum)
  - For efficiency, CFL limits are varied dependent on spectral frequency, such that long period waves use more propagation time-steps than short period waves
  - The resulting load balancing requirement sets a limit on the optimal number of processors that the model can use (~1/4-1/3 number of spectral bins)
  - WWIII very efficient for moderate sized grids and limited HPC capacity – but will not scale well for large grids (1,000,000 cells+)
  - Problem where we want to run regular grids over large domains at high resolution; however, these resolutions are most valuable near the coast, so why not use coarser scaled cells offshore? Cell 'refinement'…

Why adopt a refined resolution model?

- Efficiency
  - The use of a mixture of coarse and high resolution grid cells and multiple time-steps ensures the model is cost effective. The need to run multiple nested models in regions of interest is reduced.
- Accuracy
  - The new model improves representation of coastal fetches and swell blocking by small islands. An update to WWIII vn4.18 is accompanied by use of physics scheme following Ardhuin et al. (2010) leading to further skill improvements.
- Relevance
  - Increasing resolution in inshore waters enables us to have an improved coastal product anywhere in the world.
- Support
  - The “ww3_ounf” post-processing program has been updated to enable generation of netCDF data in both SMC and regular grid modes.

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The Spherical Multiple-Cell grid

- Proposed by Li (2011, 2012) and based on the concept of a reduced grid (Rasch, 1994) – regular lat-lon cells are halved or doubled in size depending on need to introduce extra resolution or reduce CFL restrictions
- Spatial arrays used in the wave model propagation time-step are unstructured; i.e. land points not included in array, metadata is passed to determine which cells talk to which (propagation scheme order dependence)
- Li and Saulter (2014) demonstrate a multiple resolution SMC grid in WAVEWATCH III; extends WWIII's internal time-step variability to cells of specific sizes
- The unstructured grid can also be used to deal with singularity and rotation issues in high latitudes. Li (2016) demonstrates the use of an 'Arctic part' in a global wave model

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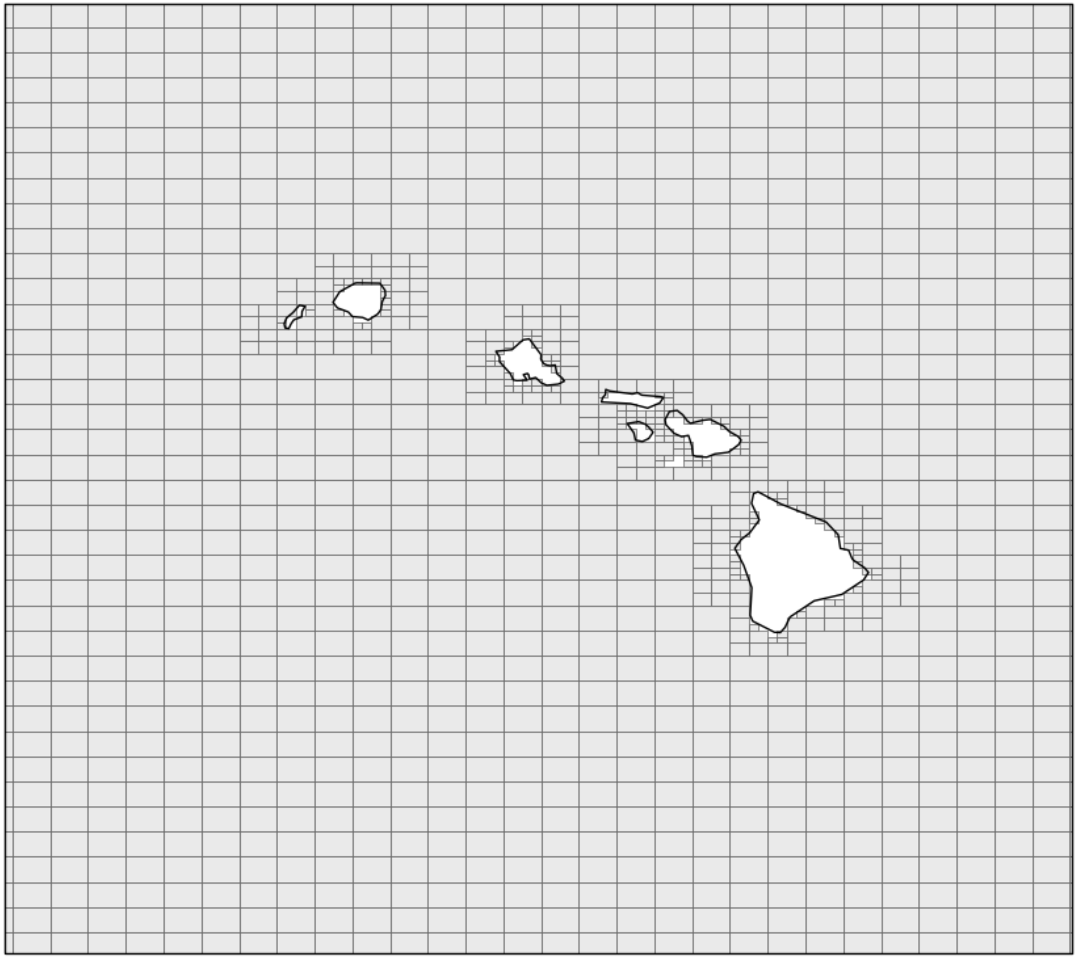
The S36125 global model

- Globally 25-12-6km grid using refinement based on proximity to coastline. Longitudinal cell sizes double at 60N, 75.5N, 82.8N, 86.4N. Includes Arctic part and 12-6-3km European region
- Source terms follow Ardhuin et al. (2010). Propagation scheme is UNO2 (Li, 2008) with GSE alleviation using a hybrid of the Booij and Holthuijsen (1987) and Tolman (2002) schemes

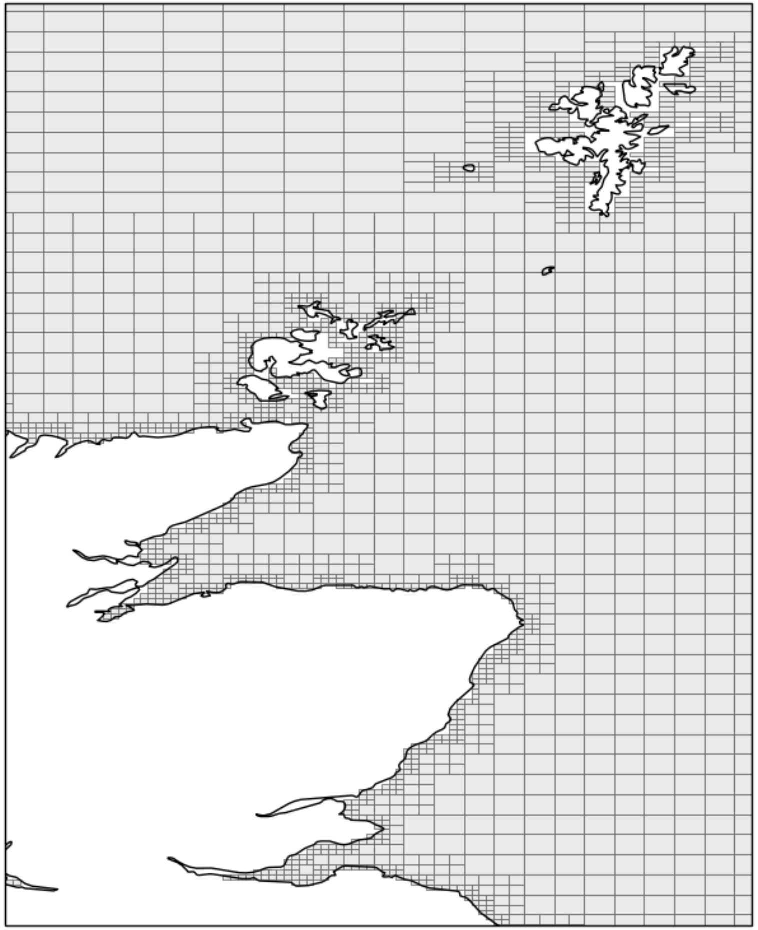
The S36125 global model

- Hawaii – 25-12-6 km grid



The S36125 global model

- Northeast Scotland – 12-6-3 km grid + longitude cell increase at 60 degrees north



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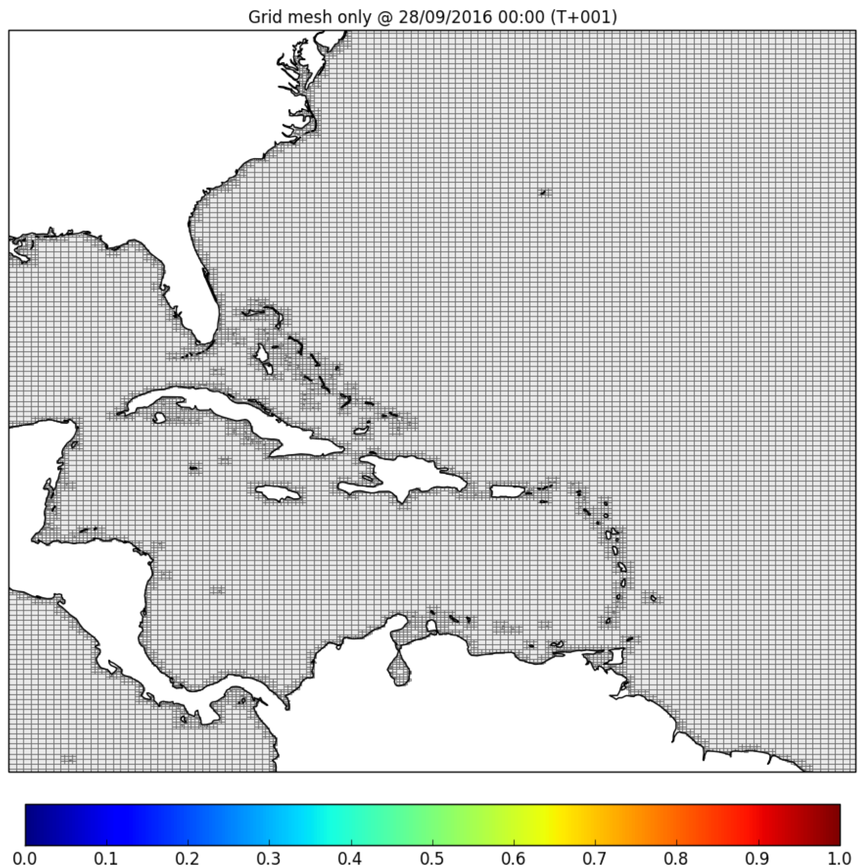
Example: Hurricane Matthew

- Hindcast plus forecast from 0600z 06/10/2016



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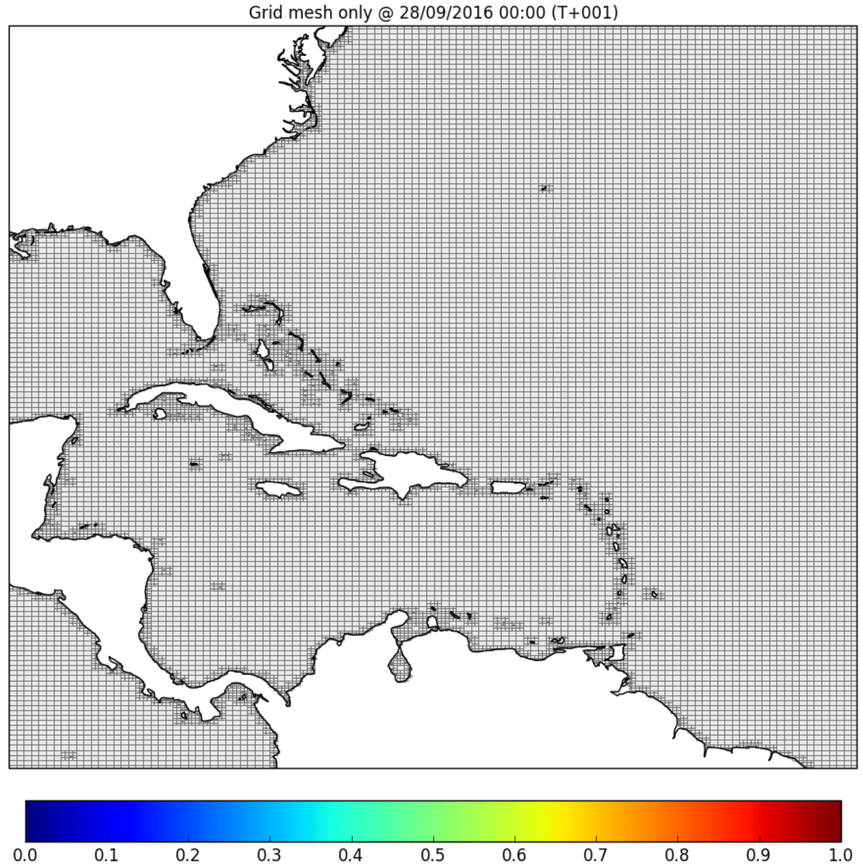
Example: Hurricane Matthew

- Hindcast plus forecast from 0600z 06/10/2016

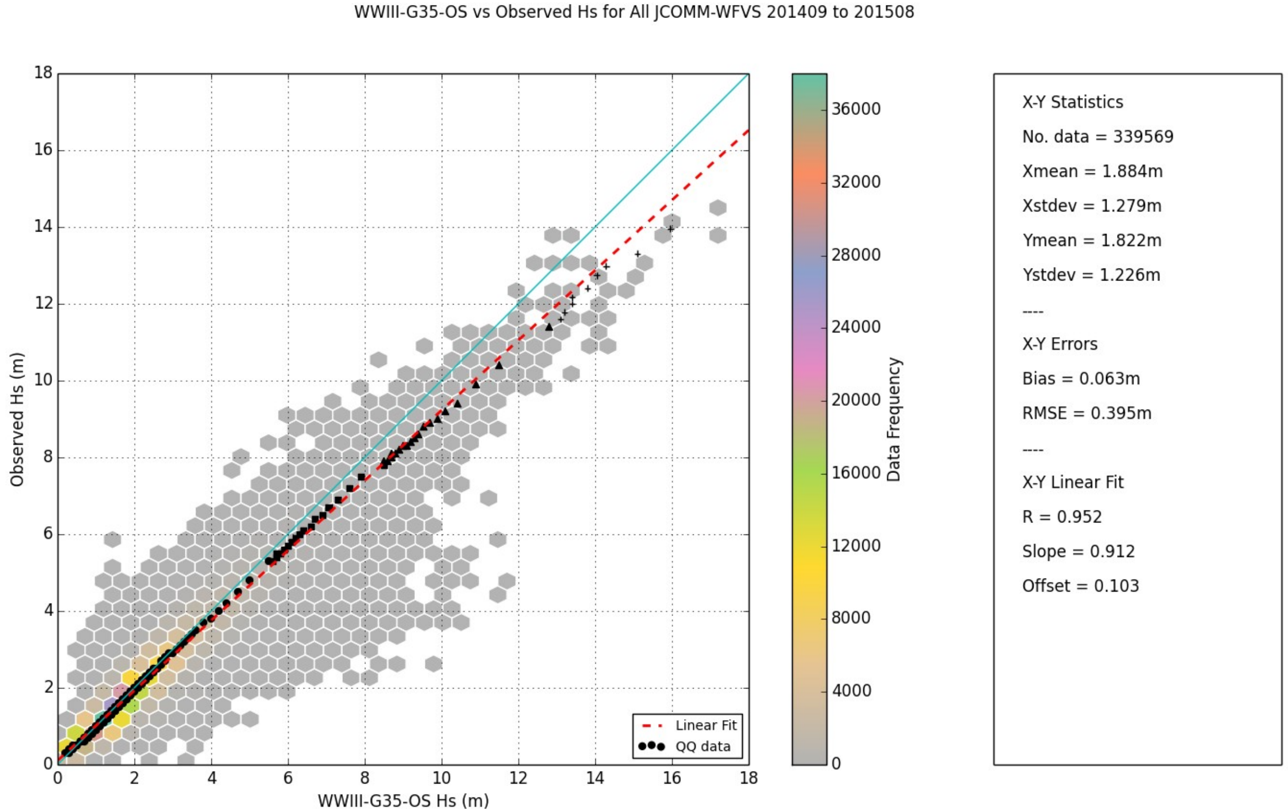


Trials – key results

- Trials run using a 1-year experiment under analysis winds forcing (from Met Office operational atmospheric model, ~17km horizontal resolution)
- Comparisons versus:
  - JCOMM-WFVS in-situ data (Bidlot et al., 2007)
  - CERSAT merged altimeter product (Queffeulou, 2013)
  - Operational 35km global wave model (Saulter, 2015)

Trials – key results

- JCOMM-WFVS: relative improvement in Hs prediction errors of ~15-20% (5% in real terms)



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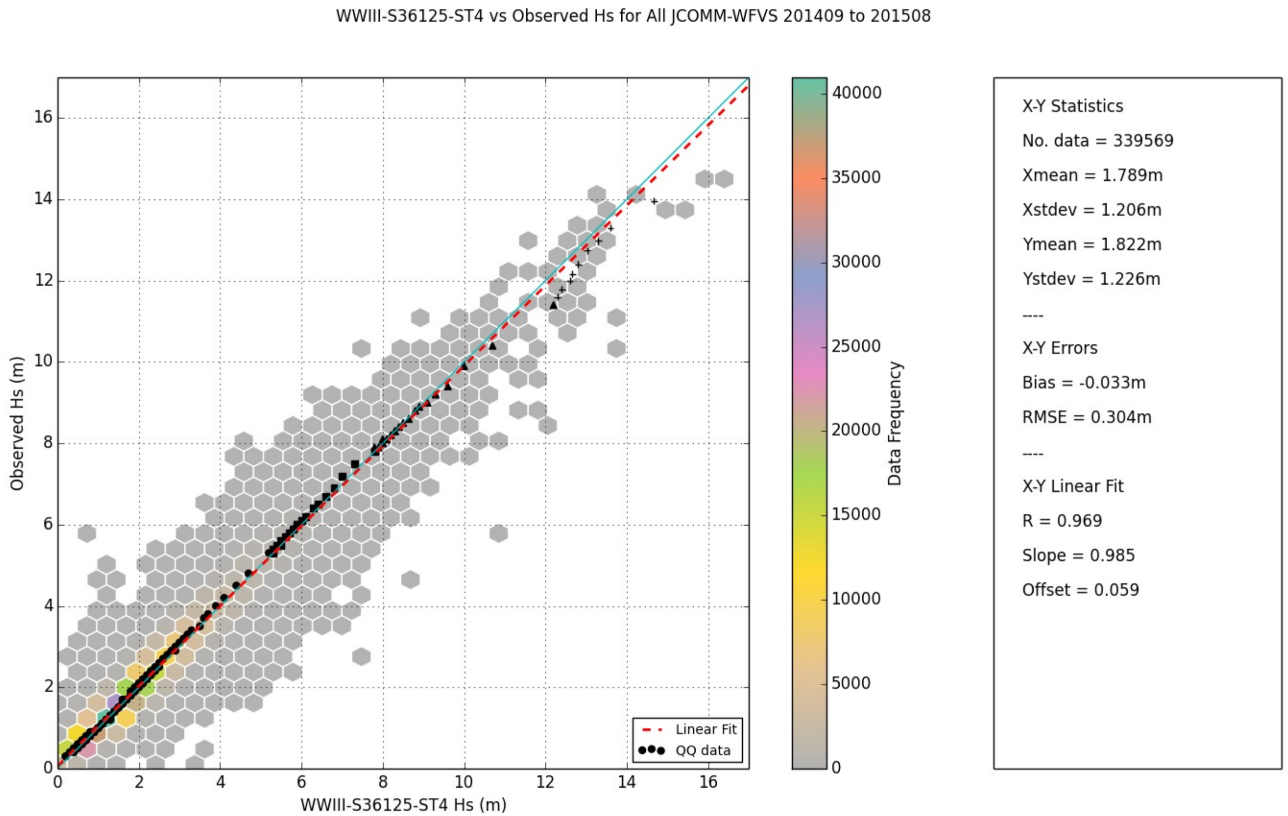

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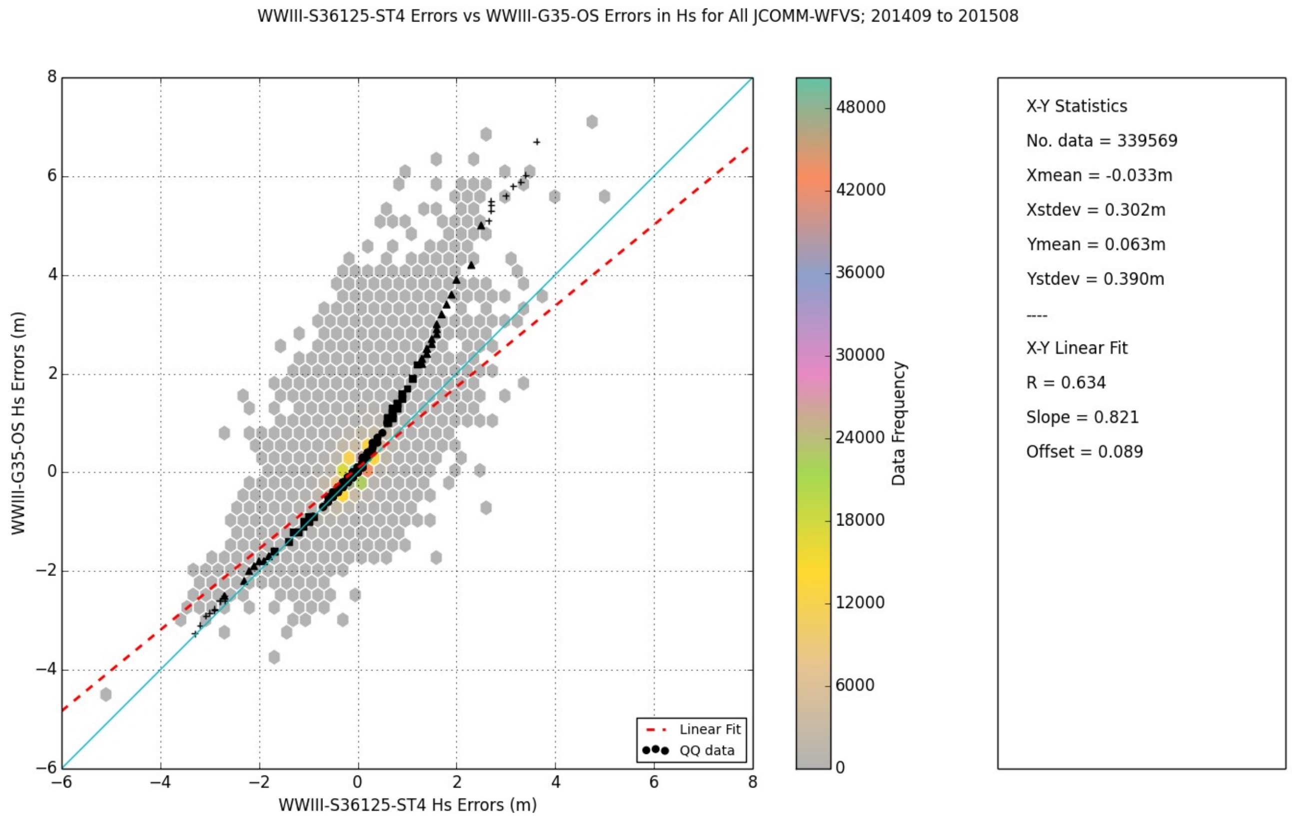

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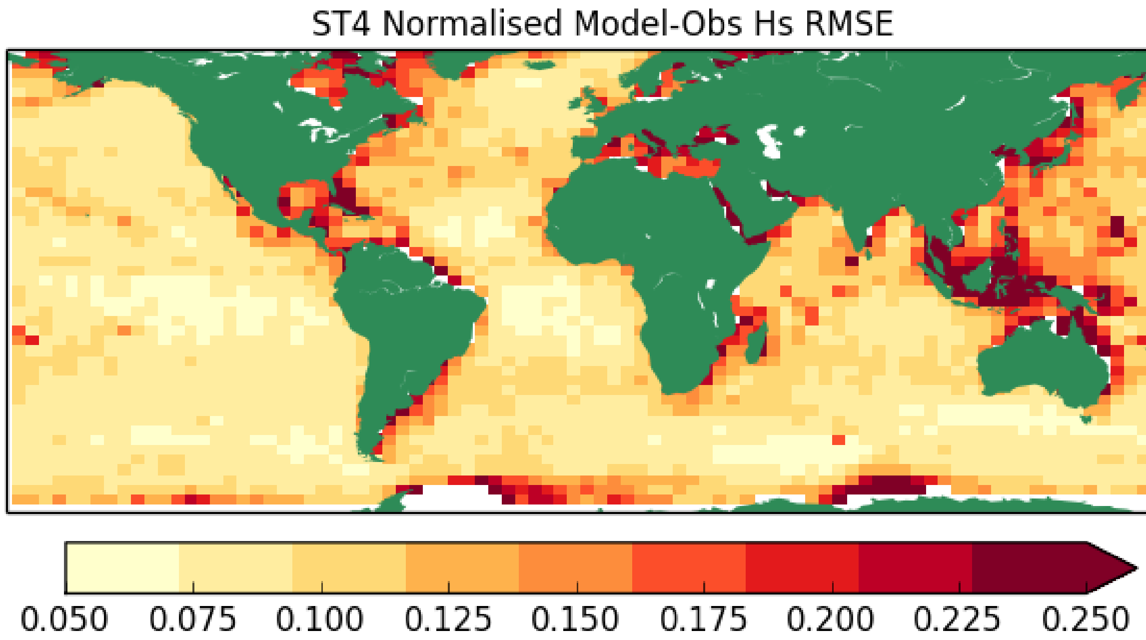
Trials – key results

- Altimeter: NRMSE generally 10-15% across globe; larger errors associated with high bias magnitudes and where wind forcing also performs poorly



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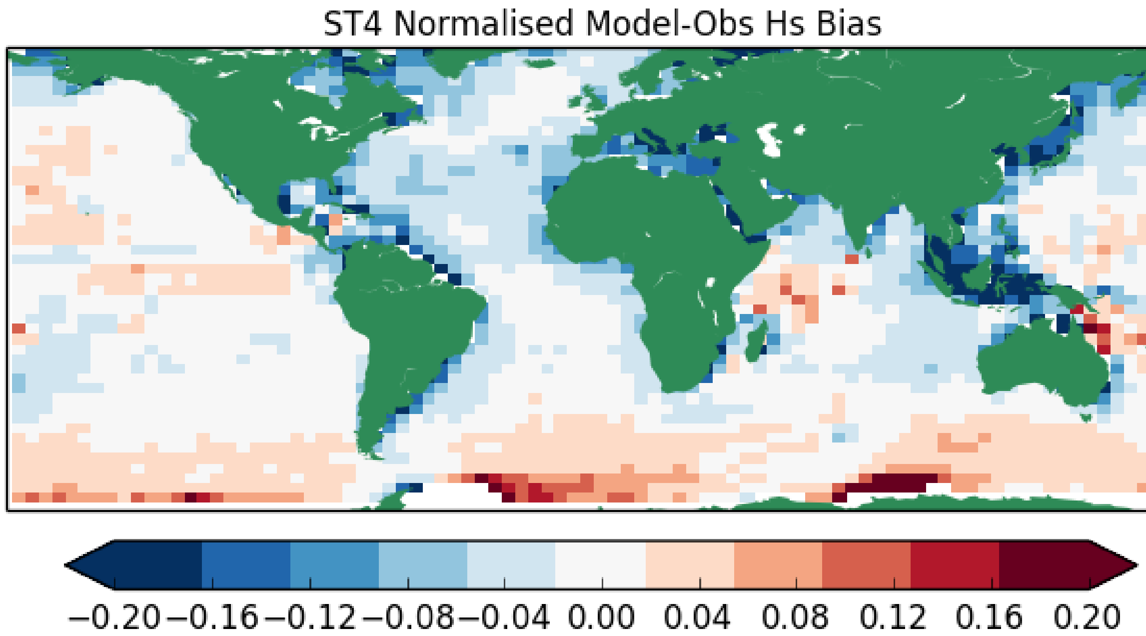

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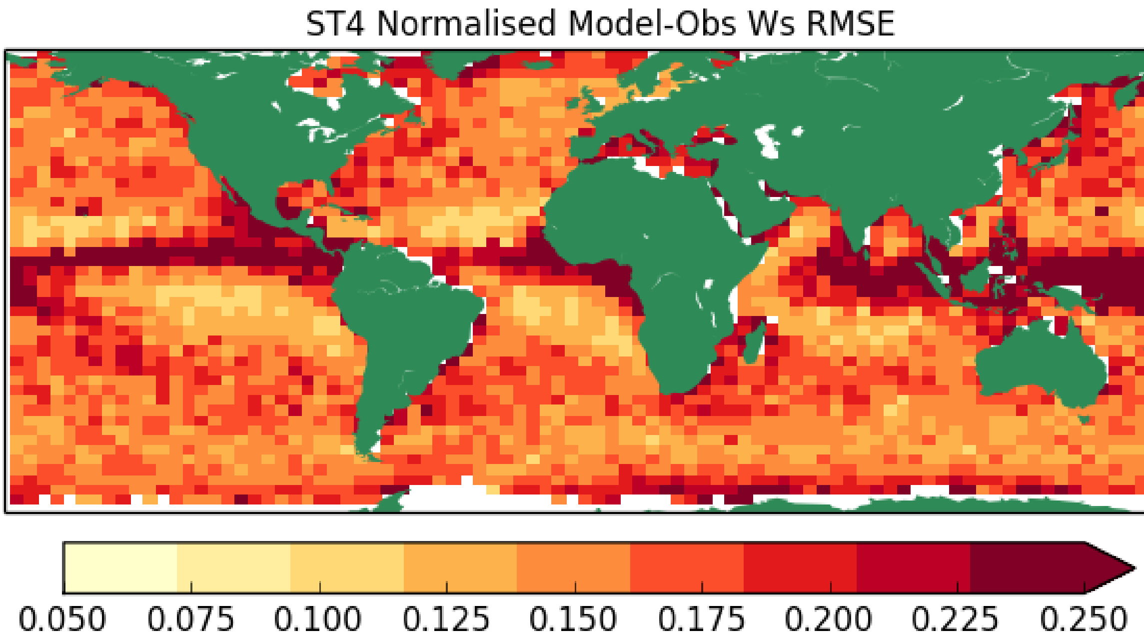
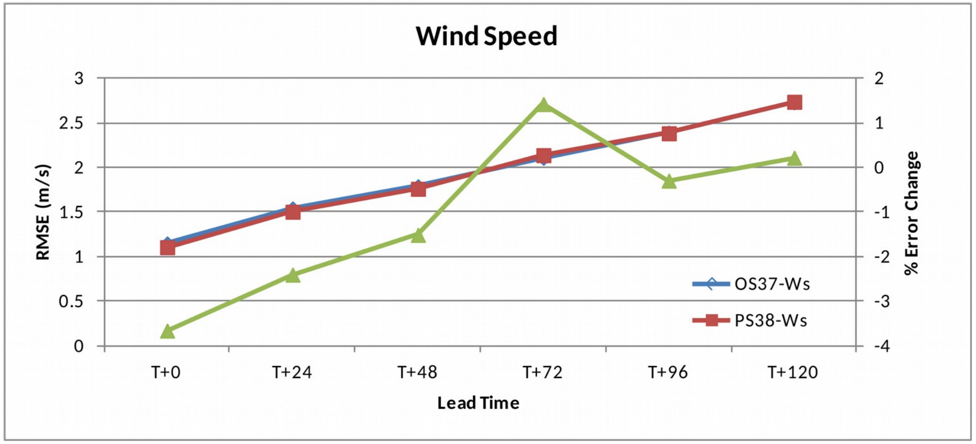
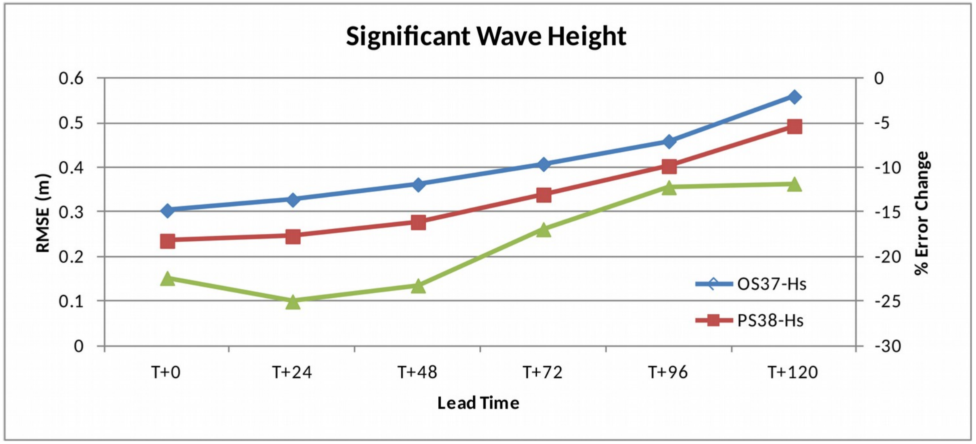


Parallel suite, early results

- JCOMM-WFVS: Trials results consistent with 1st month production





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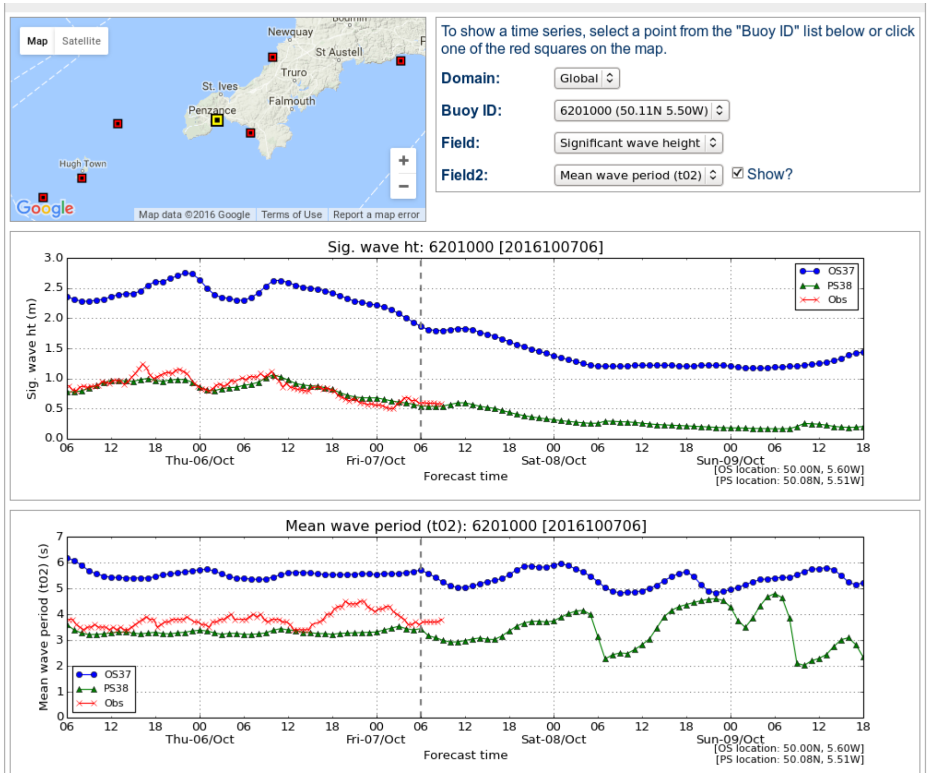
Parallel suite, early results

- Coastal data comparison: High resolution cells give significant improvement versus global model. Further work to be done, but results appear consistent with Li and Saulter (2014)



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Summary

- A refined grid scheme has been introduced in WAVEWATCH III and forms the basis for the Met Office's operational global wave model
- The combined model package (grid scheme, source terms, code version) leads to significant improvement in model skill
- Largest effects are seen in significant wave height predictions and are strongly linked to a reduction in forecast busts at high wave heights
- A specific benefit of the model should be a global improvement in inshore waters forecast capability – further work is required to quantify this benefit
- The SMC grid defers the issue of scale-ability in the wave model, but does not resolve it…

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References

- Ardhuin, F., E. Rogers, A.V. Babanin, J.-F. Filipot, R. Magne, A. Roland, A. Van der Westhuysen, P. Queffeulou, J.-M. Lefevre, L. Aouf and F. Collard, 2010: Semi-empirical dissipation source functions for wind-wave models. Part I: definition, calibration and validation. J. Phys. Oceanogr., 40 (9), 1917–1941.
- Bidlot, J.-R., J.-G. Li, P. Wittmann, M. Faucher, H. Chen, J.-M, Lefevre,T. Bruns, D. Greenslade, F. Ardhuin, N. Kohno, S. Park and M. Gomez, 2007: Inter-Comparison of Operational Wave Forecasting Systems. In Proc. 10th International Workshop on Wave Hindcasting and Forecasting and Coastal Hazard Symposium,North Shore, Oahu, Hawaii, November 11-16, 2007.
- Booij, N. and L. H. Holthuijsen, 1987: Propagation of ocean waves in discrete spectral wave models. J. Comp. Phys., 68, 307-326.
- Li, J.G. 2008: Upstream Non-Oscillatory (UNO) advection schemes. Monthly Weather Review, 136, 4709-4729.
- Li, J.G. 2011: Global transport on a spherical multiple-cell grid. Monthly Weather Review, 139, 1536-1555.
- Li, J.G. 2012: Propagation of ocean surface waves on a spherical multiple-cell grid. Journal of Computational Physics, 231, 8262-8277.
- Li, J. G., and A. Saulter 2014: Unified global and regional wave model on a multi-resolution grid. Ocean Dynamics, 64, 1657-1670.
- Li, J.G. 2016: Ocean surface waves in an ice-free Arctic Ocean. Ocean Dynamics, 66, 989-1004.
- Queffeulou, P., 2013. Merged altimeter data base. An update. Proceedings ESA Living Planet Symposium 2013, Edimburgh, UK, 9–13 September, ESA SP-722. Available at ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/publications/ESA LivingPlanet Symposium 2013.pdf .
- Rasch, P. J., 1994: Conservative shape-preserving two-dimensional transport on a spherical reduced grid. Mon. Wea. Rev., 122, 1337–1350.
- Saulter, A., 2015. Assessment of WAM Cycle-4 based source terms for the Met Office global-regional wave modelling system. Met Office Forecasting Research Technical Report 598. http://www.metoffice.gov.uk/media/pdf/c/s/FRTR598.pdf
- Tolman, H. L., 2002: Alleviating the garden sprinkler effect in wind wave models. Ocean Mod., 4, 269-289.

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Regional WFVS stats - Hs

- Error stats normalised by RMS of observation

	Observed		S36125-ST4				G35-OS			
Region	Mean	StDev	RMSE	Bias	StDev	Corr	RMSE	Bias	StDev	Corr
All	1.82	1.23	0.14	-0.02	0.98	0.97	0.18	0.03	1.04	0.95
Irish Sea	1.15	0.77	0.16	-0.04	1.03	0.96	0.19	-0.06	0.95	0.94
North Sea	2.04	1.33	0.09	0.02	0.98	0.99	0.13	0.06	1.04	0.98
UK Western Approaches	3.08	1.79	0.09	0.00	1.00	0.98	0.14	0.03	1.08	0.97
Northeast Atlantic	2.82	1.75	0.13	-0.02	0.97	0.97	0.18	0.04	1.05	0.95
Iberian Atlantic	2.14	1.27	0.14	0.00	0.96	0.96	0.18	0.04	1.04	0.94
West Mediterranean	1.09	0.90	0.17	-0.09	1.00	0.97	0.20	-0.01	1.09	0.96
East Mediterranean	1.02	0.78	0.20	-0.14	0.96	0.96	0.28	0.09	1.17	0.93
Australia West Coast	2.04	0.64	0.12	0.02	0.88	0.91	0.20	0.10	1.18	0.86
Australia East Coast	1.82	0.93	0.27	-0.13	0.71	0.85	0.22	-0.06	0.85	0.89
Brazil	2.01	0.74	0.18	-0.04	0.85	0.86	0.19	-0.01	0.96	0.85
Caribbean	1.47	0.63	0.14	0.05	0.97	0.94	0.18	0.10	1.03	0.93
Northwest Atlantic	1.98	1.30	0.14	-0.01	0.89	0.97	0.15	-0.01	0.94	0.96
Central West Atlantic	1.80	0.62	0.09	0.01	0.91	0.96	0.11	-0.02	1.00	0.94
US East Coast	1.40	0.80	0.14	0.01	0.95	0.96	0.16	-0.01	0.98	0.95
Korea-Japan	1.12	0.83	0.25	-0.17	0.89	0.93	0.26	-0.03	0.96	0.91
India	1.62	0.88	0.14	-0.03	0.89	0.96	0.16	-0.01	0.91	0.95
Hawaii	2.10	0.65	0.12	0.03	0.96	0.92	0.18	0.10	1.06	0.87
US West Coast	2.03	0.91	0.12	-0.03	0.93	0.96	0.16	0.03	0.99	0.93
Northeast Pacific	2.43	1.22	0.11	-0.01	0.94	0.97	0.14	0.01	0.99	0.95
Gulf of Mexico	1.02	0.61	0.17	-0.02	0.97	0.94	0.18	0.01	1.00	0.94

Regional WFVS stats - Tp

- Error stats normalised by RMS of observation

	Observed		S36125-ST4				G35-OS			
Region	Mean	StDev	RMSE	Bias	StDev	Corr	RMSE	Bias	StDev	Corr
All	8.88	3.17	0.24	0.06	1.12	0.78	0.29	0.05	1.22	0.73
Irish Sea	4.70	1.38	0.41	0.01	1.62	0.46	0.48	0.06	1.71	0.31
North Sea	5.68	2.11	0.31	0.06	1.15	0.69	0.27	-0.06	0.99	0.72
UK Western Approaches	11.30	2.62	0.09	-0.02	0.95	0.92	0.12	-0.03	1.00	0.87
Northeast Atlantic	11.30	2.45	0.08	-0.01	1.02	0.93	0.12	-0.03	1.02	0.86
Iberian Atlantic	8.48	2.32	0.39	0.31	1.14	0.63	0.39	0.30	1.23	0.64
West Mediterranean	5.39	1.37	0.22	0.02	1.27	0.73	0.24	0.03	1.28	0.66
East Mediterranean	5.46	1.43	0.23	-0.14	0.90	0.71	0.26	-0.19	0.82	0.73
Australia West Coast	12.39	2.20	0.16	0.06	0.75	0.58	0.18	0.04	0.92	0.49
Australia East Coast	10.00	2.27	0.19	-0.03	1.19	0.72	0.22	-0.03	1.29	0.65
Brazil	8.87	1.88	0.17	-0.05	0.94	0.67	0.20	-0.04	1.13	0.62
Caribbean	7.12	1.40	0.18	0.05	1.13	0.65	0.20	0.05	1.19	0.61
Northwest Atlantic	8.29	2.07	0.18	-0.01	0.93	0.72	0.19	-0.03	1.02	0.71
Central West Atlantic	8.94	1.90	0.13	0.01	0.83	0.79	0.16	-0.01	1.08	0.73
US East Coast	7.71	2.10	0.21	0.02	0.93	0.67	0.23	-0.03	1.04	0.65
Korea-Japan	5.96	2.05	0.30	0.10	1.26	0.71	0.39	0.16	1.39	0.61
Hawaii	10.60	2.59	0.26	0.11	1.13	0.58	0.32	0.15	1.26	0.46
US West Coast	11.59	2.88	0.24	0.10	1.06	0.60	0.29	0.12	1.15	0.49
Northeast Pacific	10.26	2.63	0.28	0.10	1.18	0.53	0.34	0.12	1.33	0.43
Gulf of Mexico	5.84	1.31	0.17	-0.06	0.92	0.70	0.24	-0.04	1.14	0.52