Appendix A

D.1.1. The Offline Coupling System and the Online Coupling System

Jianting Du, Rodolfo Bolaños, Xiaoli Larsén, Joakim Nielsen

Feb. 10th 2015

1. The offline coupling system

The offline coupling system we developed enables the coupling between WRF and MIKE 21 SW. In the system WRF uses regular structured grid and MIKE uses unstructured grid. It is called "offline" because the data exchange between the two models is not concurrently. Manual operation is needed in some routines. The aim of offline coupling is to test the sensitivity of the model resolution and different roughness length (z_0) schemes in the coupling processes. Another important aim is to investigate the remapping approach between the two different grid structures, especially in nested cases.

The offline coupling system is divided into three parts—WRF model, MIKE 21 SW model, and the data interpolation and conversion routine (DIC). The schematic diagram of the system is shown in Fig. 1. To run the system, the first step is to setup and run WRF to get hourly 10 meters wind velocity (U_{10}) for MIKE. Secondly, through a DIC routine, U_{10} will be interpolated to the unstructured grid and then converted into a "dfsu" format file (see Fig 1) which will be used by MIKE directly. MIKE is then ready to be run. Wave parameter outputs such as significant wave height (H_s), peak wave period (T_p) and peak wave length (L_p) will then be used to calculate z_0 using one of the many z_0 schemes such as Fan et al. (2012), Taylor & Yelland (2001), Charnock (1955). In MIKE, z_0 is calculated from the wind input source function using Janssen (1991) 's scheme. Those data are interpolated and converted into a WRF input data file by a post DIC routine. Finally, rerun WRF with the same setting as the first step, but now the z_0 at water points are updated hourly.

The interpolation method between the two models is linearly as described in Matlab function "griddata()". As is shown in Fig.2, MIKE grids that are inside WRF inner domain (d02) are interpolated from the WRF grids in d02. MIKE grids that are on the boundary or outside d02 are interpolated from WRF outer domain (d01), vice versa. As WRF d01 is larger than MIKE domain, water points in WRF that are outside MIKE domain will be supplemented by Charnock(1955) relation.

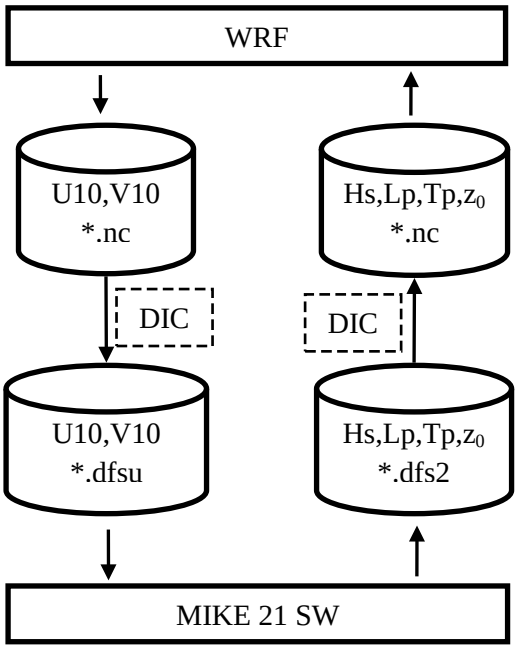

Fig. 1. Schematic diagram of the offline coupling system. The arrows indicate the data flux. The cylinders indicate data. The dished rectangles indicate DIC routines. And the solid rectangles indicate wind and wave models.

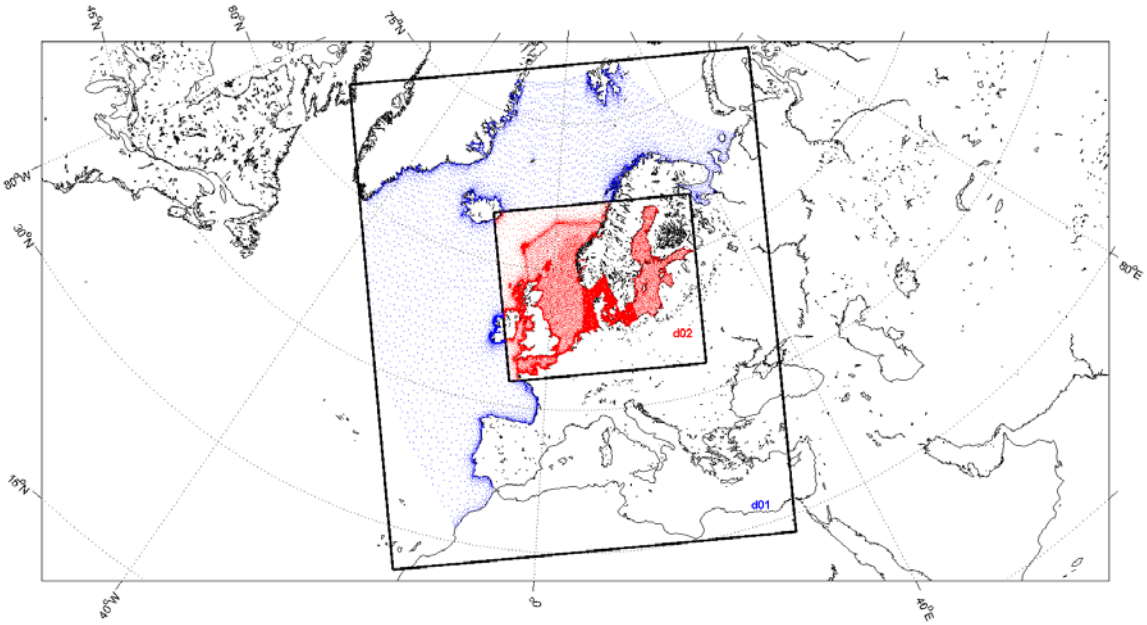

Fig. 2. Grid interpolation (remapping) method between WRF and MIKE. The red points are MIKE grids that are inside WRF inner domain (d02), which will be interpolated from d02. The points that are outside or on the boundary of d02 are marked as blue, which will be interpolated from WRF outer domain (d01). The black boxes indicate WRF domains.

2. The online coupling system

Currently, our online coupling system is based on COAWST, which is a Coupled Ocean – Atmosphere – Wave – Sediment Transport Modeling System. Currently we only use WRF+SWAN. The aim of using COAWST is to investigate and learn from the state of the art

technical of online coupling, so as to apply them to our future coupling system, intentionally using WRF and MIKE. We aim at the investigation of physics and the system development.

In COSWST, the data exchange between models is handled by the Model Coupling Toolkit (MCT) and the remapping weights between different grid structures are calculated by SCRIP—A Spherical Coordinate Remapping and Interpolation Package. Based on those data exchange and interpolation tools, COAWST is efficient enough to enable the data exchange between the two models at every time step. It also supports WRF and SWAN using different grid and nesting. But unstructured grid is not supported.

In the latest COAWST version (3.1), WRF transfers u_{10} and v_{10} to SWAN while SWAN transfers H_s, T_p, and L_p to WRF. In the current system there have been implemented a number of z_0 schemes: Taylor & Yelland (2001), Oost et al.(2002), and Drennan et al. (2005). We added Fan et al. (2012) and Janssen (1991) schemes, in line with our offline coupling system development. We also enable z_0 to be transferred from SWAN to WRF in order to use Janssen (1991) scheme.

Before running COAWST, the topography, boundary condition and initial conditions for both WRF and SWAN should be setup carefully. If the two models are using different grids, the interpolation weights should be calculated by SCRIP. COAWST has a Matlab package to help users to setup the inputs for SCRIP. Fig.3 and Fig.4 shows an example of remapping in a nested case, in which WRF and SWAN uses different grids.

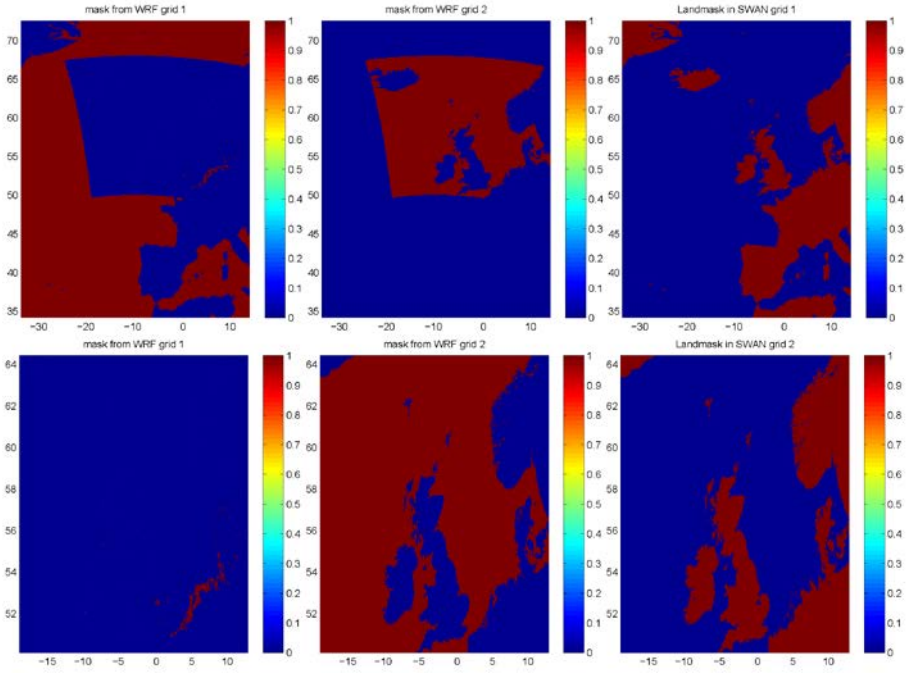

Fig. 3 Remapping masks for SWAN. The upper 3 are SWAN outer domain. The lower 3 are SWAN inner domain. Subfigures from left to right are masks that data transfers from WRF outer domain (red points), from WRF inner domain (red points), and land masks (red points), respectively.

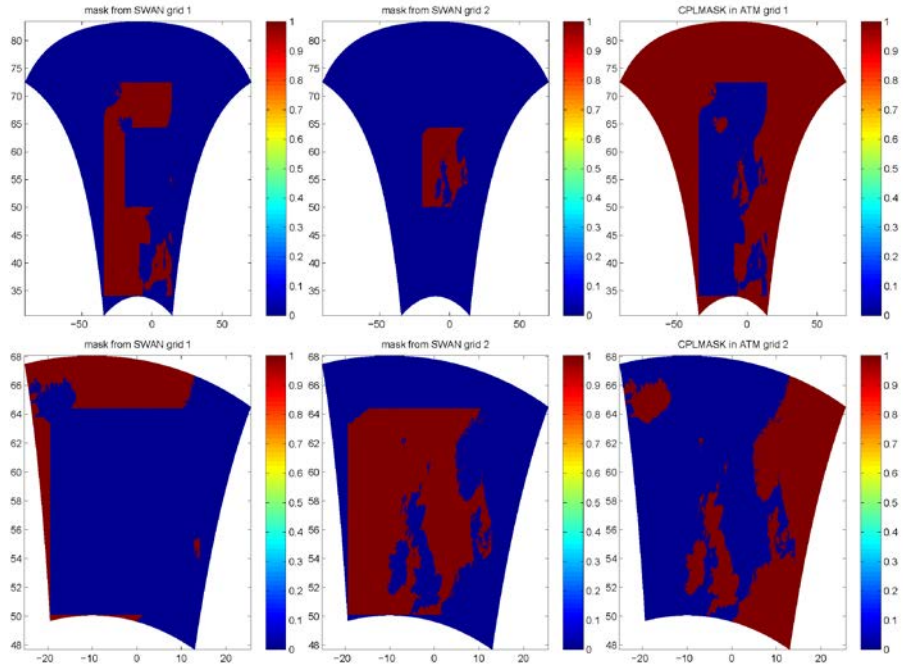

Fig. 4 Remapping masks for WRF. The upper 3 are WRF outer domain. The lower 3 are WRF inner domain. Subfigures from left to right are masks that data transfers from SWAN outer domain (red points), from SWAN inner domain (red points), and land masks (red points), respectively.

Appendix B

Appendix C

Small fetch and extreme winds wave growth in MIKE 21 SW

Blaños R.

Introduction

Tests of MIKE21 SW to assess the effect of the air-sea interaction formulation (Janssen theory, Fan (2012) roughness, Charnock, Smith and Bank wind drag) and the cap on u*/u10 (Jensen et al., 2006) were performed using the quasi-stationary option in MIKE21SW. The formulation of Bidlot (2007) for white-capping has been used for all cases. Several Cdis and Delt constants within the white capping formulation were tested as shown in table 1. The wave-growth curves of Kahma and Calkoen (1992) have been used as a reference.

The Fan (2012) roughness formulation and the extension of lookup tables for stress to properly consider winds above 30m/s are activated via pfs file in the MIKE development version.

Table 1. White-capping coefficients used in the sensitivity runs. Case 13 is the one with default values

		Cdis				
		1.7	1.9	2.1	2.3	2.5
Delt	0.2	Case 1	Case 6	Case 11	Case 16	Case 21
	0.4	Case 2	Case 7	Case 12	Case 17	Case 22
	0.6	Case 3	Case 8	Case 13	Case 18	Case 23
	0.8	Case 4	Case 9	Case 14	Case 19	Case 24
	1	Case 5	Case 10	Case 15	Case 20	Case 25

Model setup

MIKE21SW (Development version from 27/10/2014) was used for the idealized cases. Table 2 shows the model parameters used.

Table 2. MIKE 21SW setup.

Parameter	Value
Number of frequencies	25 (32 also tested)
Minimum frequency	0.055
Freq. factor	1.1
Number of directions	16
Space discretization	Low order
Ma. Number of iterations	400 (plus some tests with 800)
Type of air-sea interaction	Runs included one of: Coupled (Janssen) Uncoupled (Fan (2012), Charnock)
White capping	Bidlot (2007) (power of mean angular freq and power of mean wave number = 1)

Model Mesh

The meshes used are shown below. Different resolutions were tested to assess its effect on short fetch (down to 2 km) up to 80 km wave growth. A coarse resolution was used for most of white-capping sensitivity tests. However a high resolution was used to assess the impact of the mesh and the spectral resolution of frequencies. Model results are evaluated at winds ranging from 1 to 45 m/s.

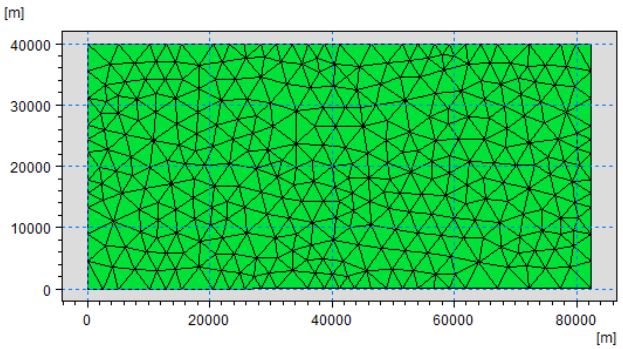

Figure 1. Domain A, coarse mesh used for sensitivity cases of very short fetches.

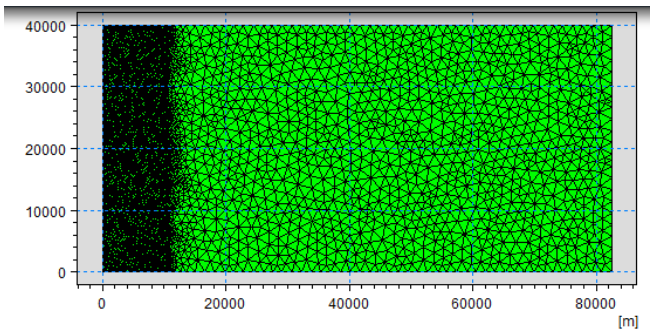

Figure 2. Domain B, High resolution mesh for very short fetches.

Discussions/conclusions

- Kahma and Kalkoen (1992) curves are derived from observations at fetch limited conditions and winds of less than 25 m/s, thus its extrapolation above that range has some uncertainty, however their use might be somewhat conservative, considering the few evidence of reduced roughness (drag) under stronger conditions.
- Estimate of stress table with MIKE 21 SW gives same results as WAM (cycle 4.5.4, http://mywave.github.io/WAM/). However, In WAM the cut off for wave stress is of 5 N/m^2 and thus it works as a capping of the total stress.
- Extension of stress tables removes discontinuity in growth curve which appeared at 30m/s.

- Janssen formulation without cap shows significant overestimation to Kahma and Calkoen (1992), especially for winds of more than 20 m/s at all fetches. For fetches of less than10 km there is also some overestimation at winds between 10-20 m/s.
- Fan results show better agreement than Janssen with the empirical curves for short fetches. However, for fetches of more than 60 km it falls in the lower range of the empirical curves.
- The uncoupled runs (Charnock and Smith and Bank) show very similar results as Fan (2012) and the empirical curves for winds of up to 25 m/s, however above that they produce some overestimation, more clearly seen at short fetches (less than 40 km)
- Cap=0.06 affects winds above 18 m/s
- Cap=0.05 affects winds above 13 m/s
- When using cap=0.05, results converge towards empirical curves except for very short fetch (less than 10 km).
- High spatial resolution and more frequencies (32) are needed to properly characterize waves at fetch of less than 10 km and winds of up to about 15 m/s.
- Quasi-Stationary and Non-stationary results agree and no issue with interations were observed

Results <u>without</u> extending stress stables in MIKE 21 SW

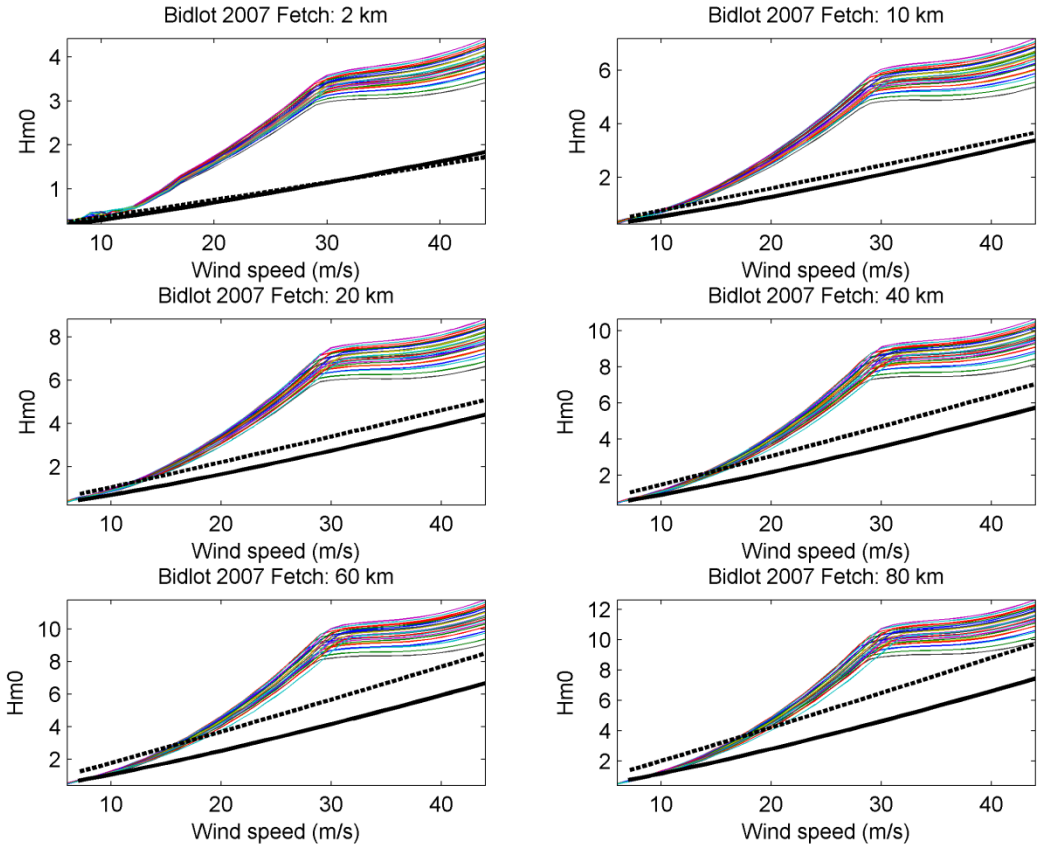

Figure 3. Stationary (domain A) Hm0 results (color lines are the 25 cases) using coupled model with Bidlot (2007) white-capping. Black lines are Kahma and Calkoen (1992) for Stable (continue line) and unstable (dashed line) atmospheric conditions. Runs were performed without extended stress tables.

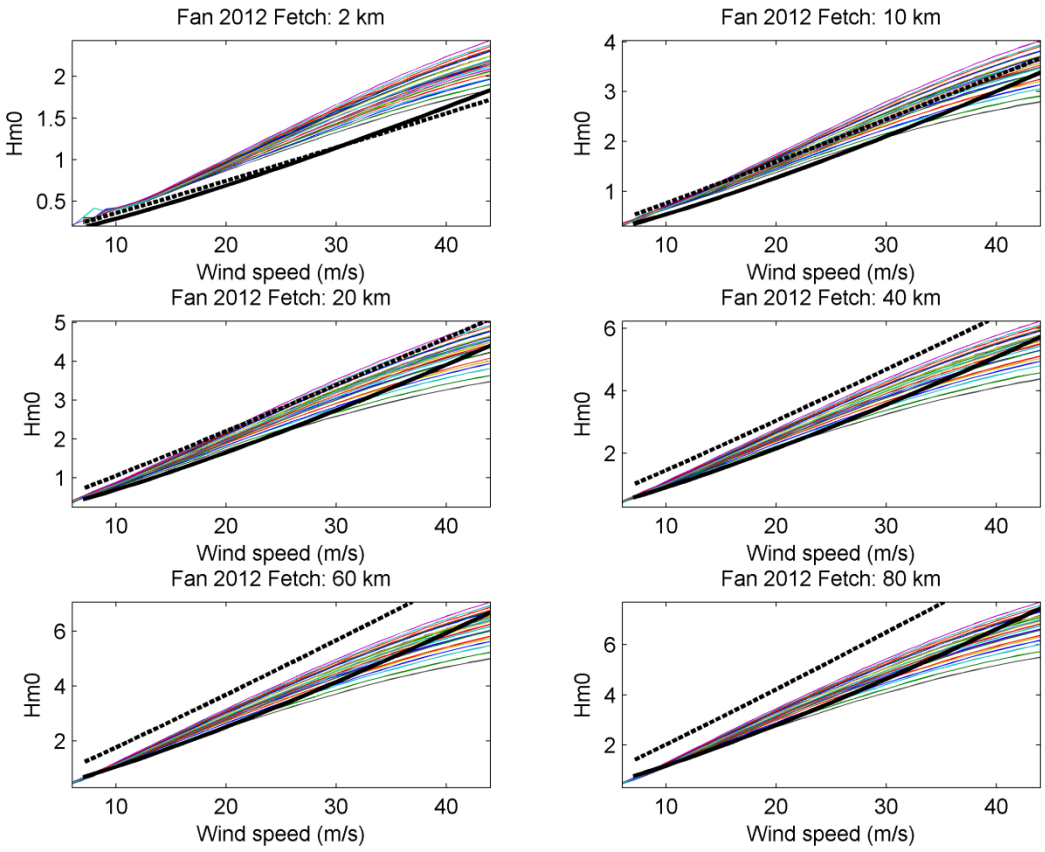

Figure 4. Stationary (domain A) Hm0 results (color lines are the 25 cases) using Fan (2012) wave-age dependent roughness with Bidlot 2007 whitecapping. Black lines are Kahma and Calkoen (1992) for Stable (continue line) and unstable (dashed line) atmospheric conditions. Runs were performed without extended stress tables.

Results <u>After</u> extending stress stables in MIKE

Janssen with Bidlot (2007), No cap. Wave height (Hm0):

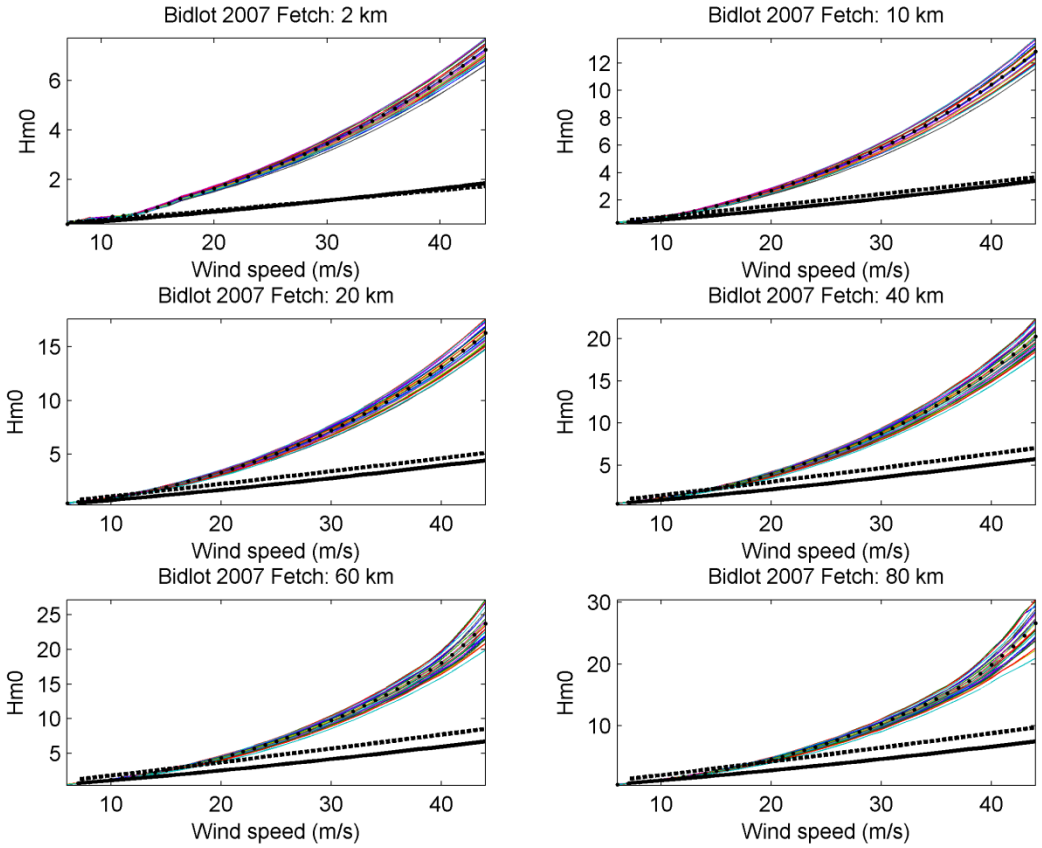

Figure 5. Stationary (domain A) Hm0 results (color lines are the 25 cases) using coupled model with Bidlot (2007) white-capping. Black lines are Kahma and Calkoen (1992) for Stable (continue line) and unstable (dashed line) atmospheric conditions. Black circles represent the run with the default Cdis and delta constant values.

Fan (2012) and uncoupled runs using Bidlot (2007), Wave height (Hm0):

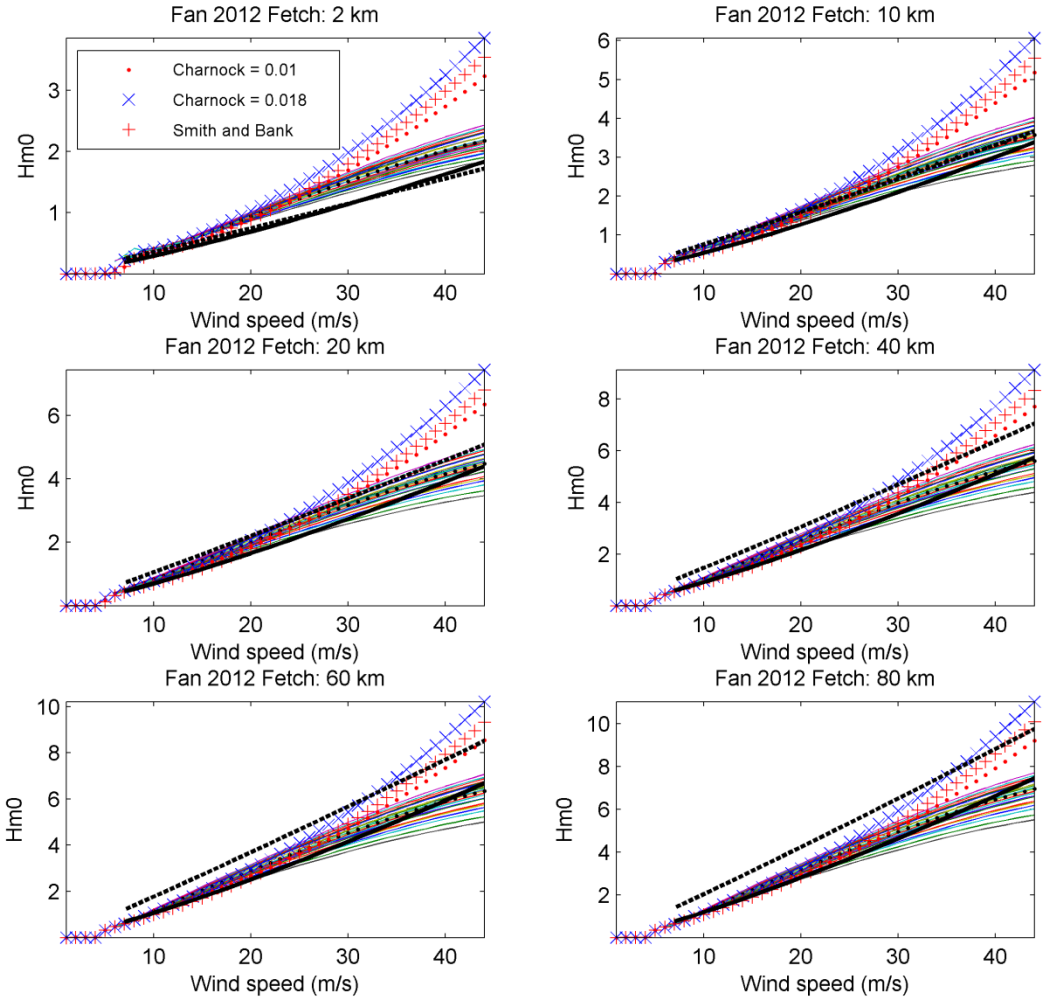

Figure 6.Stationary (domain A) Hm0 results (color lines are the 25 cases) using Fan (2012) with Bidlot (2007) white-capping. Black lines are Kahma and Calkoen (1992) for Stable (continue line) and unstable (dashed line) atmospheric conditions. Black circles indicate the Fan (2012) run when using default Bidlot (2007) white-capping coefficients. The plots also show the results when using uncoupled runs and default Bidlot (2007) coefficients.

Janssen with Bidlot (2007), Cap=0.06. Wave height (Hm0):

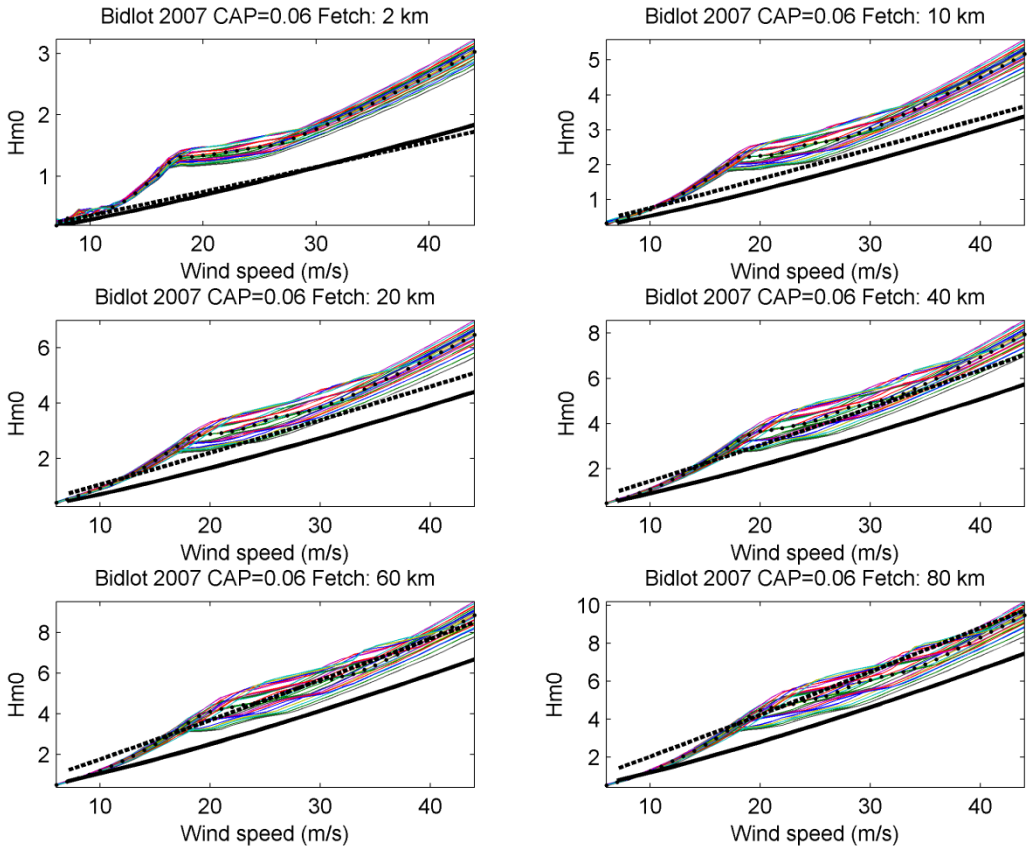

Figure 7.Stationary (domain A) Hm0 results (color lines are the 25 cases) using coupled model with Bidlot (2007) white-capping and a cap of 0.06. Black lines are Kahma and Calkoen (1992) for Stable (continue line) and unstable (dashed line) atmospheric conditions. Black circles represent the run with the default Cdis and delta constant values.

Janssen with Bidlot (2007), Cap=0.05. Wave height (Hm0):

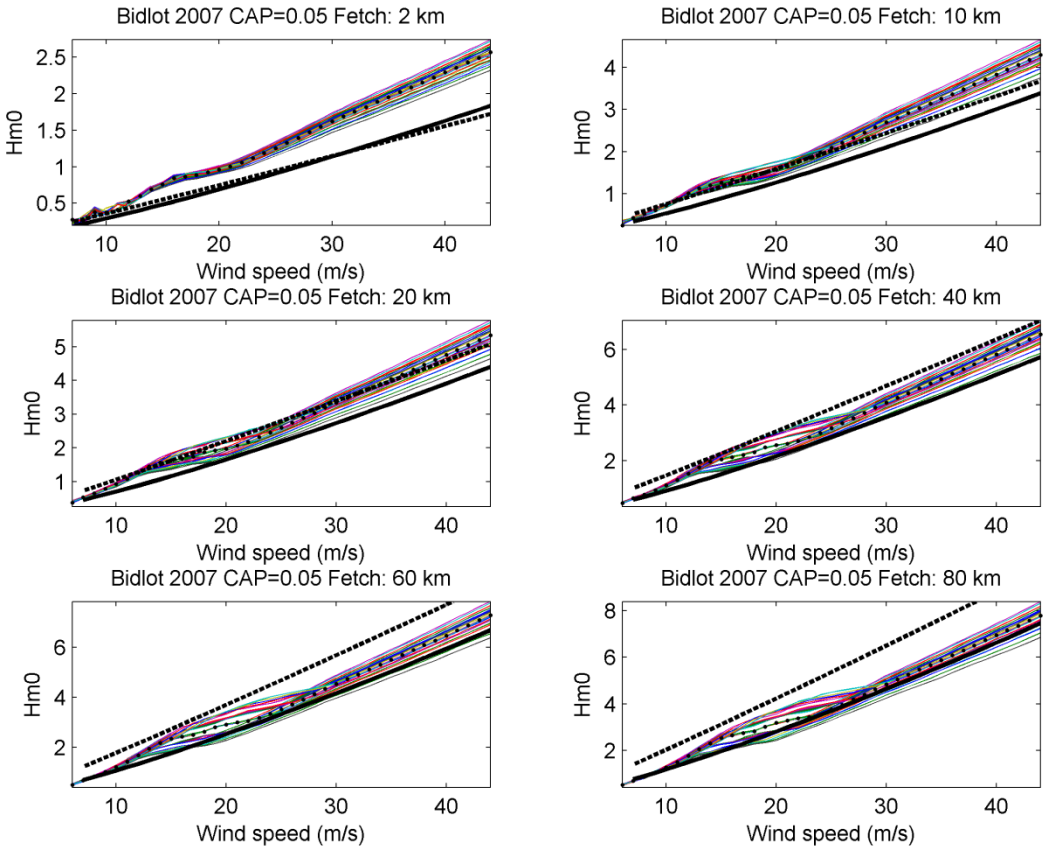

Figure 8.Stationary (domain A) Hm0 results (color lines are the 25 cases) using coupled model with Bidlot (2007) white-capping and a cap of 0.05. Black lines are Kahma and Calkoen (1992) for Stable (continue line) and unstable (dashed line) atmospheric conditions. Black circles represent the run with the default Cdis and delta constant values.

Non-stationary runs using Janssen with Bidlot (2007) for runs of

This runs where non-stationary, the plot shows the Hm0 values after reaching stationary for each wind speed, this was done in order to confirm behavior of quasi-stationary and non-stationary mode.

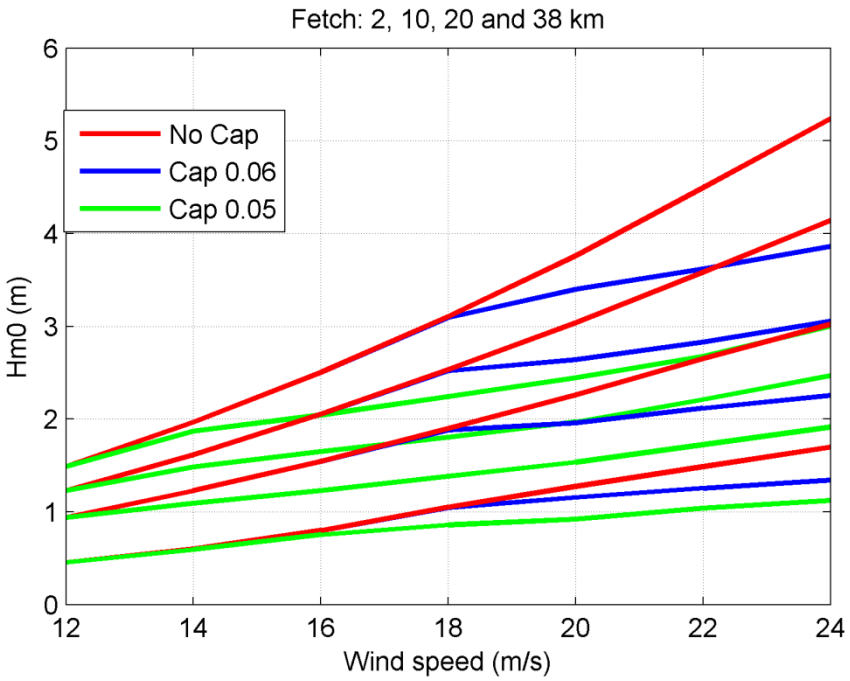

Figure 9.Non-stationary runs for winds from 12-24 m/s for No cap, cap=0.06 and Cap=0.05 and fetches of 20, 10, 20 and 38 km.

Janssen with Bidlot (2007), No cap. Peak period (Tp):

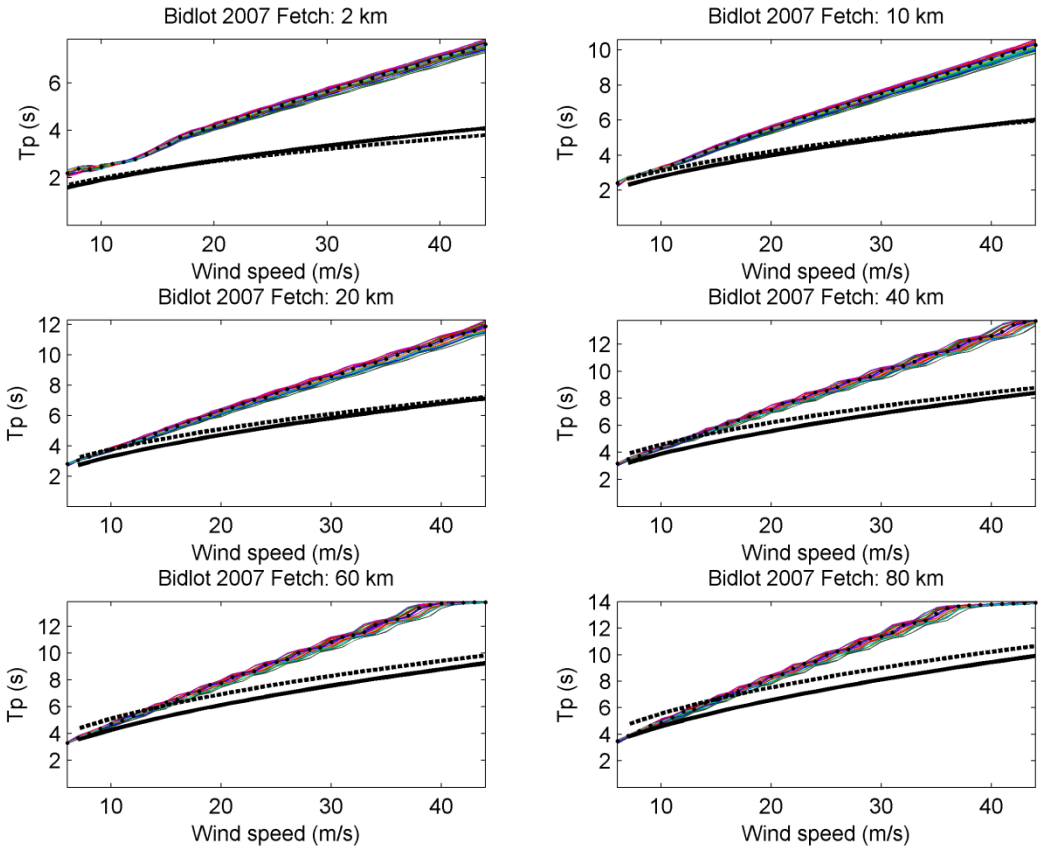

Figure 10.Stationary (domain A) Tp results (color lines are the 25 cases) using coupled model with Bidlot (2007) white-capping. Black lines are Kahma and Calkoen (1992) for Stable (continue line) and unstable (dashed line) atmospheric conditions. Black circles represent the run with the default Cdis and delta constant values.

Fan (2012) with Bidlot (2007). Peak period (Tp):

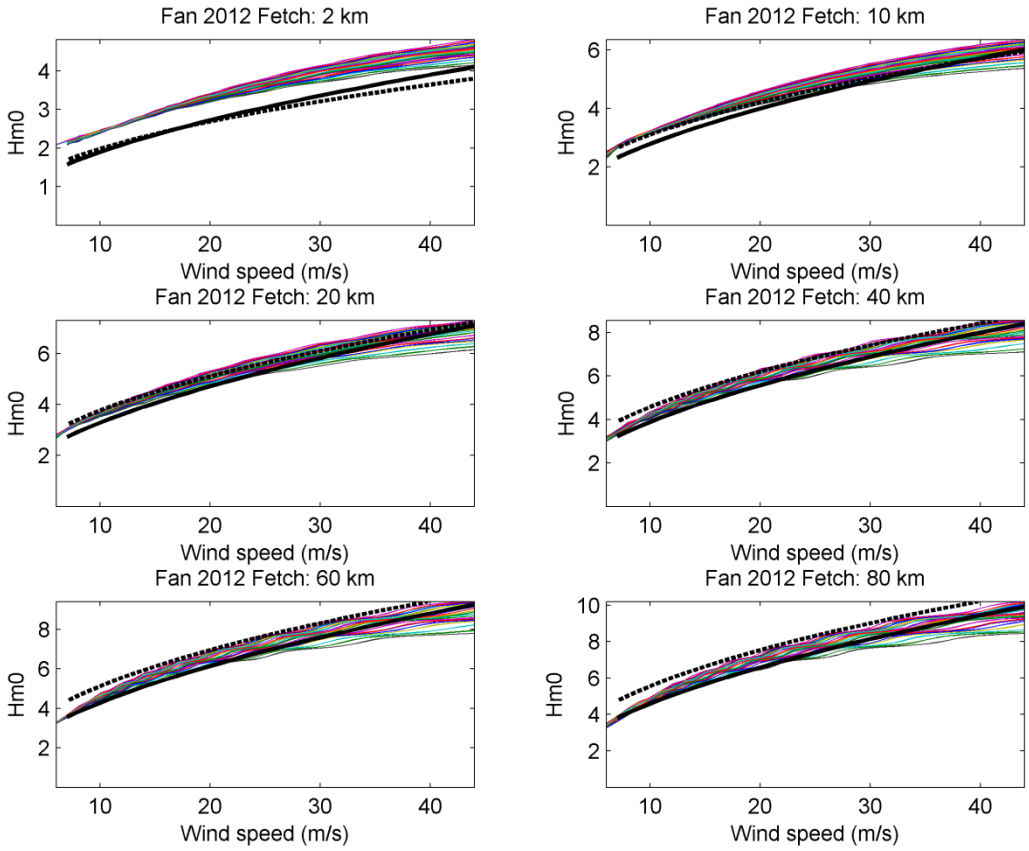

Figure 11.Stationary (domain A) Tp results (color lines are the 25 cases) using Fan (2012) with Bidlot (2007) white-capping. Black lines are Kahma and Calkoen (1992) for Stable (continue line) and unstable (dashed line) atmospheric conditions. Black circles represent the run with the default Cdis and delta constant values.

Janssen with Bidlot (2007), Cap=0.06. Peak period (Tp):

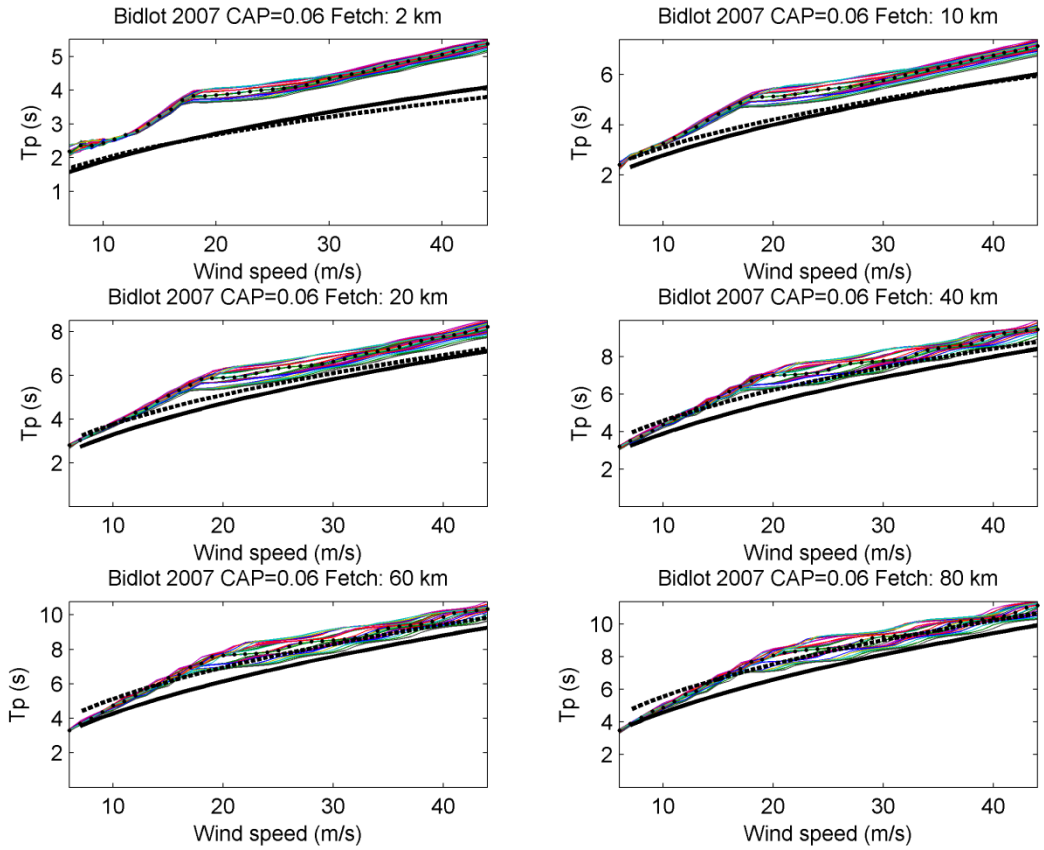

Figure 12.Stationary (domain A) Tp results (color lines are the 25 cases) using coupled model with Bidlot (2007) white-capping and a cap of 0.06. Black lines are Kahma and Calkoen (1992) for Stable (continue line) and unstable (dashed line) atmospheric conditions. Black circles represent the run with the default Cdis and delta constant values.

Janssen with Bidlot (2007), Cap=0.05. Peak period (Tp):

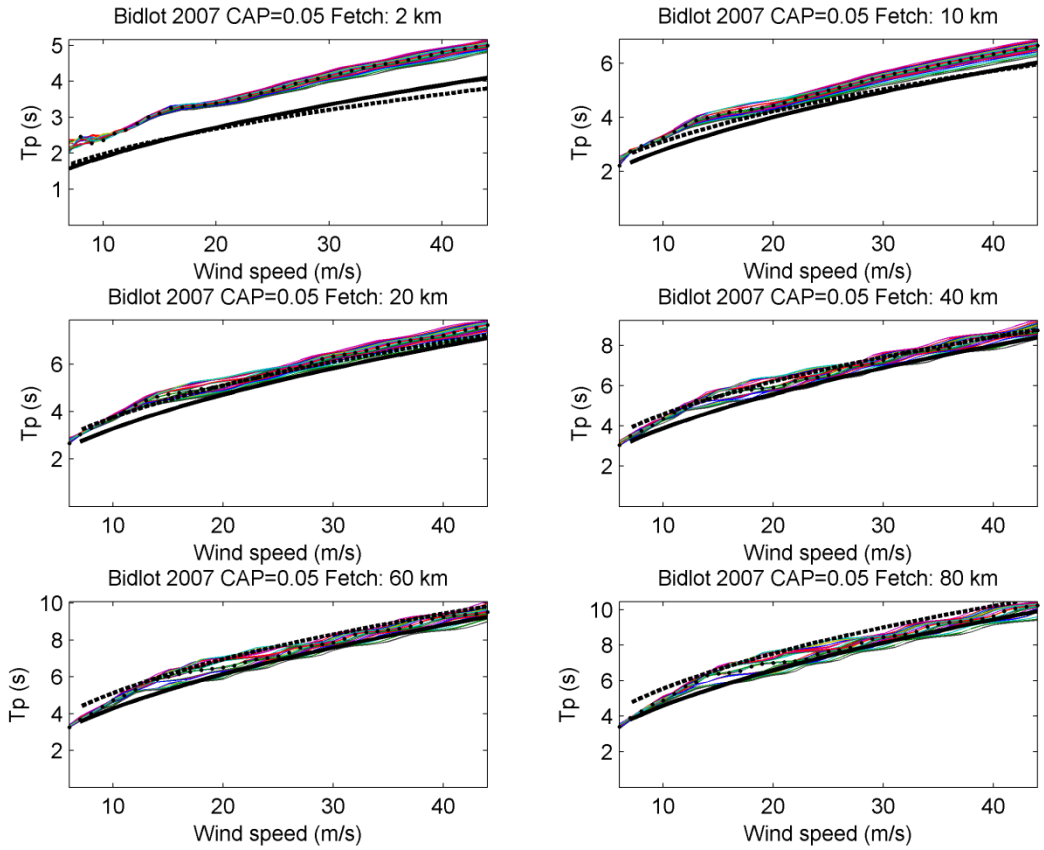

Figure 13.Stationary (domain A) Tp results (color lines are the 25 cases) using coupled model with Bidlot (2007) white-capping and a cap of 0.05. Black lines are Kahma and Calkoen (1992) for Stable (continue line) and unstable (dashed line) atmospheric conditions. Black circles represent the run with the default Cdis and delta constant values.

Effect of spatial and frequency resolution

Janssen with Bidlot (2007), No Cap.

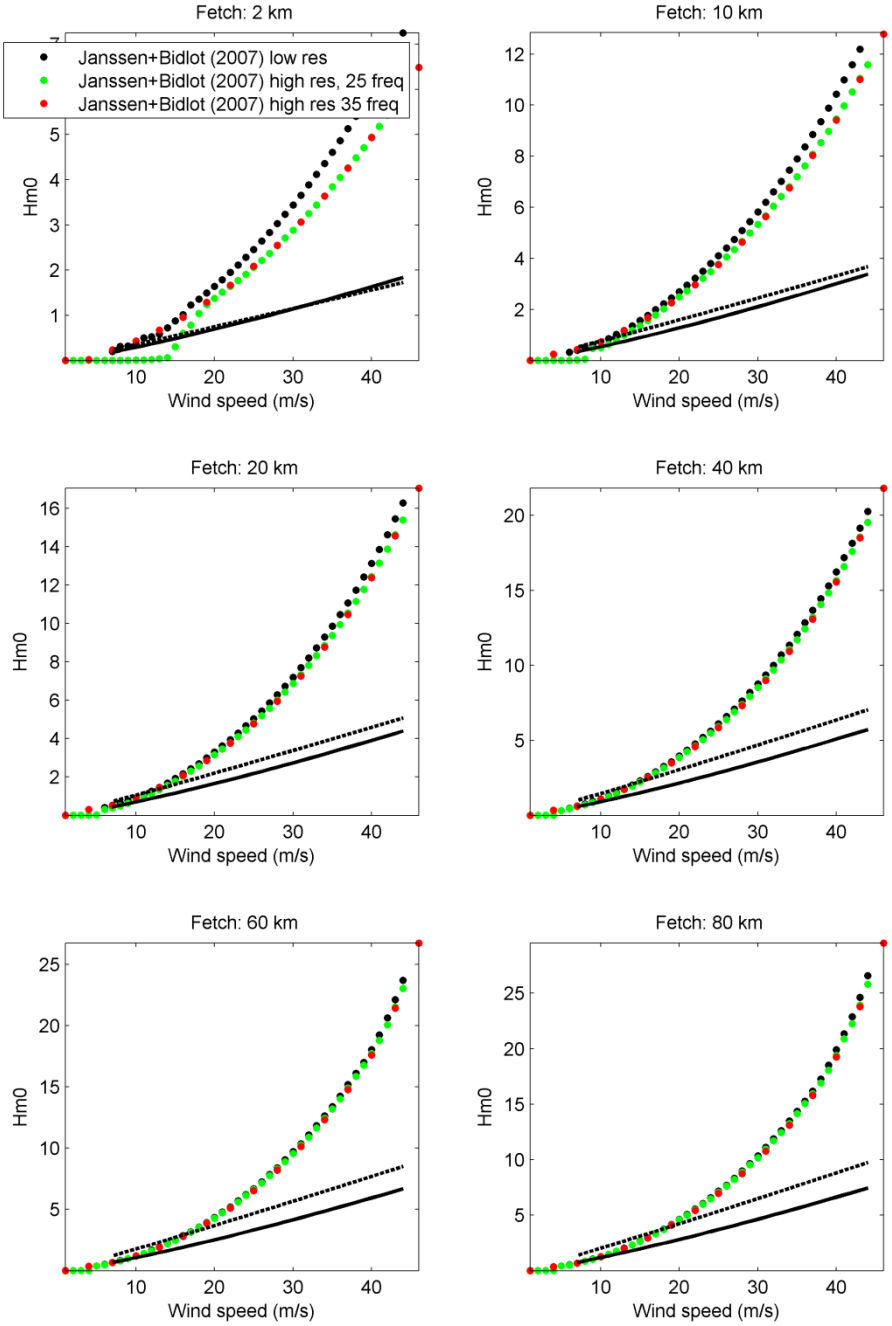

Figure 14.Results (domain A and B) using Janssen formulation and Bidlot (2007) with default coefficients, for coarse and high resolution mesh and increasing frequency resolution from 25 to 32 frequencies. Black lines represent the empirical formulation of Kahama and Calkoen (1992) for stable and unstable atmospheric conditions.

Janssen with Bidlot (2007), Cap=0.05.

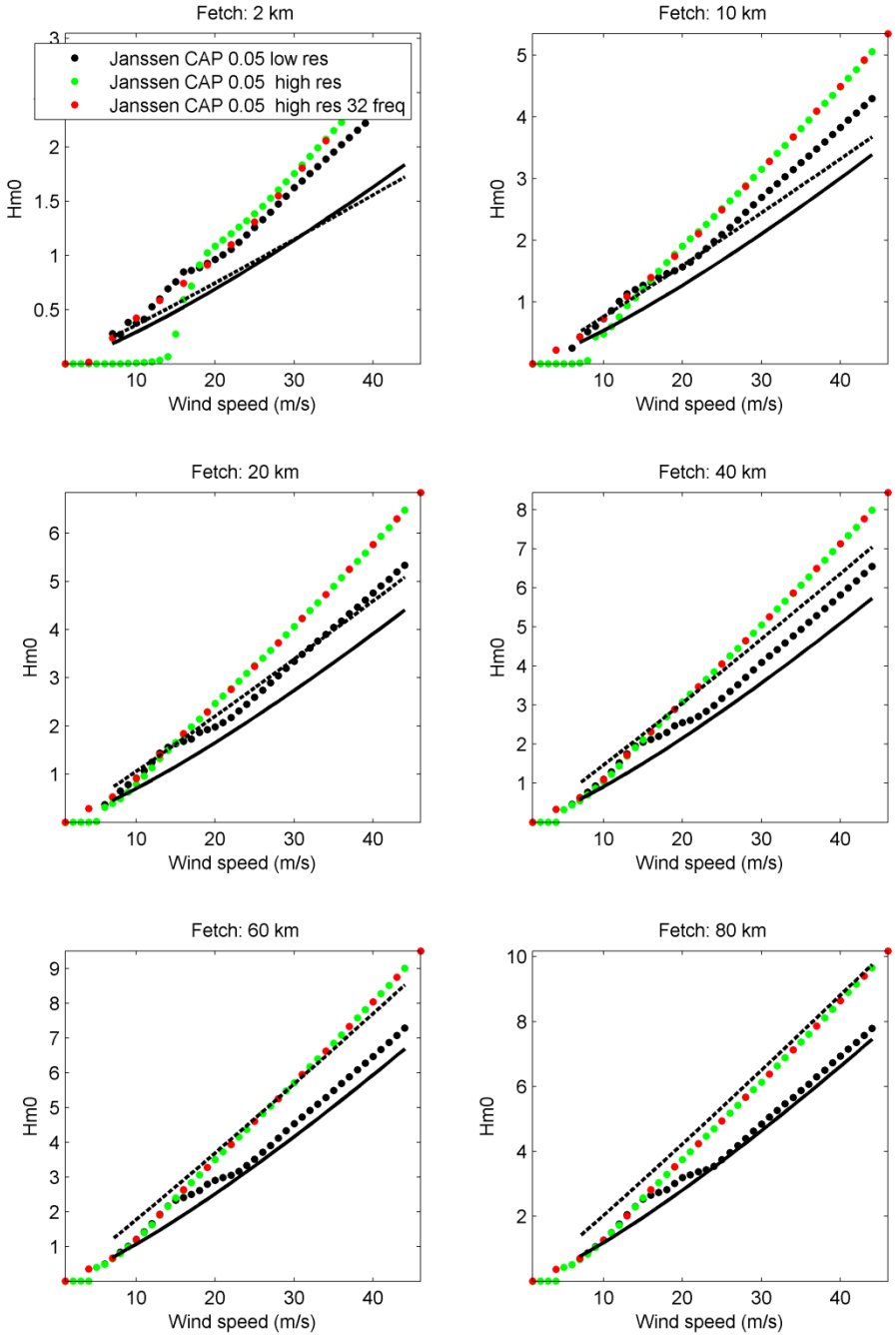

Figure 15.Results (domain A and B) using Janssen formulation and Bidlot (2007) with default coefficients and CAP=0.05, for coarse and high resolution mesh and increasing frequency resolution from 25 to 32 frequencies. Black lines represent the empirical formulation of Kahama and Calkoen (1992) for stable and unstable atmospheric conditions.

Janssen with Bidlot (2007), Cap=0.06.

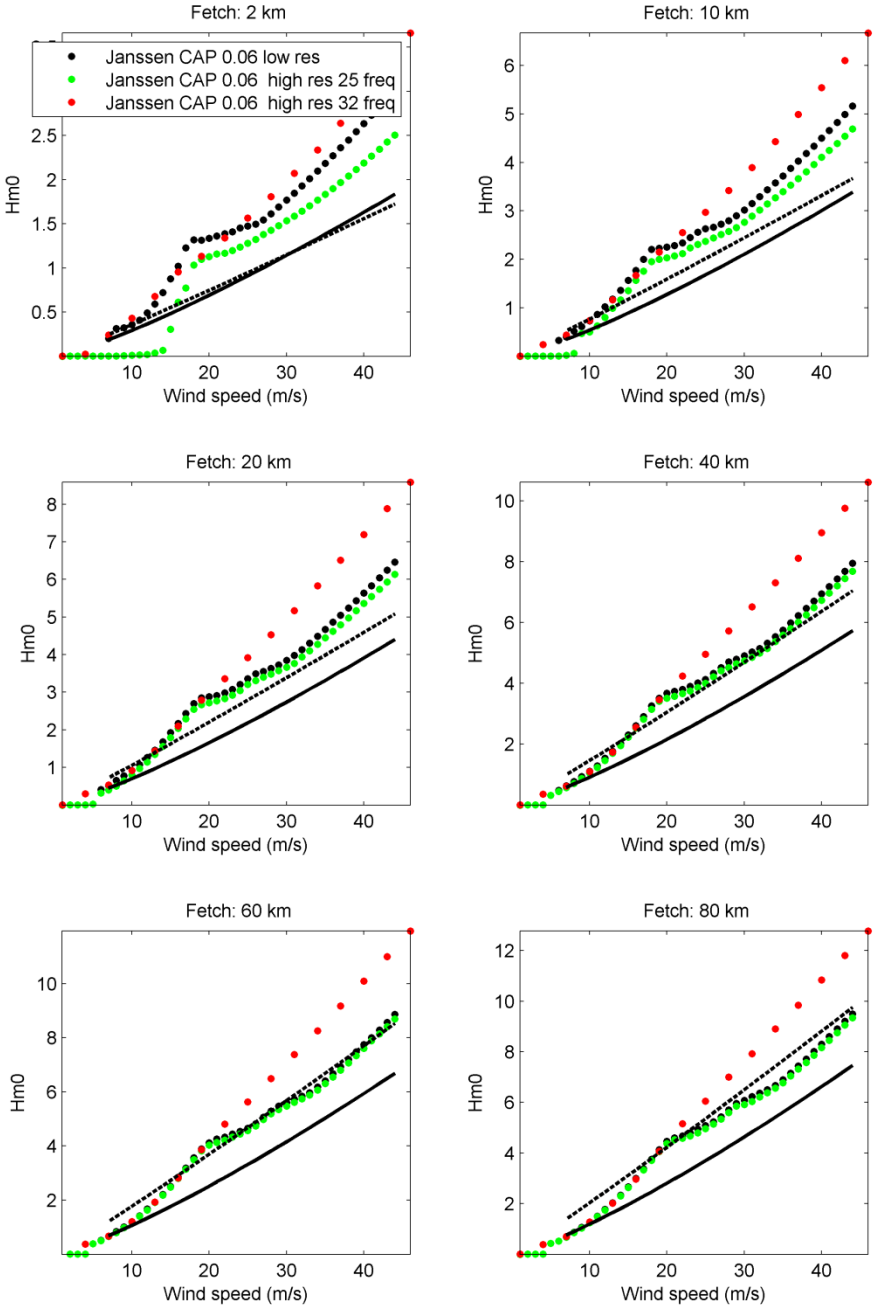

Figure 16.Results (domain A and B) using Janssen formulation and Bidlot (2007) with default coefficients and CAP=0.06, for coarse and high resolution mesh and increasing frequency resolution from 25 to 32 frequencies. Black lines represent the empirical formulation of Kahama and Calkoen (1992) for stable and unstable atmospheric conditions.

Fan (2012) with Bidlot (2007).

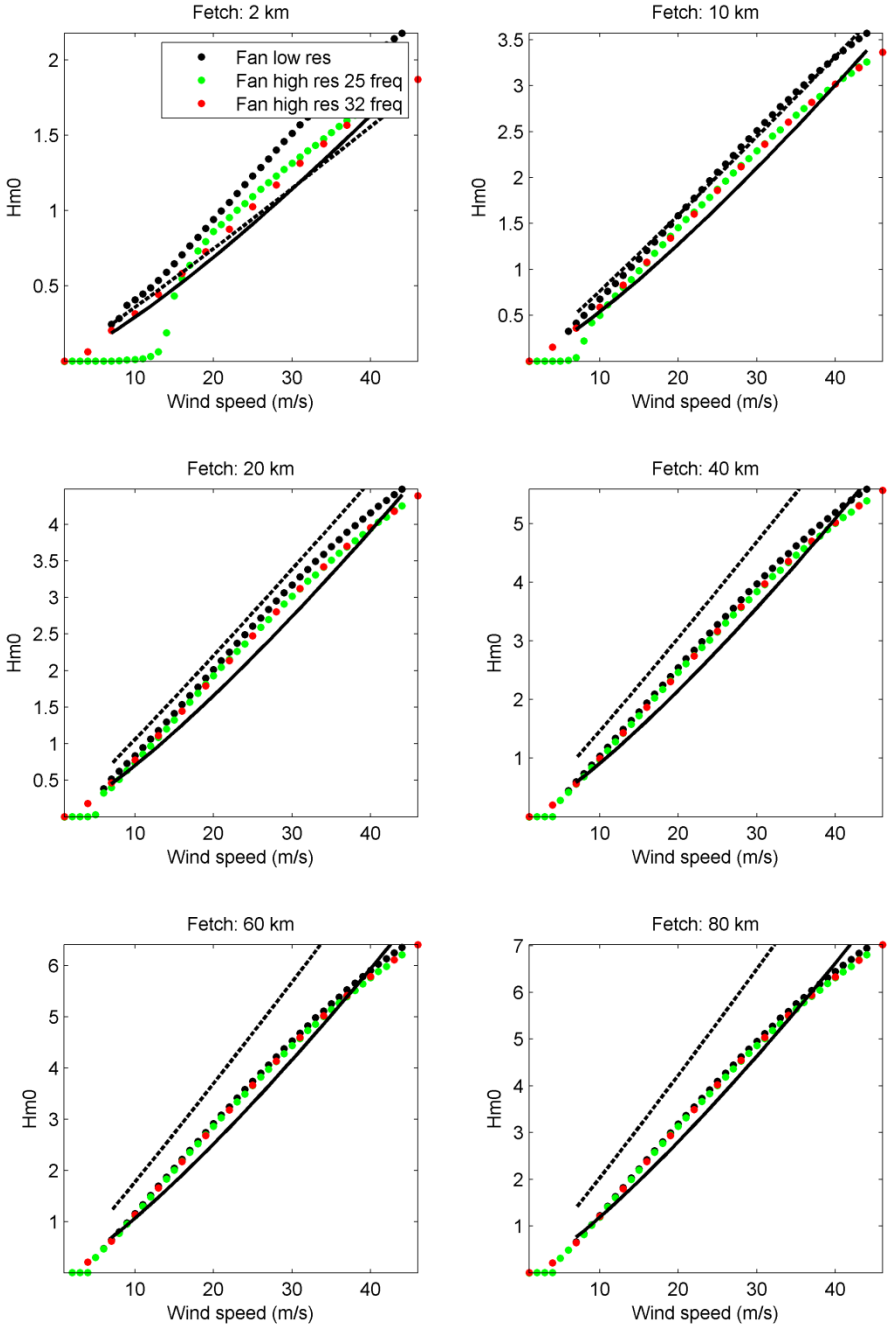

Figure 17.Results (domain A and B) using Fan formulation and Bidlot (2007) with default coefficients, for coarse and high resolution mesh and increasing frequency resolution from 25 to 32 frequencies. Black lines represent the empirical formulation of Kahama and Calkoen (1992) for stable and unstable atmospheric conditions.

Smith and Bank with Bidlot (2007).

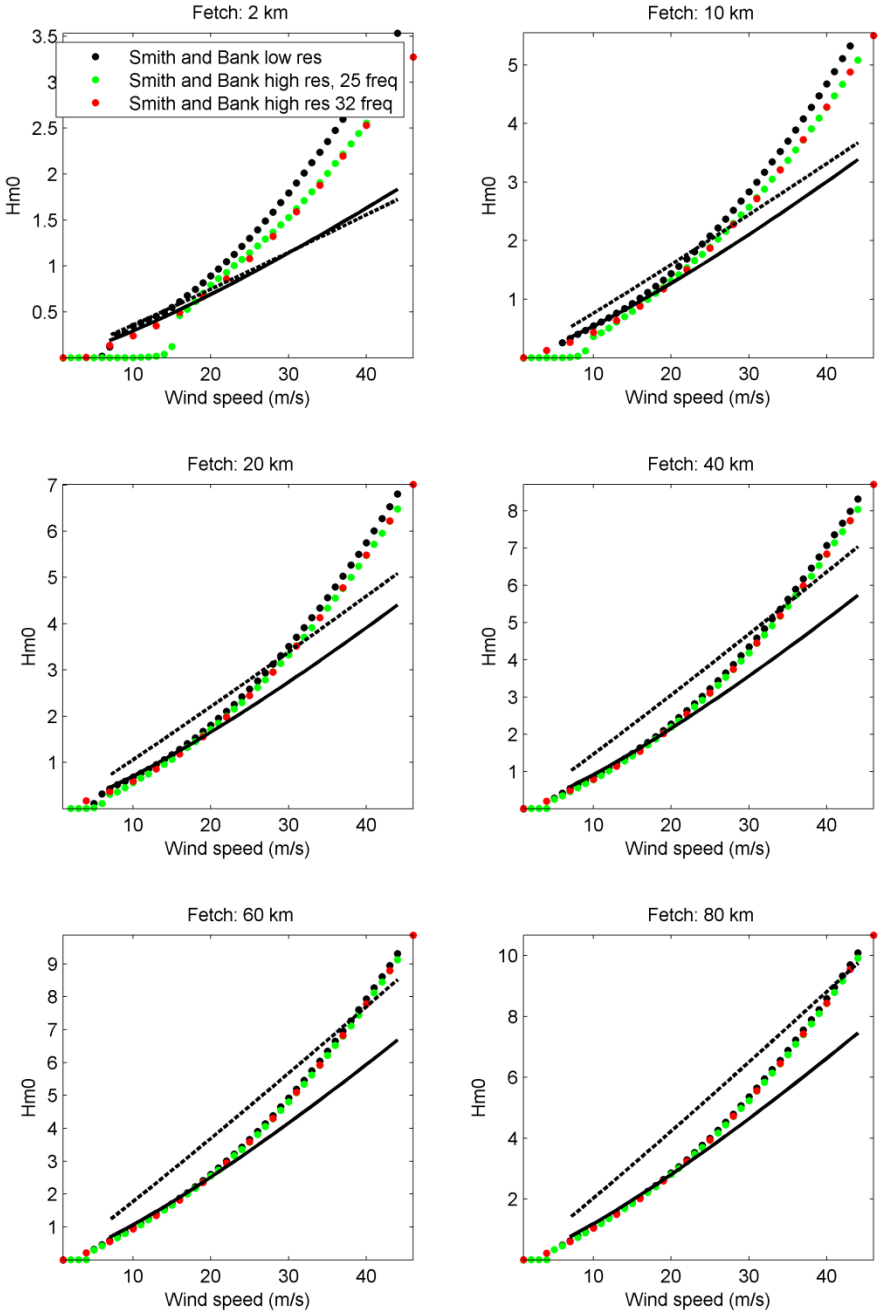

Figure 18.Results (domain A and B) using Smith and Bank formulation and Bidlot (2007) with default coefficients, for coarse and high resolution mesh and increasing frequency resolution from 25 to 32 frequencies. Black lines represent the empirical formulation of Kahama and Calkoen (1992) for stable and unstable atmospheric conditions.

Charnock (0.018) with Bidlot (2007).

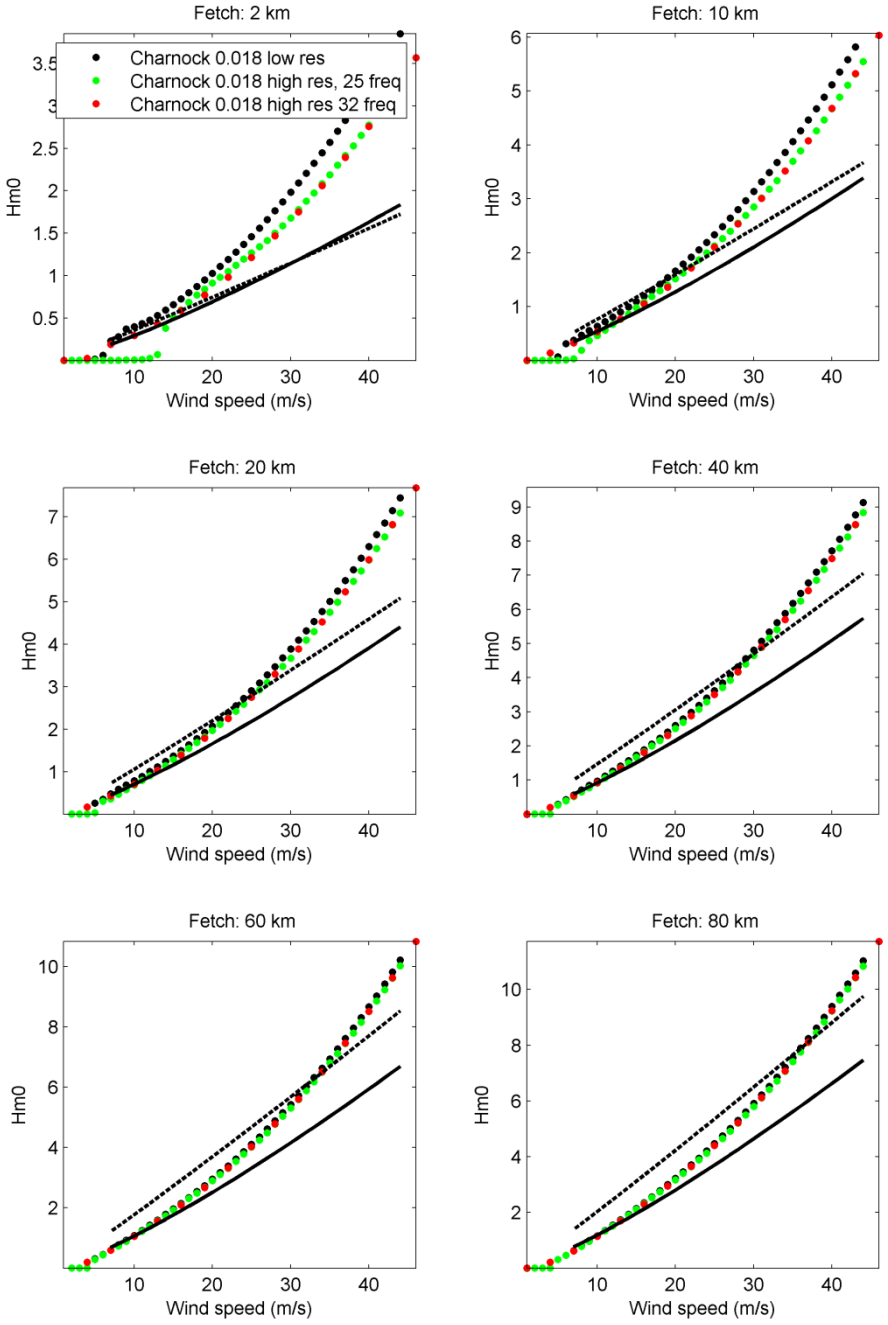

Figure 19.Results (domain A and B) using Charnock formulation with constant=0.018 and Bidlot (2007) with default coefficients, for coarse and high resolution mesh and increasing frequency resolution from 25 to 32 frequencies. Black lines represent the empirical formulation of Kahama and Calkoen (1992) for stable and unstable atmospheric conditions.

Charnock (0.01) with Bidlot (2007).

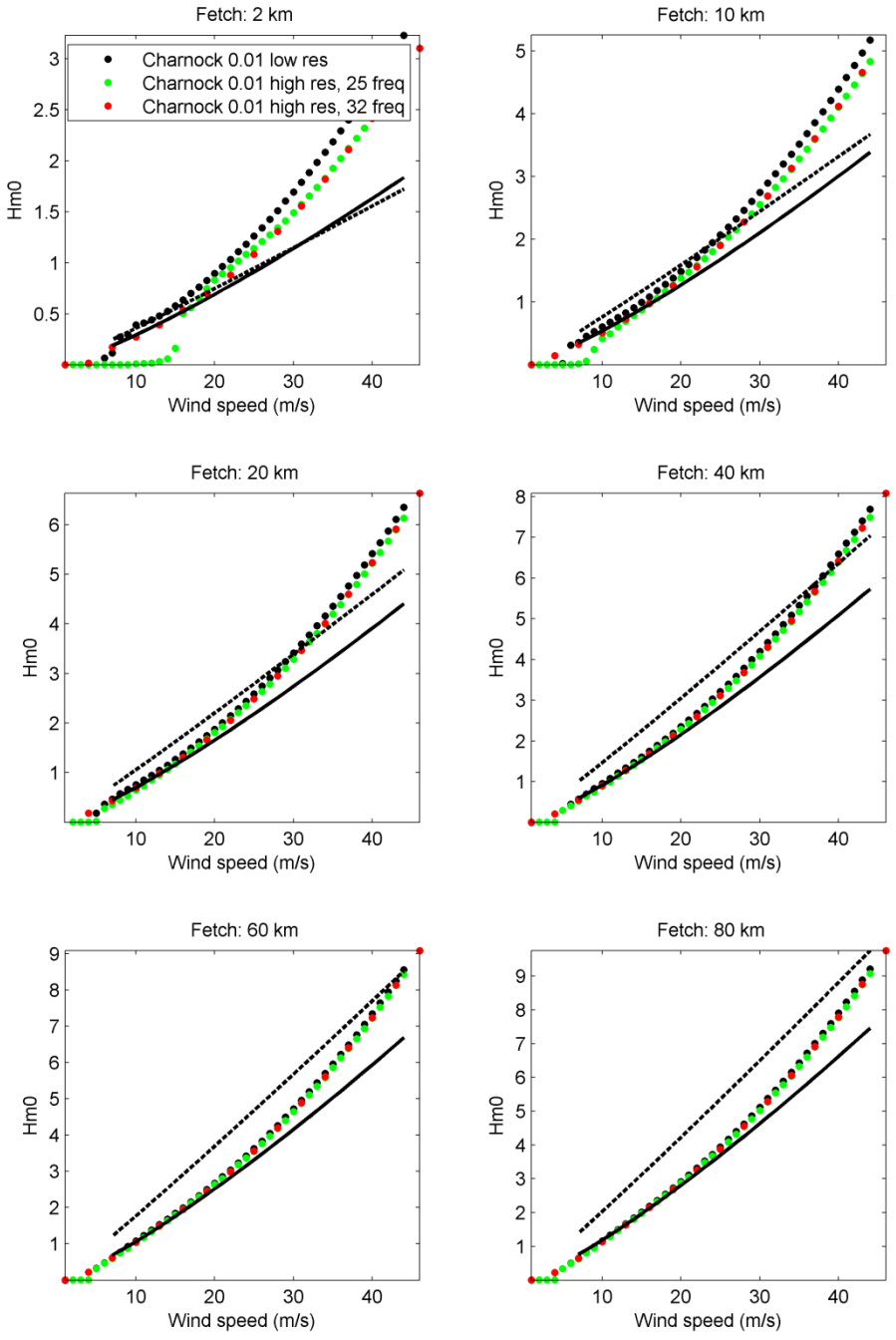

Figure 20.Results (domain A and B) using Charnock formulation with constant=0.01 and Bidlot (2007) with default coefficients, for coarse and high resolution mesh and increasing frequency resolution from 25 to 32 frequencies. Black lines represent the empirical formulation of Kahama and Calkoen (1992) for stable and unstable atmospheric conditions.

Stress table

A comparison of the stress table as estimated in MIKE 21 SW and WAM (cycle 4.5.4, http://mywave.github.io/WAM/) was done. This showed exactly the same results, however it was noted that in WAM the table is limited to 5 N/m^2 in the wave stresses and to 50 m/s in wind speed. This is an actual “capping” to the wave stresses which reduces the total stress and thus reduce wave growth as shown below.

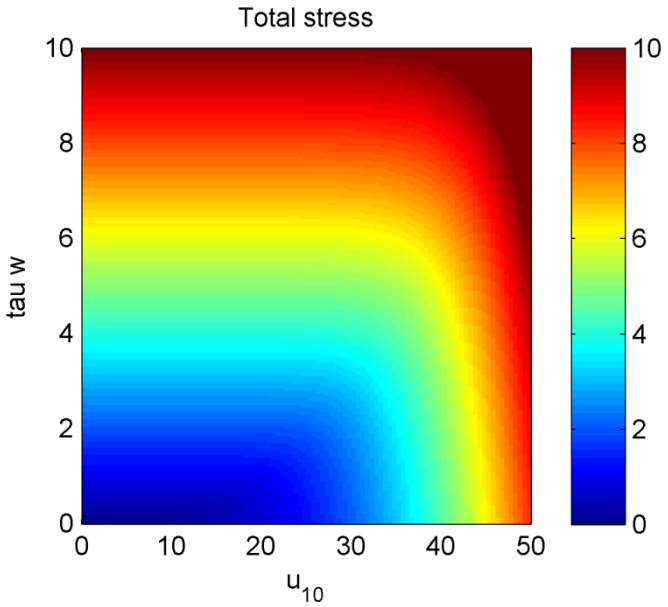

Figure 21.Total stress contour dependent on wind speed (m/s) and wave stresses (N/m^2) as estimated with MIKE 21 SW and WAM.

Quasi-stationary run Janssen with Bidlot (2007) using MIKE21 SW extended tables and tables as limited in WAM:

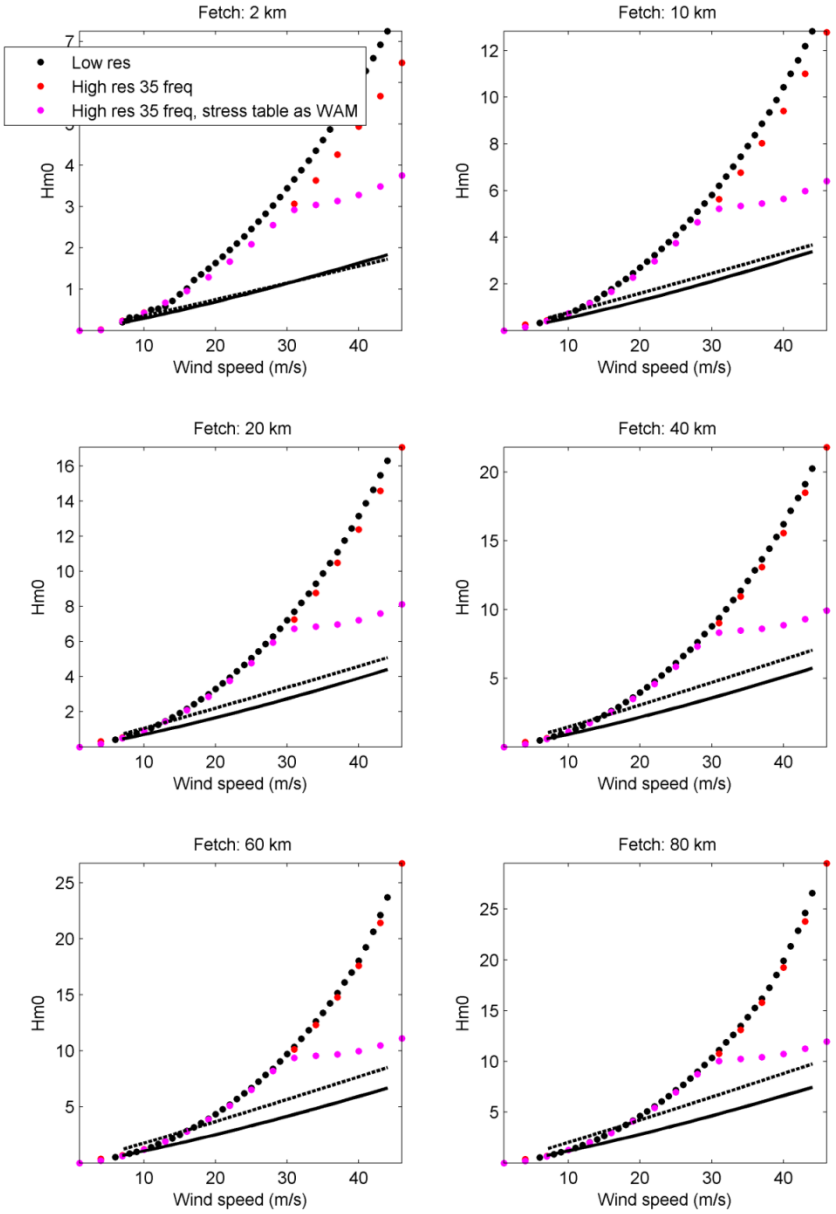

Figure 22.Fetch limited results (domain A and B) using Janssen formulation and Bidlot (2007) white-capping with the low resolution domain and 25 frequencies, the high resolution domain and 35 frequencies, and the high resolution domain with 35 frequencies and stress table limited as in WAM.

Appendix D

Appendix E.

Click on it to see its content.

Appendix F
Click on it to see its content