Model Validation

1. Model Grid Refinement

To obtain the desired resolution for this Project, a domain decomposition model (refined grid) was generated from the original WHM. The decision to use domain decomposition as the method for grid refinement was based on practical considerations, which included the following:

- The large coverage extent of the original WHM makes it impractical to refine the entire grid to achieve the desired resolution within the study area;
- The deeper parts of the original WHM reach more than 55m, but the bathymetry within the study area is mainly between 5 – 15m deep, while the strongest currents occur at the Ma Wan Channel, where depths reach approx. 30m, determining the timestep possible;
- The domain decomposition method follows the grid alignment of the original calibrated WHM, thereby retaining most of the original grid alignment with the main features of the bathymetry, and minimising potential inaccuracies associated with boundaries; and
- The alternative method of grid refinement by nesting has the disadvantage of creating inaccuracies at the local model boundaries, and less accuracy in the transfer of the hydrodynamic boundary information from the overall model.

A 3x3 domain decomposition grid was created covering the larger North Lantau waters including Tuen Mun to the north and Tsing Yi to the west. A comparison of the original WHM grid against the refined grid for the 'with' and 'without Project' scenarios are provided in **Annex A** and **Annex B**.

Limitations of the Grid Refinement

Within this refined grid, the grid cell resolution at WSRs ranges mainly between 30 to 150m. Due to the large coverage area of the WSRs and model stability constraints, it is not possible to meet the desired resolution criteria of less than 75m x 75m at all the WSRs, particularly those located furthest away from the Project. However, those WSRs that are not within range are sufficiently far from the project boundary that they are unlikely to be significantly affected by a coarser grid resolution. Around the project boundary, grid cell resolution is mostly between 100 to 120m. This is mainly due to the generally larger grid cells of the original WHM at the western part of Hong Kong. While it is possible to generate a more refined (e.g. 5x5) grid, this would lead to a substantial increase in computational run times (approximately 1 week for the 5x5 grid refinement compared to approximately 1.5 days for the current 3x3 grid refinement), and is unlikely to lead to a significant improvement of results. Thus provided that the model validation shows the refined (3x3) WHM to be consistent with the original WHM, the purpose of the grid refinement would be met and there would be no significant benefit to further reducing grid sizes around the project boundary. A comparison of the horizontal grid resolution between the original and refined WHM is shown in **Annex C**.

In the refined grid, the boundary grid cells have been adjusted to best match the land boundaries, however, due to the curvilinear shape of the original WHM and the orientation of the Project, the boundaries at the northern edge of the Project appear slightly staggered, and the amount of adjustment that can be made is limited by the domain decomposition. Despite the appearance of staggering along the Project boundary, this staggering effect is within the resolution of the grid, hence there would be no significant impact on the overall model performance and the refined grid is considered to be suitable for modelling purposes.

2. Model Set Up

To check the effect of the grid refinement on the original calibration of the WHM, validation runs were completed using the refined grid for comparison against the results of the original calibrated WHM. Eight spring-neap simulations were run for validation, comprising four models under both wet and dry season. A constant wind speed was included in all simulations:

Dry season – wind of 5 m/s, 45^{o} from North (northeasterly)

Wet season – wind of 5 m/s, 225^{o} from North (southwesterly)

Dry season simulations included salinity while wet season simulations included both salinity and temperature. River discharges between the seasons also differ significantly. All simulations were run over a period of 15 days and 22 hours (from 25 July 1996 14:00 hours until 10 August 1996 12:00 hours). Initial conditions (water levels, currents, temperature and salinity) were taken from the original WHM and interpolated onto the refined grid. The initial conditions were generated after a spin up period of one tidal cycle (15 days). Model parameters follow those adopted in the Updated Model by Deltares in 2000-2001. The eight simulations are summarised in **Table A.1**.

Table A.1: Simulations for model validation

ID	Grid	Depth	Shoreline	Dt (min)
Run00d	Original WHM (MNKmax = 218x182x10)	Original	2000	1.0
Run00w	Original WHM (MNKmax = 218x182x10)	Original	2000	1.0
Run01d	Refined WHM (MNKmax = 218x171x10) (MNKmax = 416x320x10)	Re-sampled into finer, central domain	2000	0.5
Run01w	Refined WHM (MNKmax = 218x171x10) (MNKmax = 416x320x10)	Re-sampled into finer, central domain	2000	0.5
Run02d	Refined WHM (MNKmax = 218x171x10) (MNKmax = 416x320x10)	New	2012 (with Project)	0.5
Run02w	Refined WHM (MNKmax = 218x171x10) (MNKmax = 416x320x10)	New	2012 (with Project)	0.5
Run03d	Refined WHM (MNKmax = 218x171x10) (MNKmax = 416x320x10)	New	2000	0.5
Run03w	Refined WHM (MNKmax = 218x171x10) (MNKmax = 416x320x10)	New	2000	0.5

New bathymetry data from electronic navigational charts (obtained in 2012) and swath and single-beam echo sounding surveys carried out in late 2012 / early 2013 was used to update the bathymetry in the study area. Model initial conditions were taken from the original WHM and were converted into the two refined WHM domains.

Validation Results

The main validation of the refined WHM against the original WHM is obtained from a comparison between simulations Run00d and Run01d (dry season scenario), and between Run00w and Run01w (wet season scenario). Timeseries plots for water levels, salinities (near bottom and near surface) and current magnitudes and directions (near bottom and near surface) at six validation sites were generated. The validation sites and the results are shown in **Annex D**.

The findings show that water levels comparisons at all locations are near identical for both the dry and wet scenarios. Salinity timeseries for dry scenarios also show a good match at all locations, though the salinity timeseries for wet scenarios show small differences at some stations, namely ‘ADCP Yuen Hong 23’, ‘P W4’ and ‘RO Lok On Pai’. At ‘ADCP Yuen Hong 23’ and ‘P W4’, the refined model sometimes generated higher salinity peaks (only near-surface) by 1-4 ppt. At ‘RO Lok On Pai’, the refined model sometimes generated lower salinity peaks (only near-surface) by 1-4 ppt.

The findings for current timeseries show very similar results at all locations except ‘RO Lok On Pai’, which showed lower peak magnitudes by up to 0.2 m/s in the refined WHM for both dry and wet scenarios. It is considered that the main cause of this discrepancy is the interpolation of the bathymetry on a higher resolution grid, leading to local depth differences, particularly near the coastline. However, the timing and current directions are well captured.

In addition to the timeseries generated for comparison between simulations Run00d and Run01d, and between Run00w and Run01w, plots were also generated for comparison between the following simulations:

Run00d and Run02d – comparison of original WHM and refined WHM with updated bathymetry and shoreline (including Project boundary) for dry season

Run00w and Run02w – comparison of original WHM and refined WHM with updated bathymetry and shoreline (including Project boundary) for wet season

Run00d and Run03d – comparison of original WHM and refined WHM with updated bathymetry for dry season

Run00w and Run03w – comparison of original WHM and refined WHM with updated bathymetry for wet season

These plots are shown in **Annex E**. They illustrate the effect of grid refinement and adjustments to the shoreline and bathymetry compared to the original WHM.

Residual Flows

Changes to residual flows across relevant cross-sections were evaluated from simulations with the original WHM and those with the refined WHM. In order to separate the impact of the domain decomposition from the impact of finer resolution throughout the airport domain of the refined WHM, an ‘intermediate model’ was also used. This is essentially the domain of the refined WHM, but without refinement. The grid of the intermediate model and the four cross-sections are shown in **Annex F**. The integrated residual flows are determined at each cross-section by taking the differences in cumulative discharge from beginning to end, and dividing by the time elapsed. The first day of simulations was not used for this calculation. The ‘end’ was taken such that the elapsed time covers an integer number of tidal cycles. The integrated residual flows are summarised in **Table A.2** and **Table A.3** below.

Table A.2: Dry season residual discharges (m^3/s) across four cross-sections within the refined WHM domain

Cross-Section ID	Original WHM (Run00d)	Intermediate Model (DD 1x1, dry)	Refined WHM (Run01d)
Midway	-2590	-2470	-2110
Kap Shui Mun	+1140	+1050	+710
Ma Wan Channel 2	+1950	+1920	+1840
Rambler Channel	-510	-510	-450

Noted: Values are integrated over a 15.05 day period

Table A.3: Wet season residual discharges (m^3/s) across four cross-sections within the refined WHM domain

Cross-Section ID	Original WHM (Run00w)	Intermediate Model (DD 1x1, wet)	Refined WHM (Run01w)
Midway	-590	-600	+270
Kap Shui Mun	-40	-90	-630
Ma Wan Channel 2	+1570	+1650	+1350
Rambler Channel	-940	-950	-990

Noted: Values are integrated over a 15.05 day period

As shown in **Table A.2**, the dry season output shows very similar residual discharges between Run00d and Run01d, with the same discharge direction and differences varying between 5 – 20 %. Differences between the original WHM and the intermediate model are smaller, ranging from 0 – 8 %, indicating that the domain decomposition has been properly implemented.

For the wet season output (shown in **Table A.3**), a comparison between output from the original WHM and the intermediate model shows little change, with the same signs and differences of only 1 – 5 %, except at 'Kap Shui Mun' which has very small absolute difference. However, a comparison between output from Run00w and Run01w at 'Midway' and 'Kap Shui Mun' yields larger differences.

Sensitivity tests were run to evaluate the effect of small changes to bottom roughness. A comparison was made between model output using a constant (Manning's) M=0.024 throughout the refined WHM domain and output using the spatially-varying values interpolated from original WHM, which vary from 0.020 and 0.026. It was found that this change had negligible impact on the residual flows through the cross sections. The differences described above are thus interpreted as caused by increased horizontal resolution, and of minor importance given the dimension of the tidal prisms along these channels (peak discharges summarised in **Table A.4**).

Table A.4: Peak (absolute) instantaneous discharges (m^3/s) through the four cross-sections of the original WHM

Cross-Section ID	Run00d Spring	Run00d Neap	Run00w Spring	Run00w Neap
Midway	59400	28500	61300	29700
Kap Shui Mun	18500	9000	18400	9500
Ma Wan Channel 2	46000	18500	47700	21800
Rambler Channel	4200	2400	5500	1100

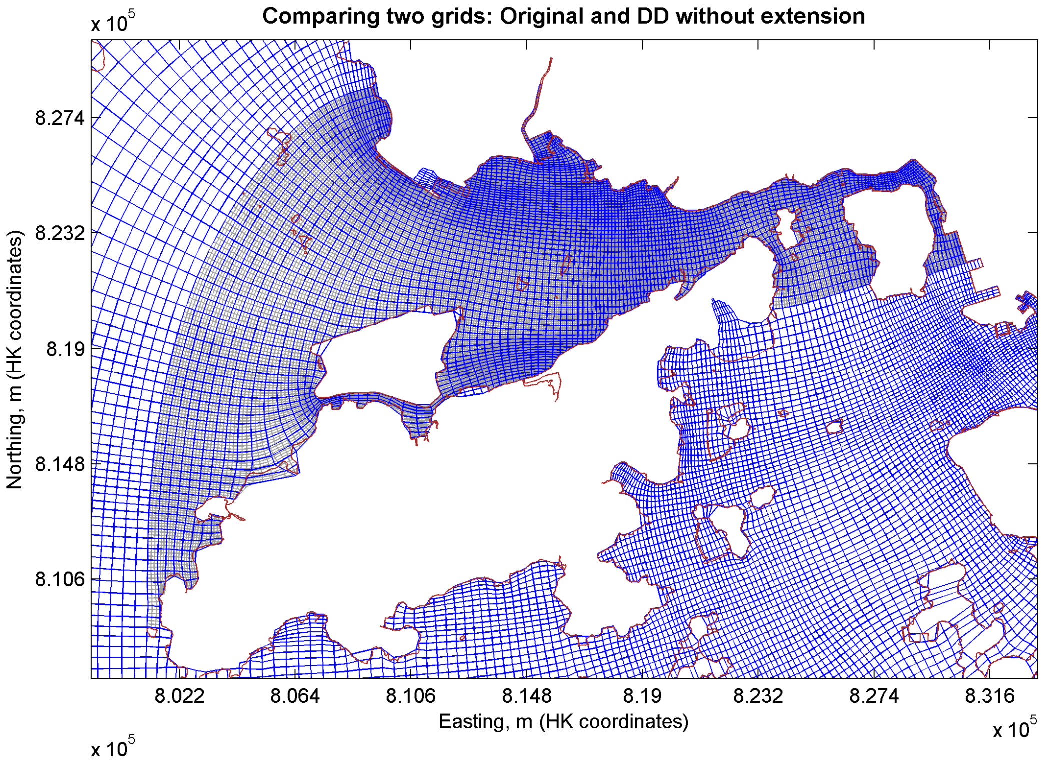
Summary of Model Validation

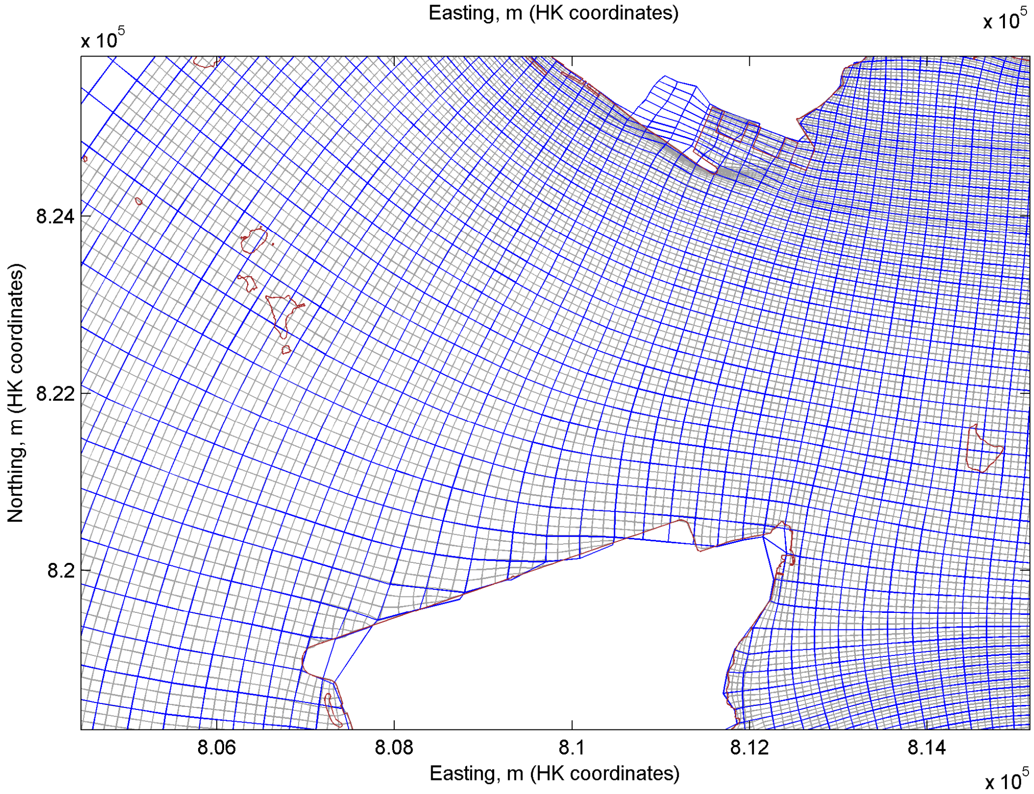
Four sets of runs (for both dry and wet seasons) were simulated and their results were analysed against the original WHM (Updated Model) by Deltares in 2000-2001. Validation was carried out between the original WHM (Run00d and Run00w) and the refined WHM (Run01d and Run01w), and the results showed very small differences between the two models, which can be interpreted as attributed to the finer model grid. Domain decomposition boundary information is shown to have been transferred correctly to the refined domain, and an analysis of residual flows across important channels / cross sections generally shows little change as a result of the refinement.

The refined WHM is thus shown to be consistent with the results of the original WHM and differences are mainly the result of finer horizontal grid resolution.

Annex A Comparison of Original WHM Grid with Refined Model Grid (without Project)

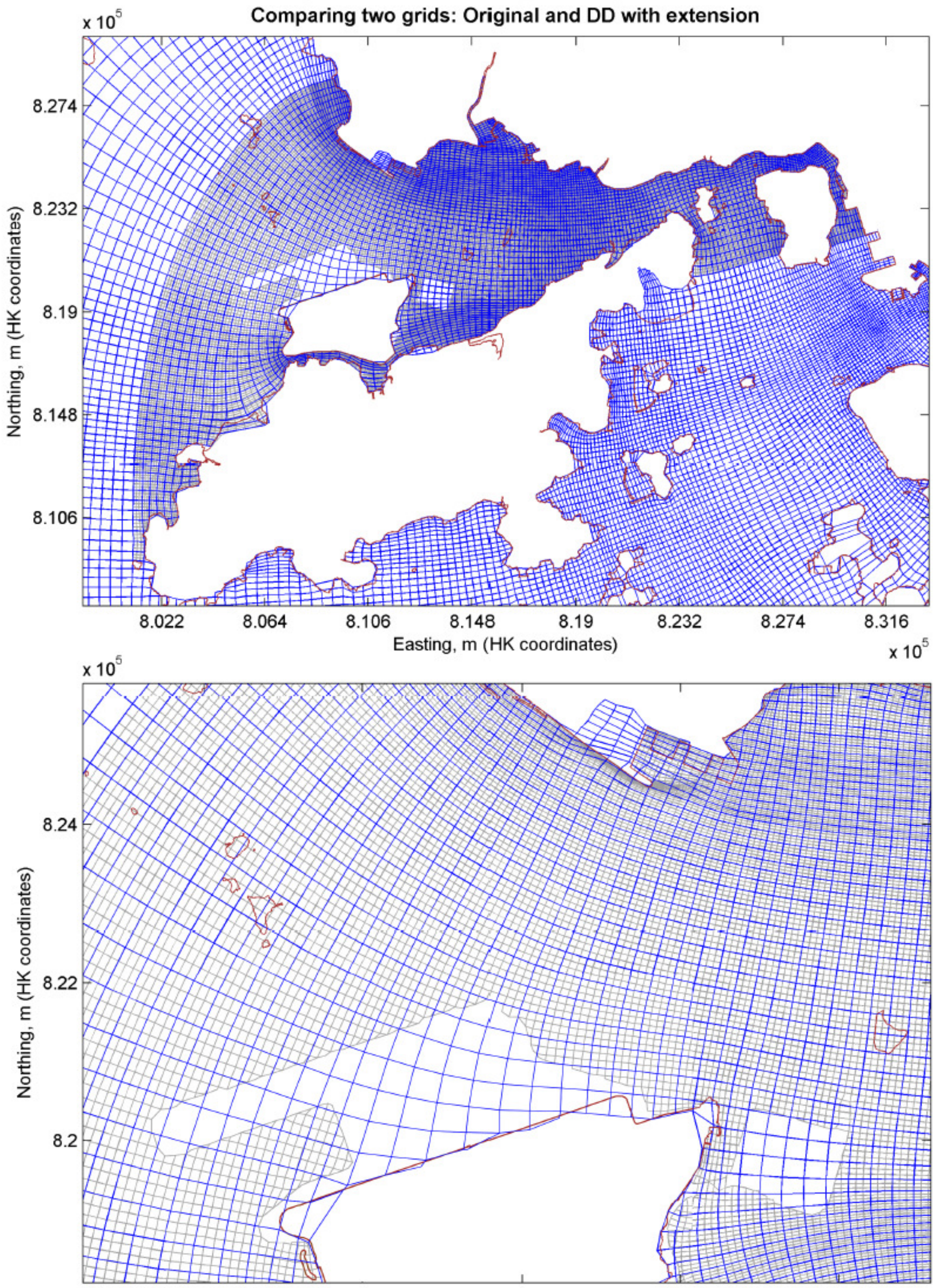
Comparison of Original WHM Grid with Refined Model Grid (without Project)





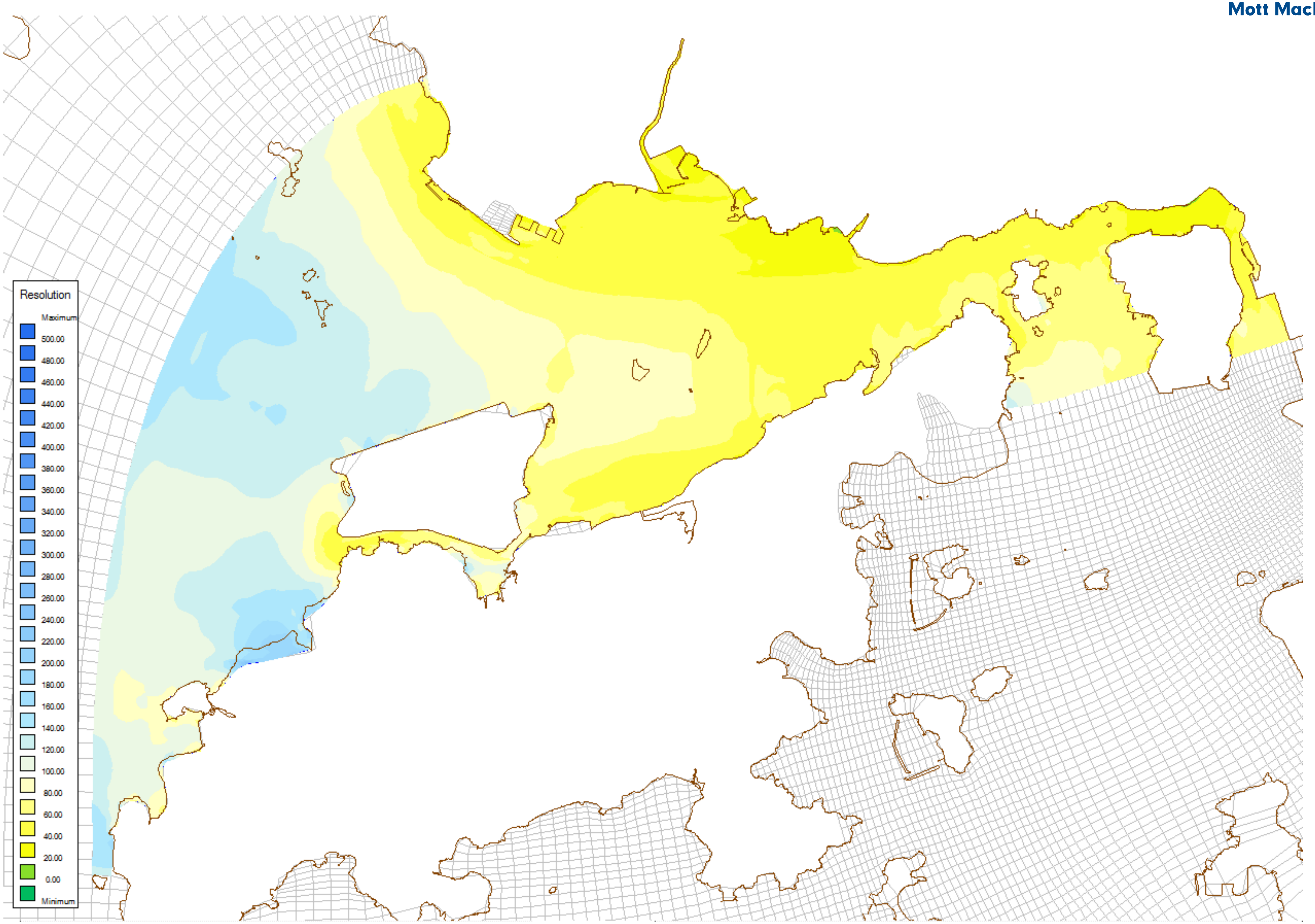
Annex B Comparison of Original WHM Grid with Refined Model Grid (with Project)

Comparison of Original WHM Grid with Refined Model Grid (with Project)

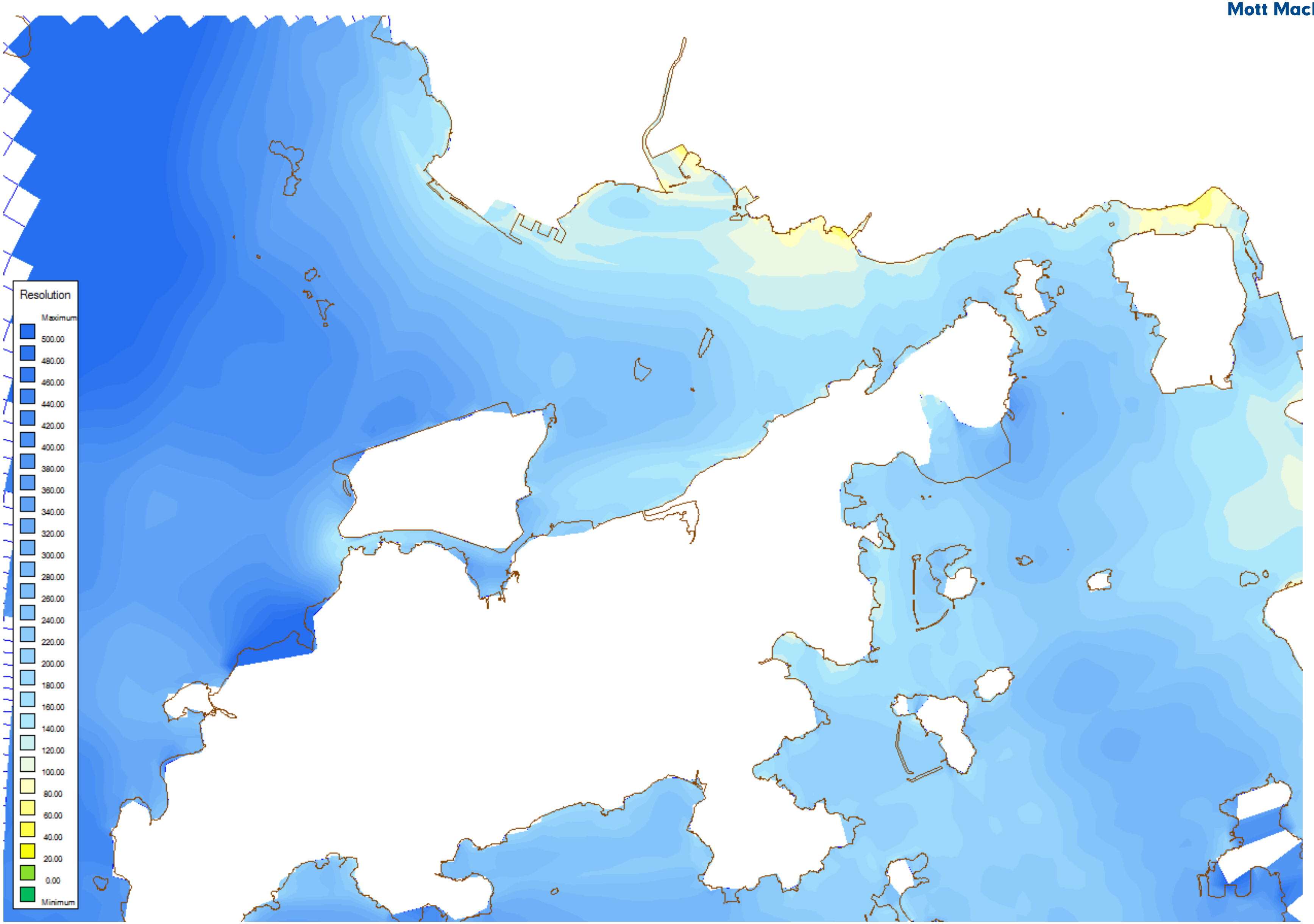


Note: While the outline of the Hong Kong-Zhuhai-Macao Bridge Boundary Crossing Facility is shown, it is a concurrent project and does not form part of this Project.

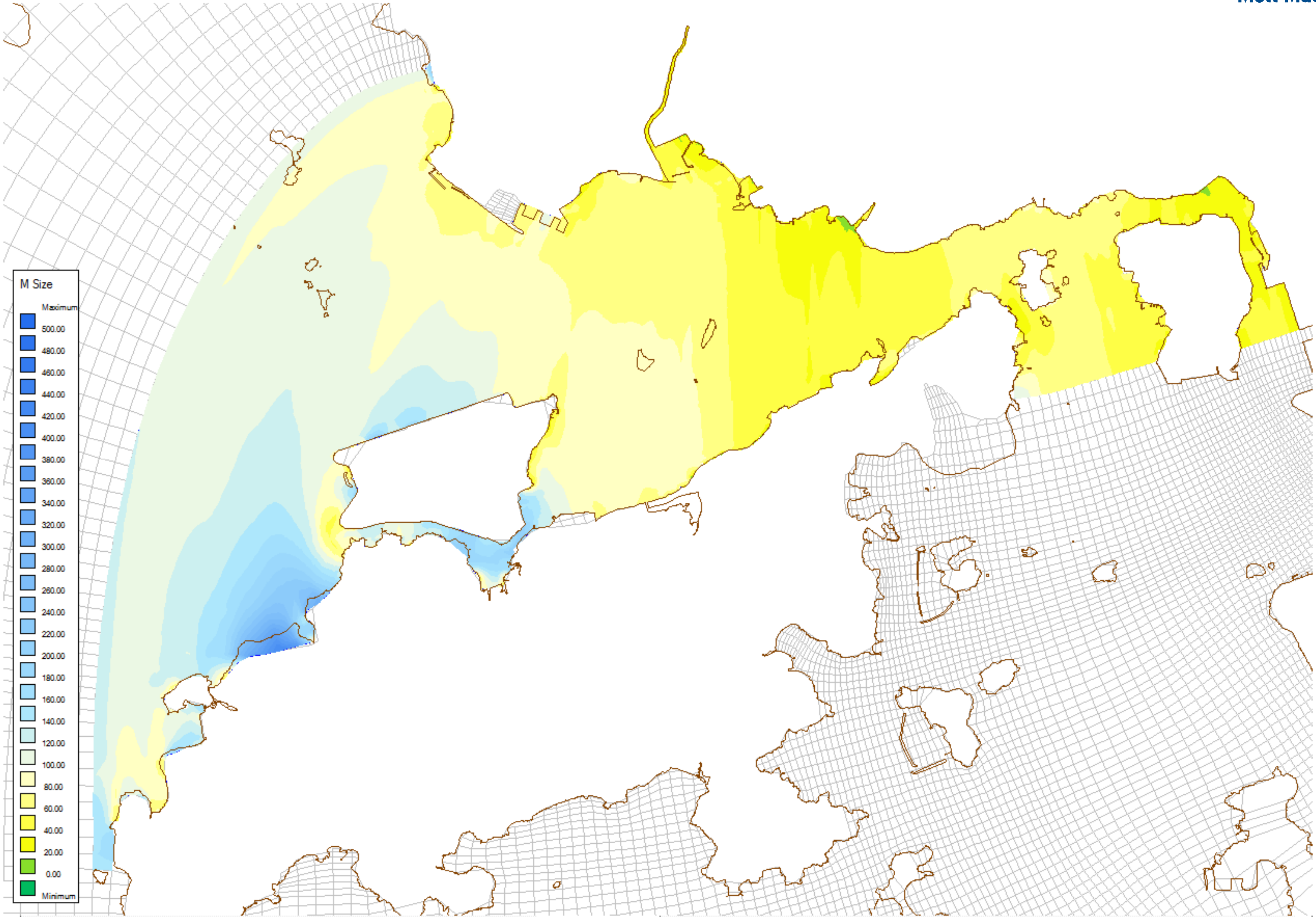
Annex C Comparison of Grid Parameters



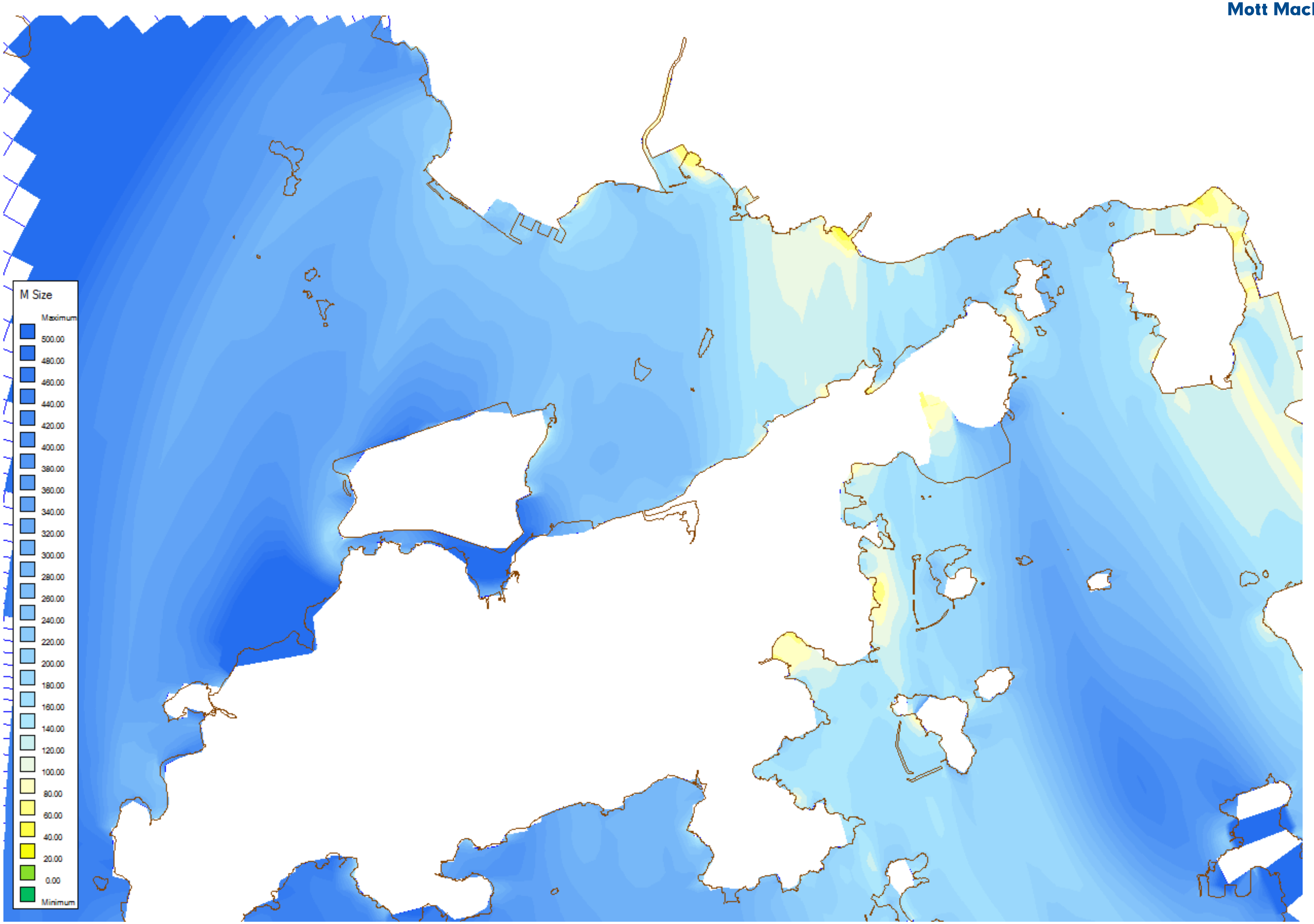
Resolution plot for refined grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



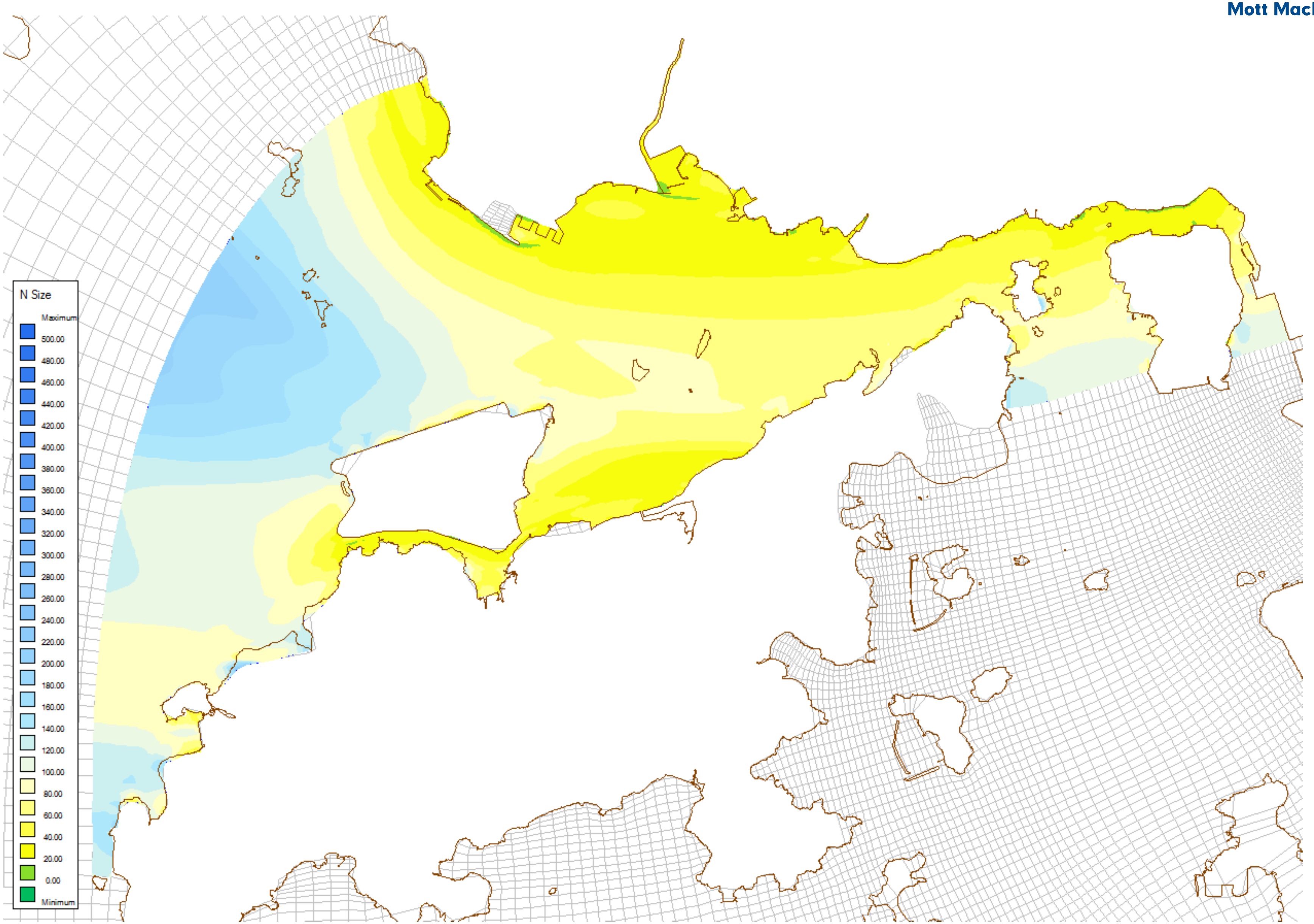
Resolution plot for original grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



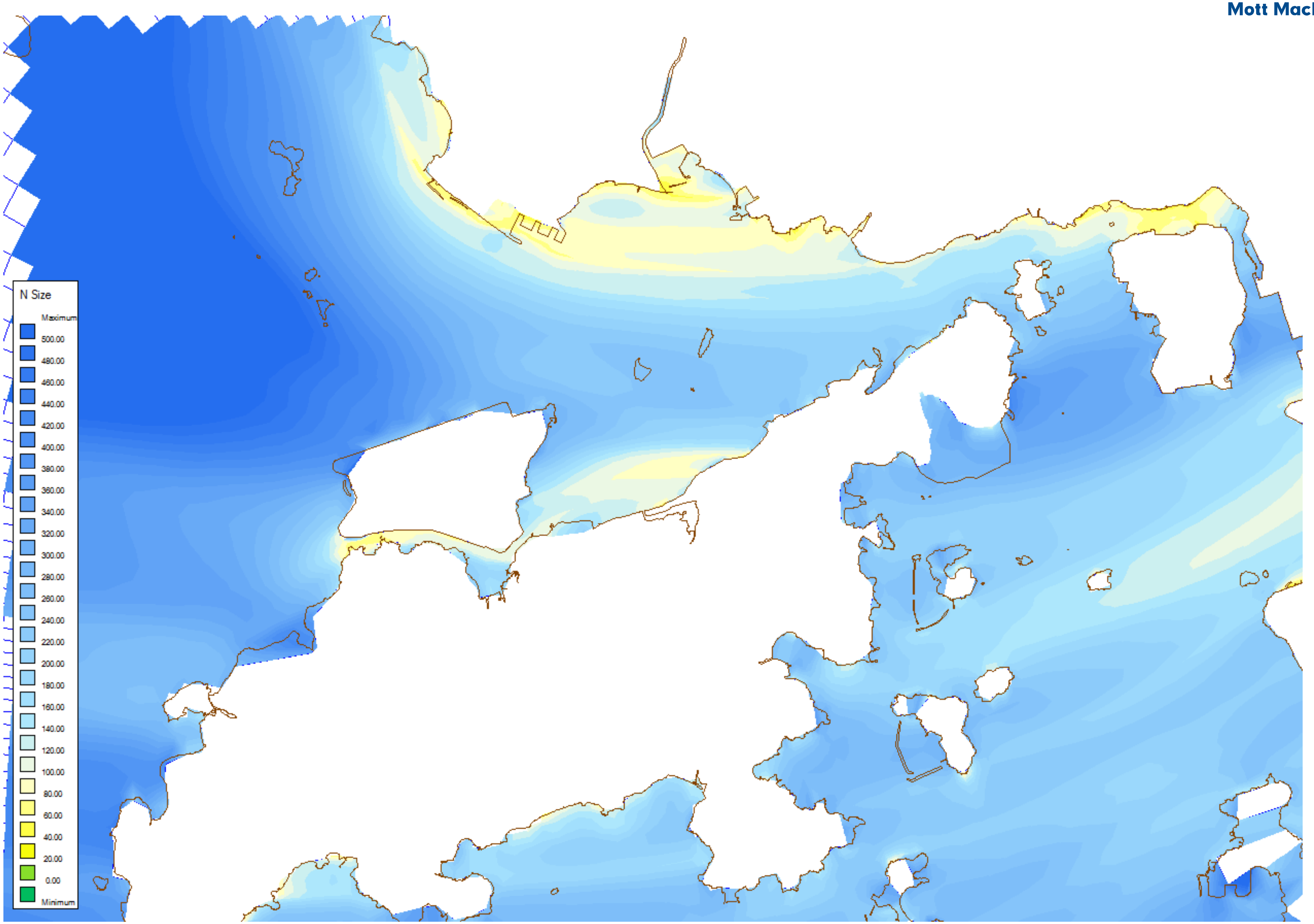
M Size plot for refined grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



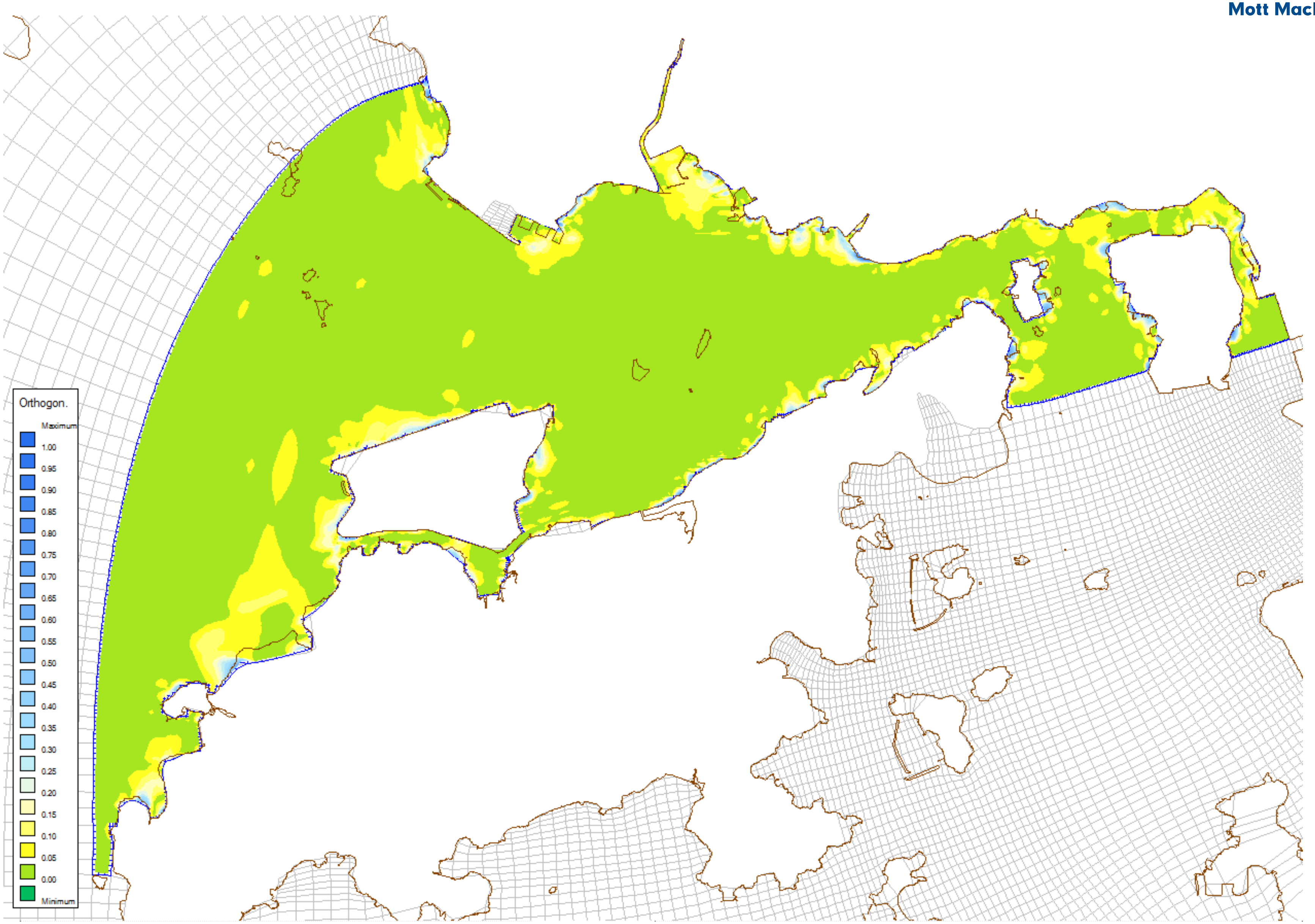
M Size plot for original grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



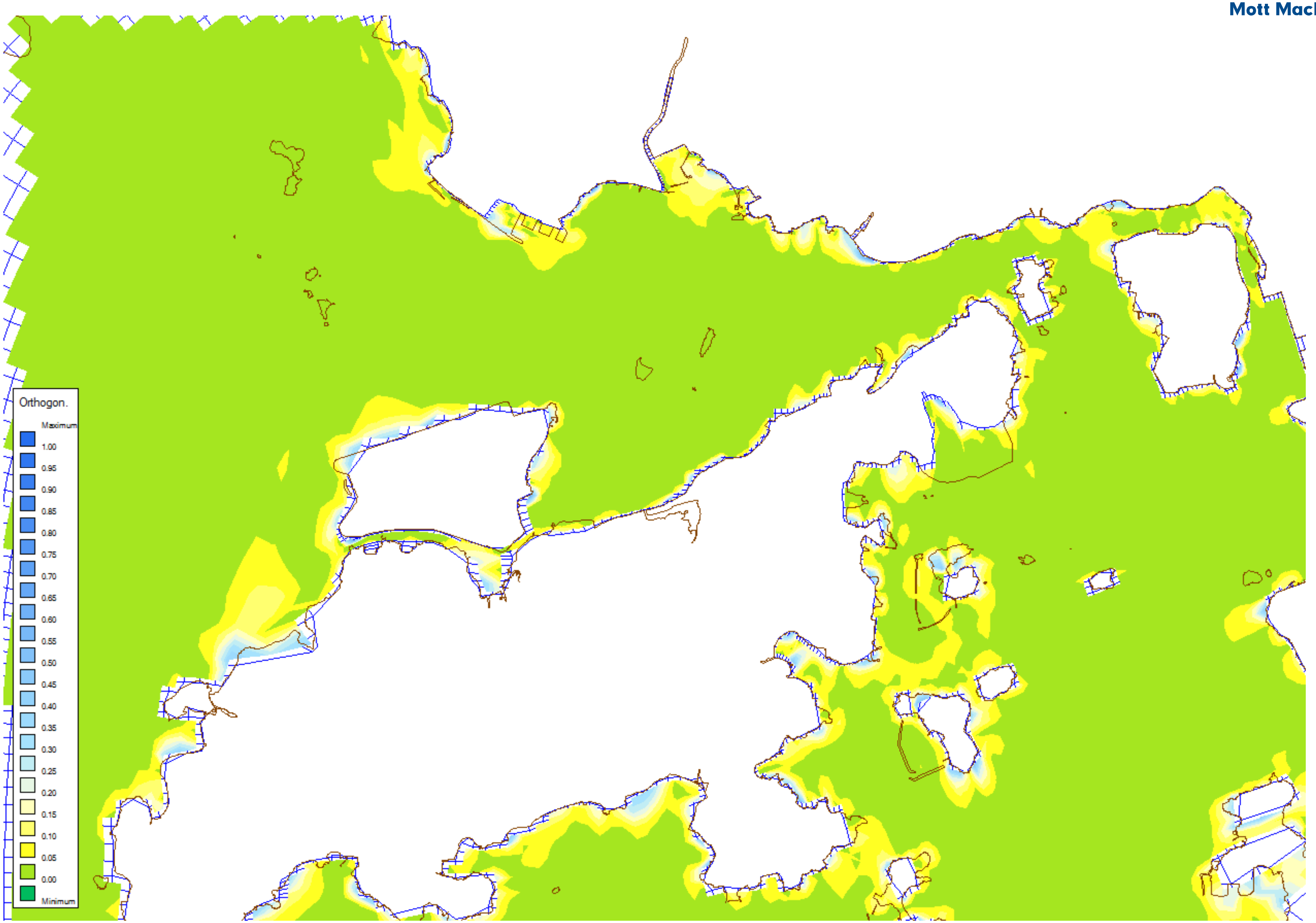
N Size plot for refined grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



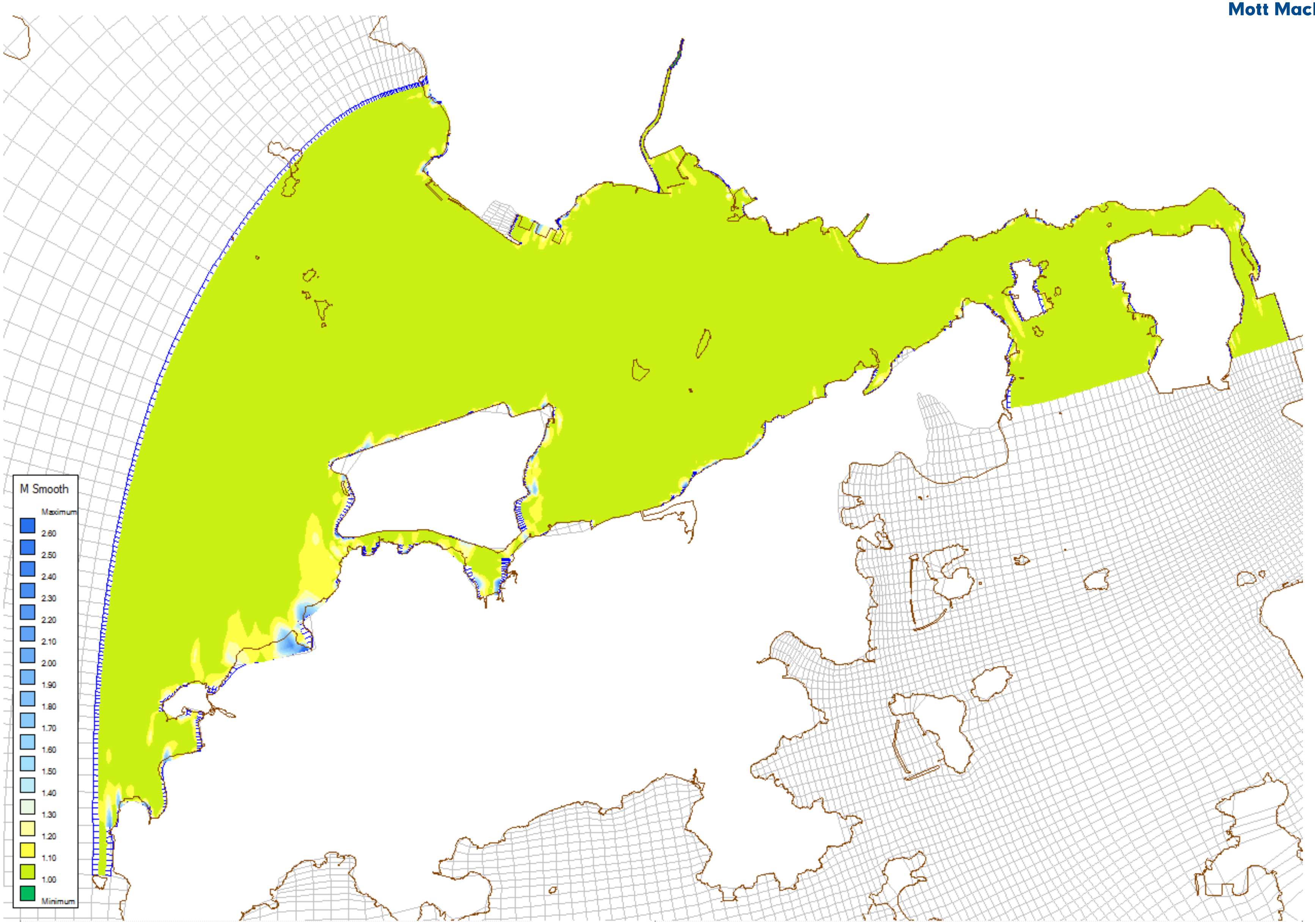
N Size plot for original grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



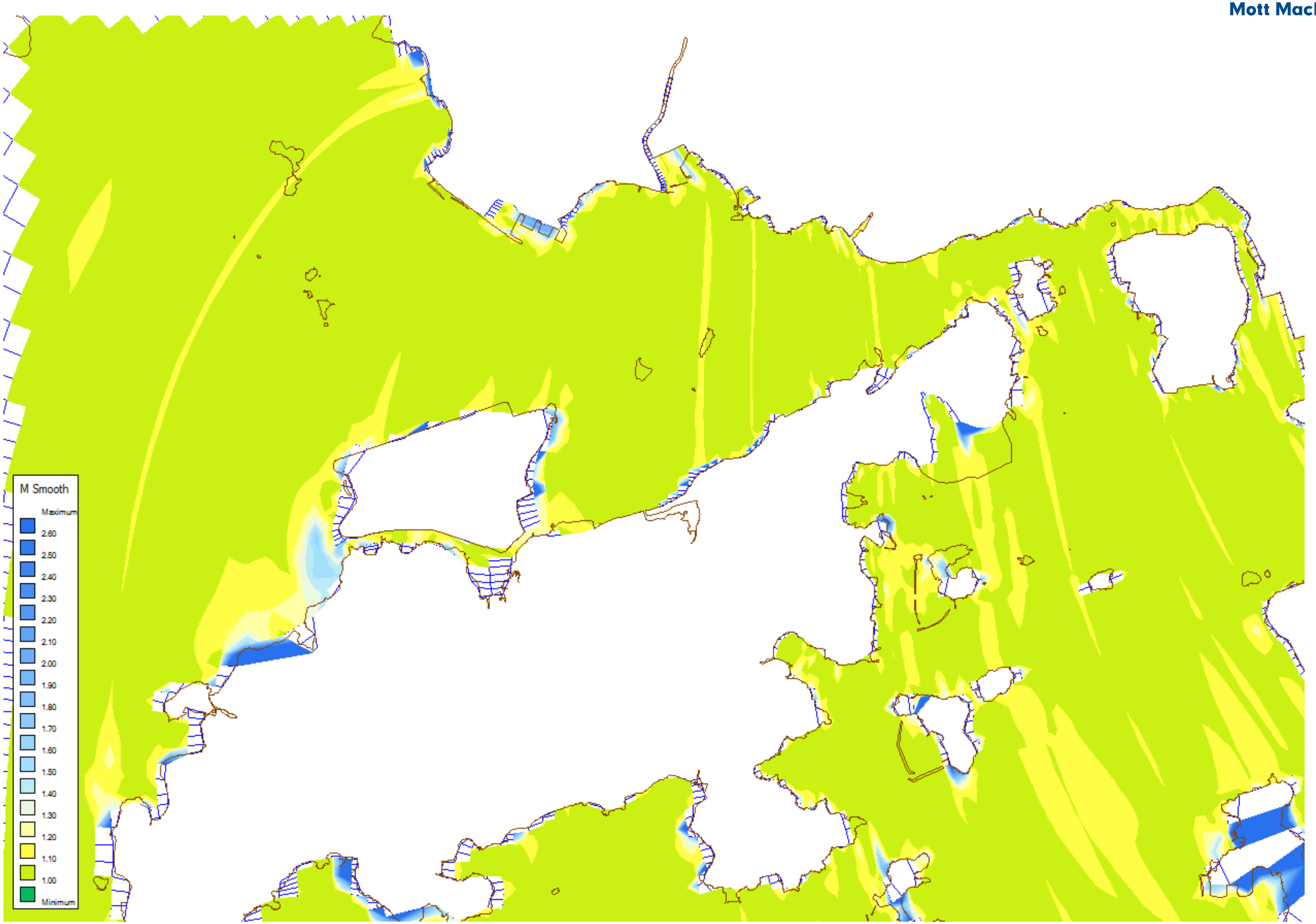
Orthogonality plot for refined grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



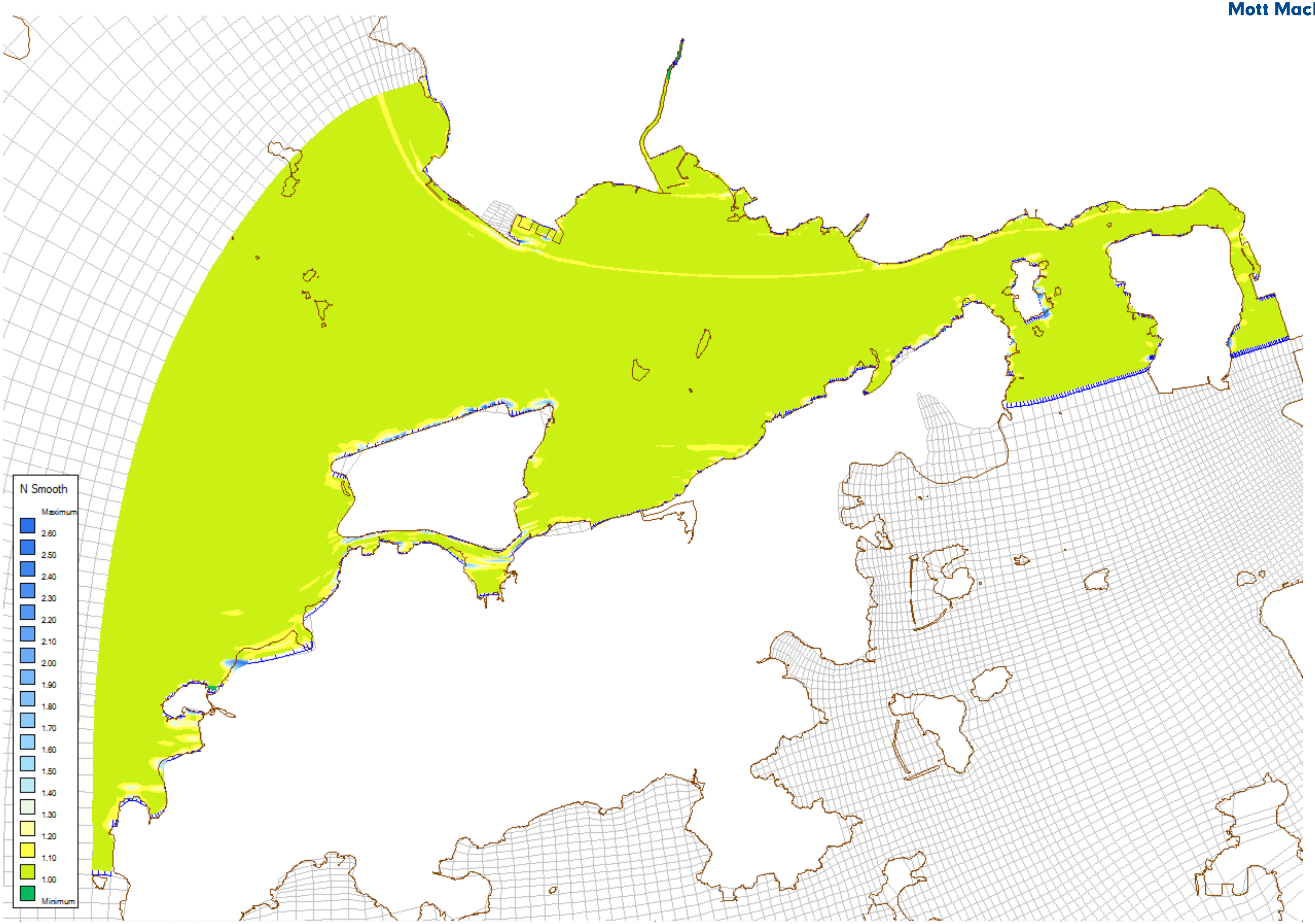
Orthogonality plot for original grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



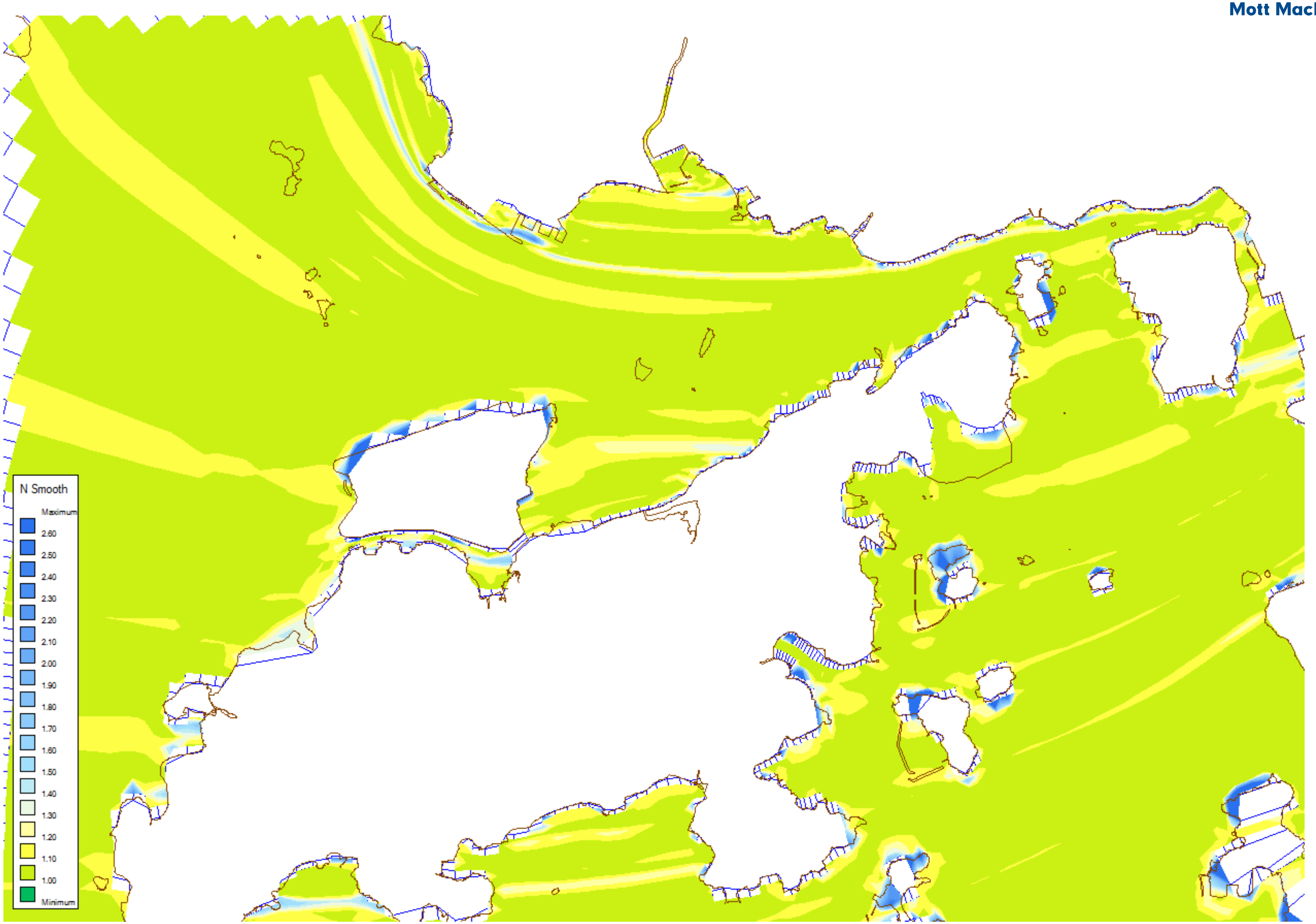
M Smoothness plot for refined grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



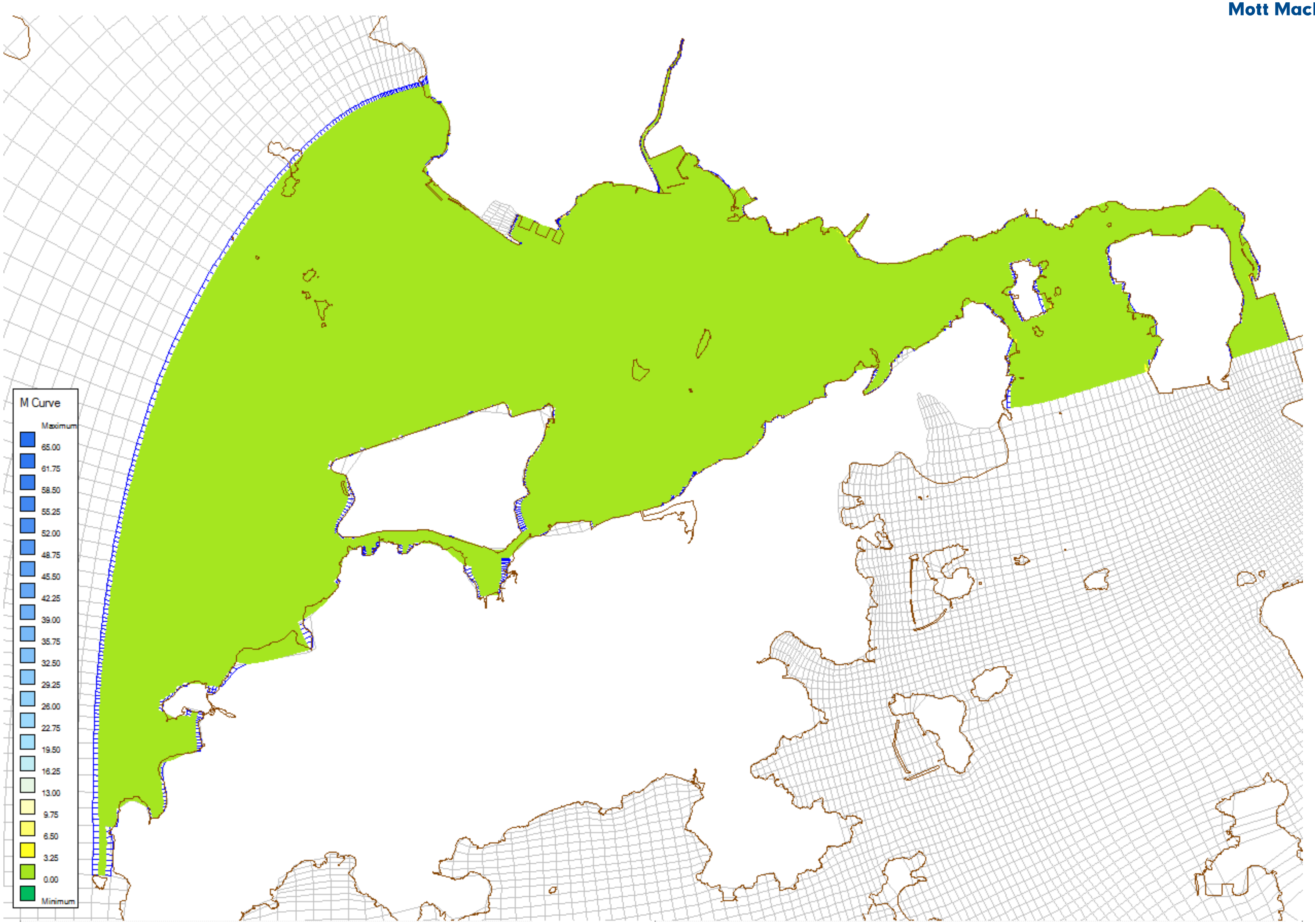
M smoothness plot for original grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



N Smoothness plot for refined grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.

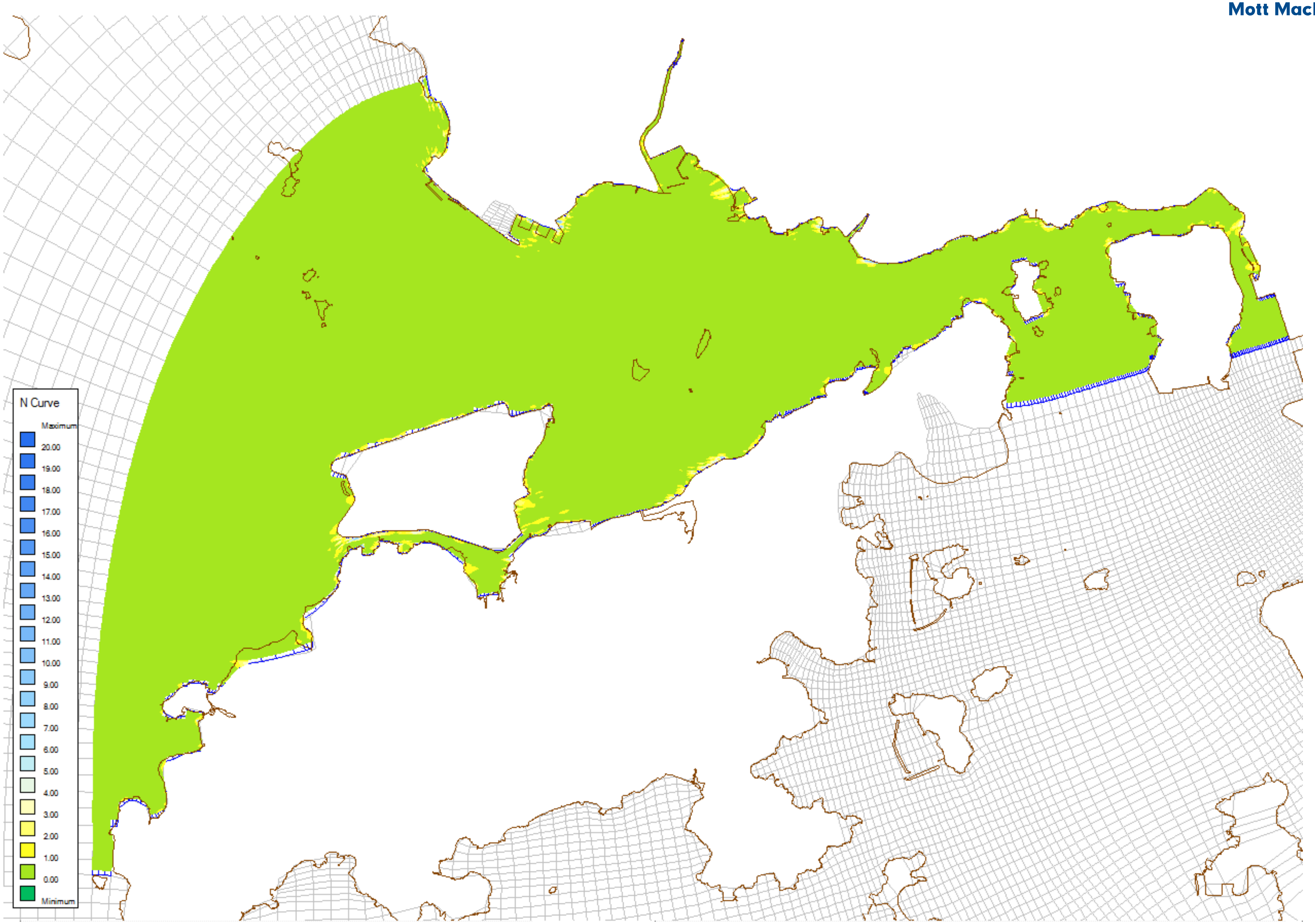


N smoothness plot for original grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.

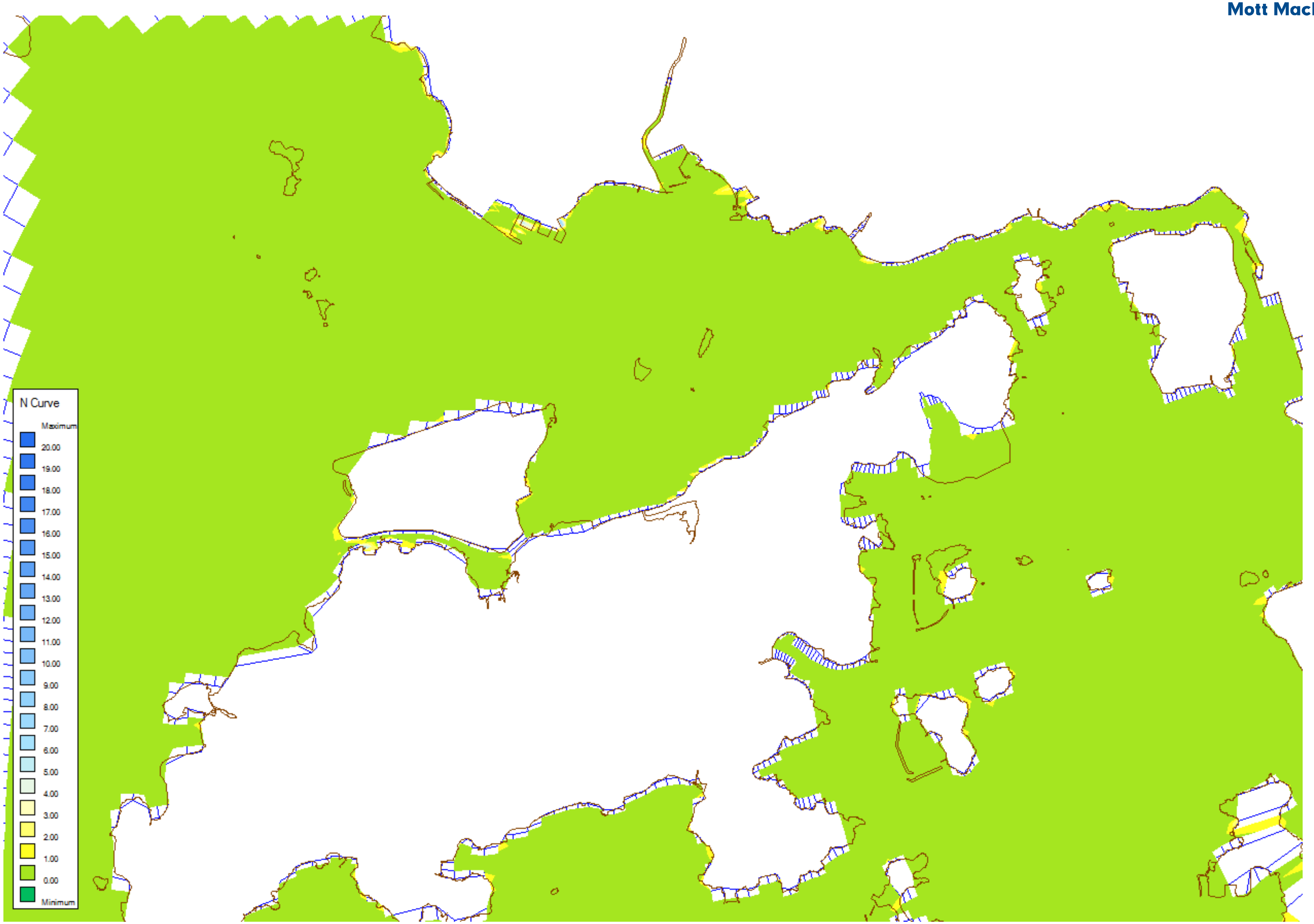


M Curvature plot for refined grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.

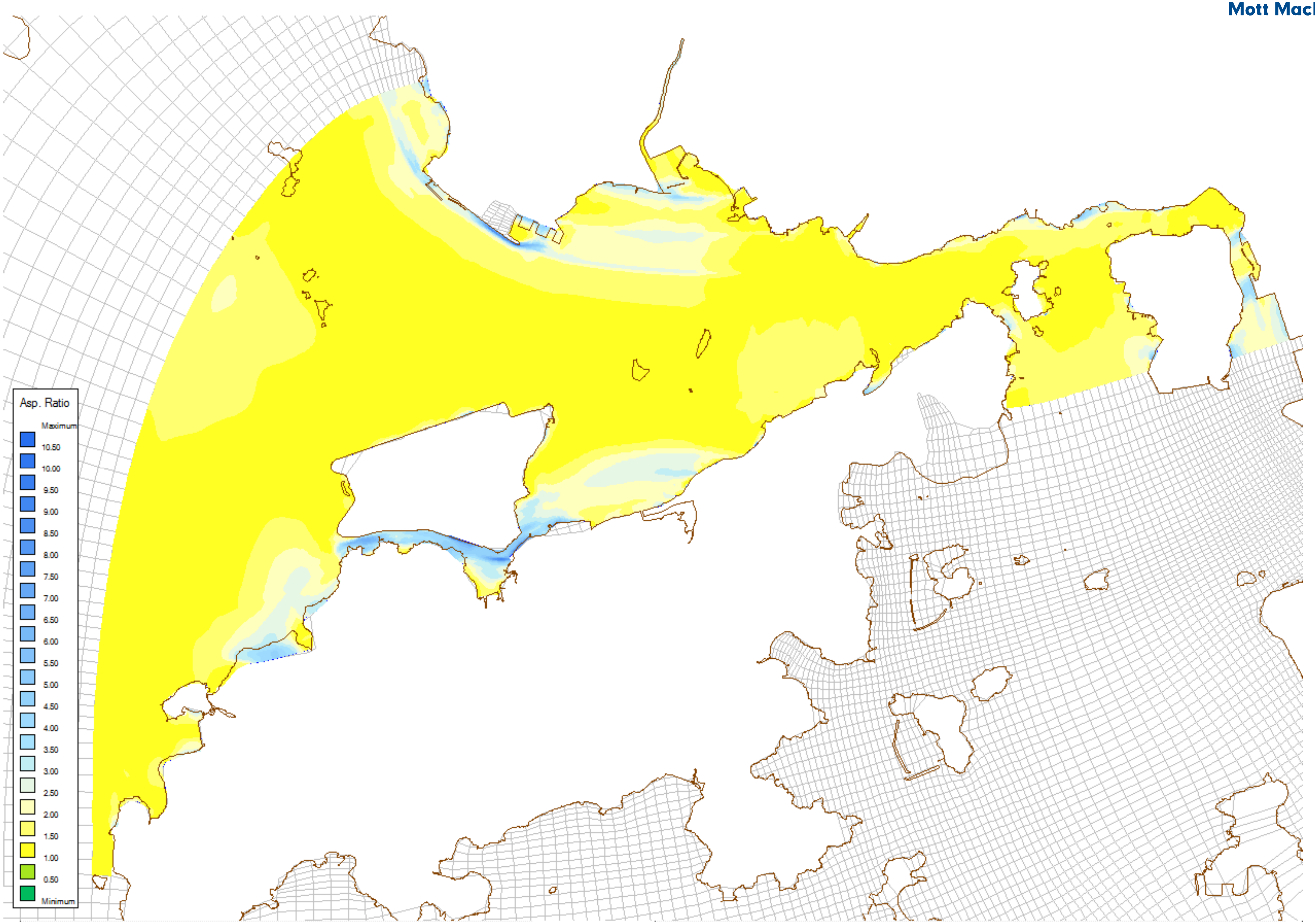
M Curvature plot for original grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



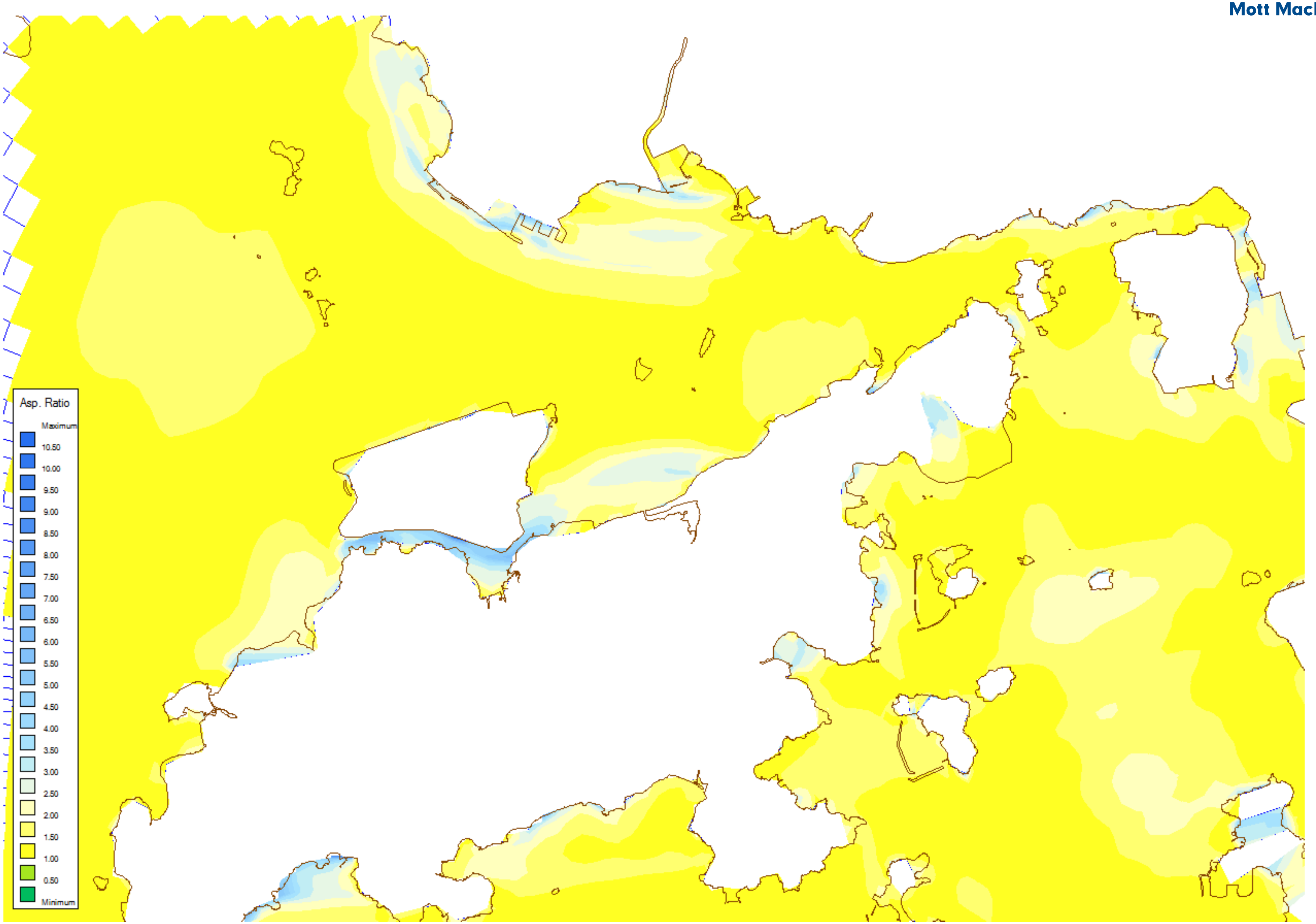
N Curvature plot for refined grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



N Curvature plot for original grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.



Aspect Ratio plot for refined grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.

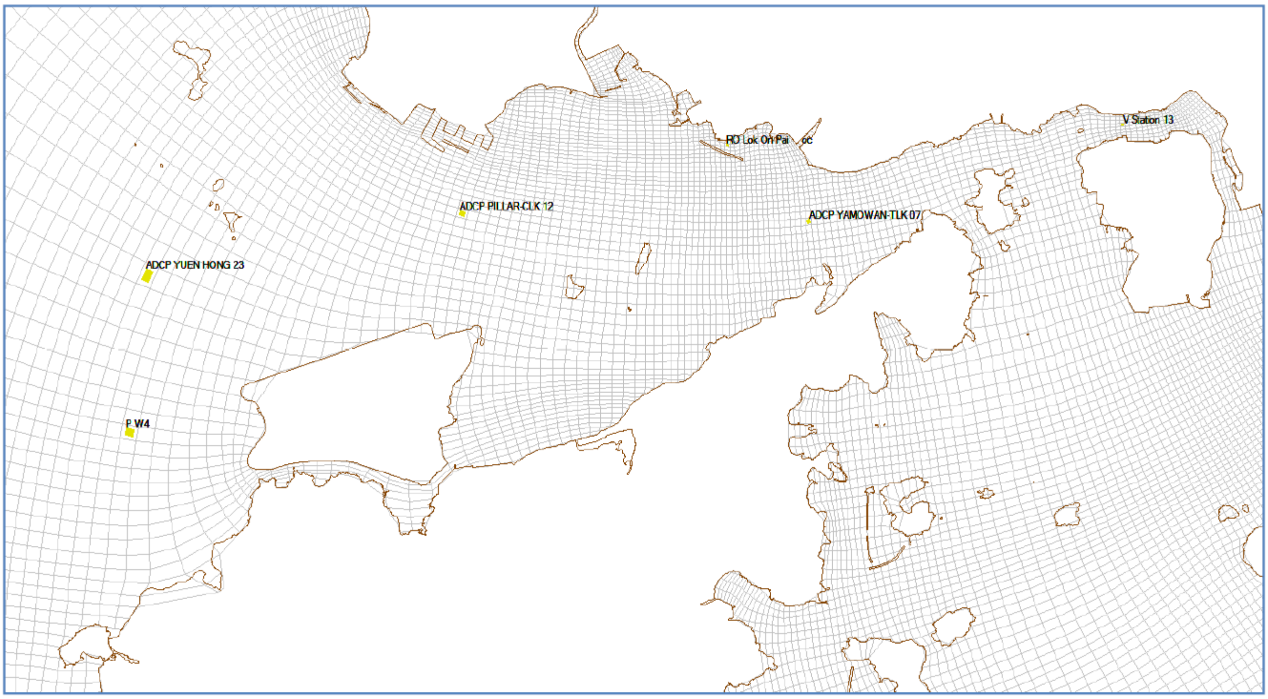


Aspect Ratio plot for original grid. Land boundary of 2012 is shown. Note that the same colour scale is used in both panels.

Annex D Model Validation Results

Model Validation Results

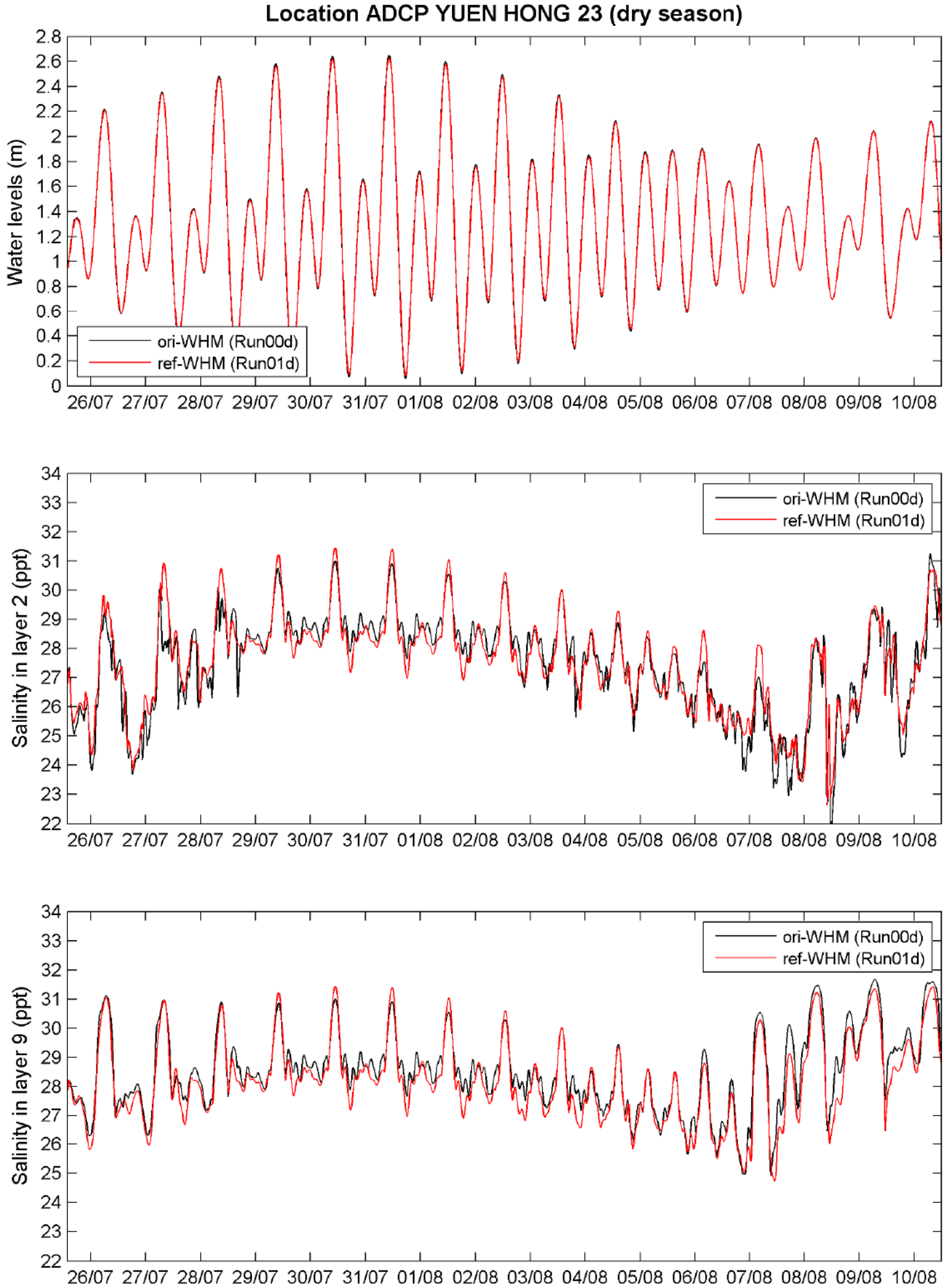
Location of validation sites



Timeseries Plots

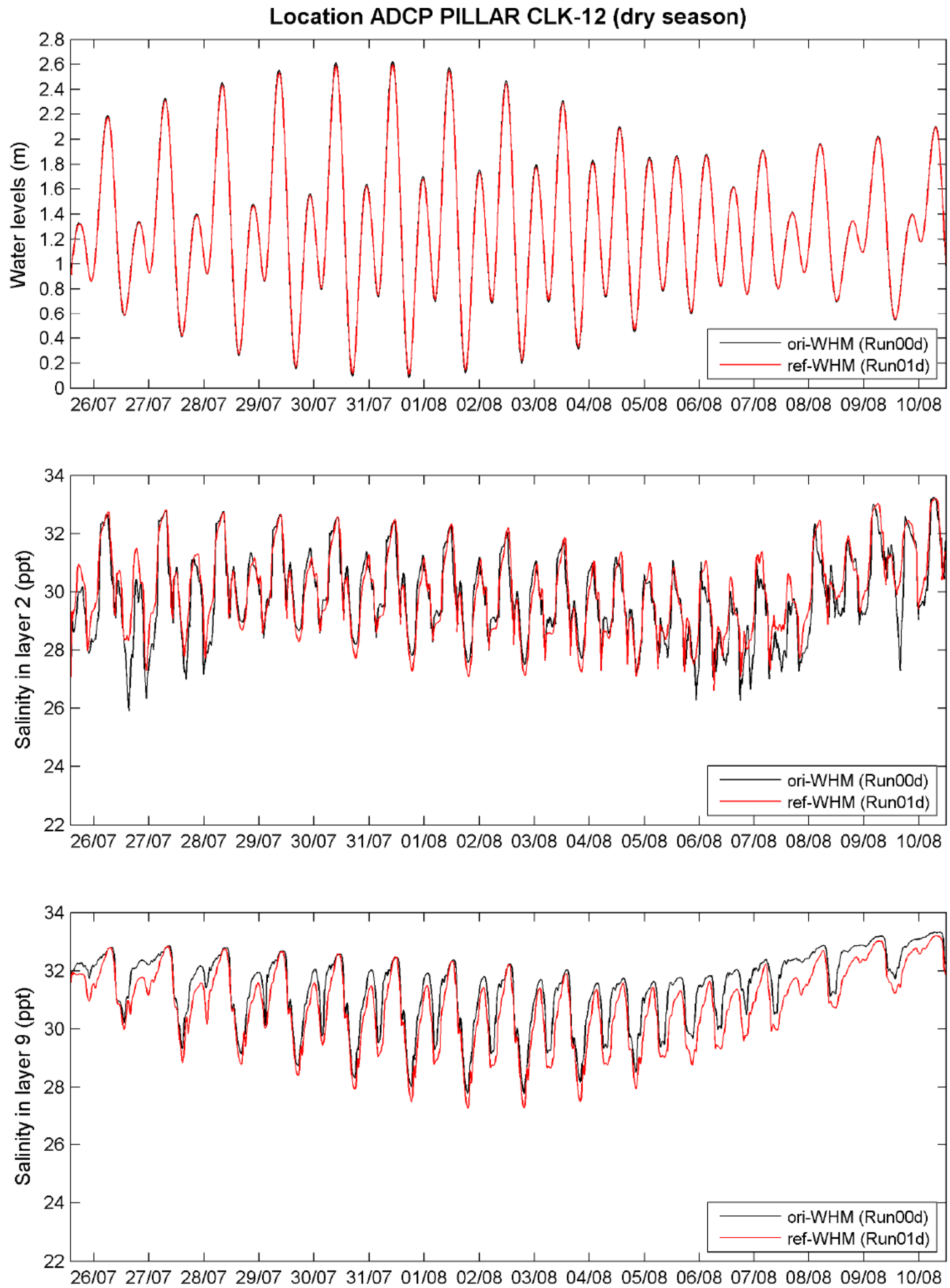
Page 2	Water level and salinity “validation” for dry season, at location “ADCP Yuen Hong 23”
Page 3	Water level and salinity “validation” for dry season, at location “ADCP Pillar CLK 12”
Page 4	Water level and salinity “validation” for dry season, at location “P W4”
Page 5	Water level and salinity “validation” for dry season, at location “RO Lok On Pai”
Page 6	Water level and salinity “validation” for dry season, at location “V station 13”
Page 7	Water level and salinity “validation” for dry season, at location “ADCP Yamowan TLK-07”
Page 8	Current magnitude and direction “validation” for dry season, at location “ADCP Pillar CLK-12”
Page 9	Current magnitude and direction “validation” for dry season, at location “P W4”
Page 10	Current magnitude and direction “validation” for dry season, at location “RO Lok On Pai”
Page 11	Current magnitude and direction “validation” for dry season, at location “V station 13”
Page 12	Current magnitude and direction “validation” for dry season, at location “ADCP Yamowan TLK-07”
Page 13	Current magnitude and direction “validation” for dry season, at location “ADCP Yuen Hong 23”
Page 14	Water level and salinity “validation” for wet season, at location “ADCP Yuen Hong 23”
Page 15	Water level and salinity “validation” for wet season, at location “ADCP Pillar CLK-12”
Page 16	Water level and salinity “validation” for wet season, at location “P W4”
Page 17	Water level and salinity “validation” for wet season, at location “RO Lok On Pai”
Page 18	Water level and salinity “validation” for wet season, at location “V station 13”
Page 19	Water level and salinity “validation” for wet season, at location “ADCP Yamowan TLK-07”
Page 20	Current magnitude and direction “validation” for wet season, at location “ADCP Yuen Hong 23”
Page 21	Current magnitude and direction “validation” for wet season, at location “ADCP Pillar CLK-12”
Page 22	Current magnitude and direction “validation” for wet season, at location “P W4”
Page 23	Current magnitude and direction “validation” for wet season, at location “RO Lok On Pai”
Page 24	Current magnitude and direction “validation” for wet season, at location “V station 13”
Page 25	Current magnitude and direction “validation” for wet season, at location “Yamowan TLK-07”

Water level and salinity "validation" for dry season, at location "ADCP Yuen Hong 23".



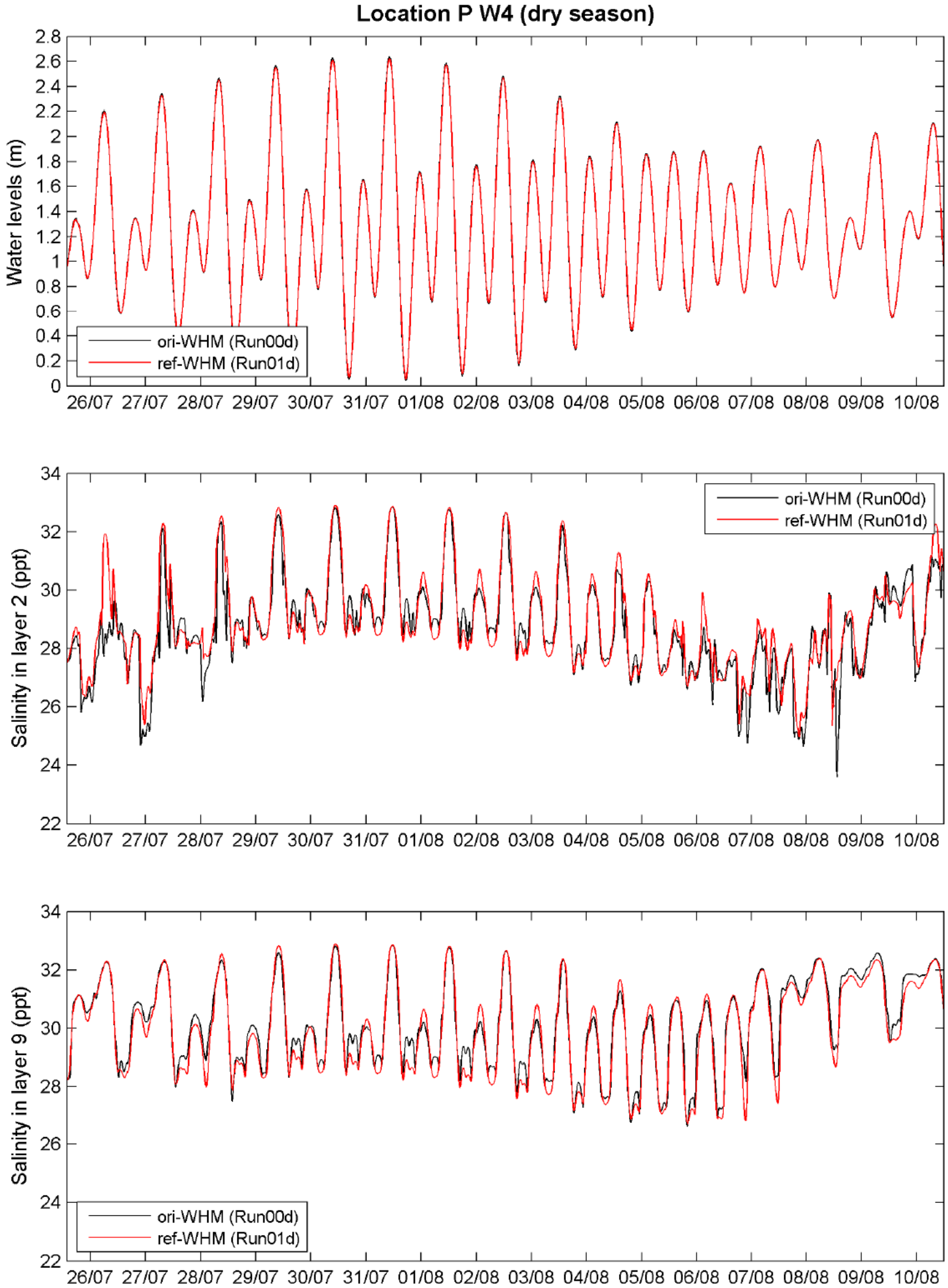
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00d vs. Run01d		
Deltares Delft Hydraulics		

Water level and salinity "validation" for dry season, at location "ADCP Pillar CLK 12"



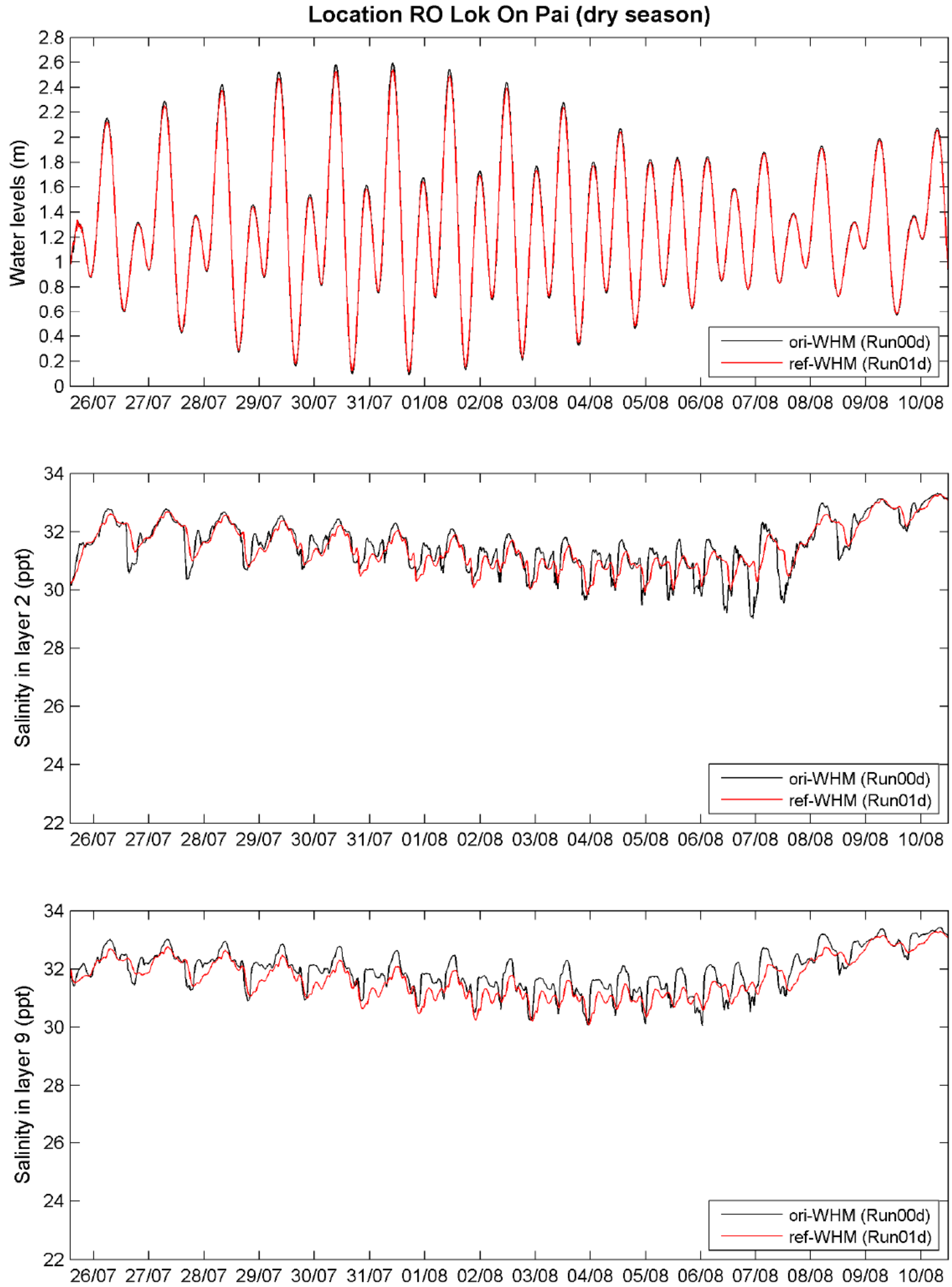
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00d vs. Run01d		
Deltares Delft Hydraulics		

Water level and salinity "validation" for dry season, at location "P W4".



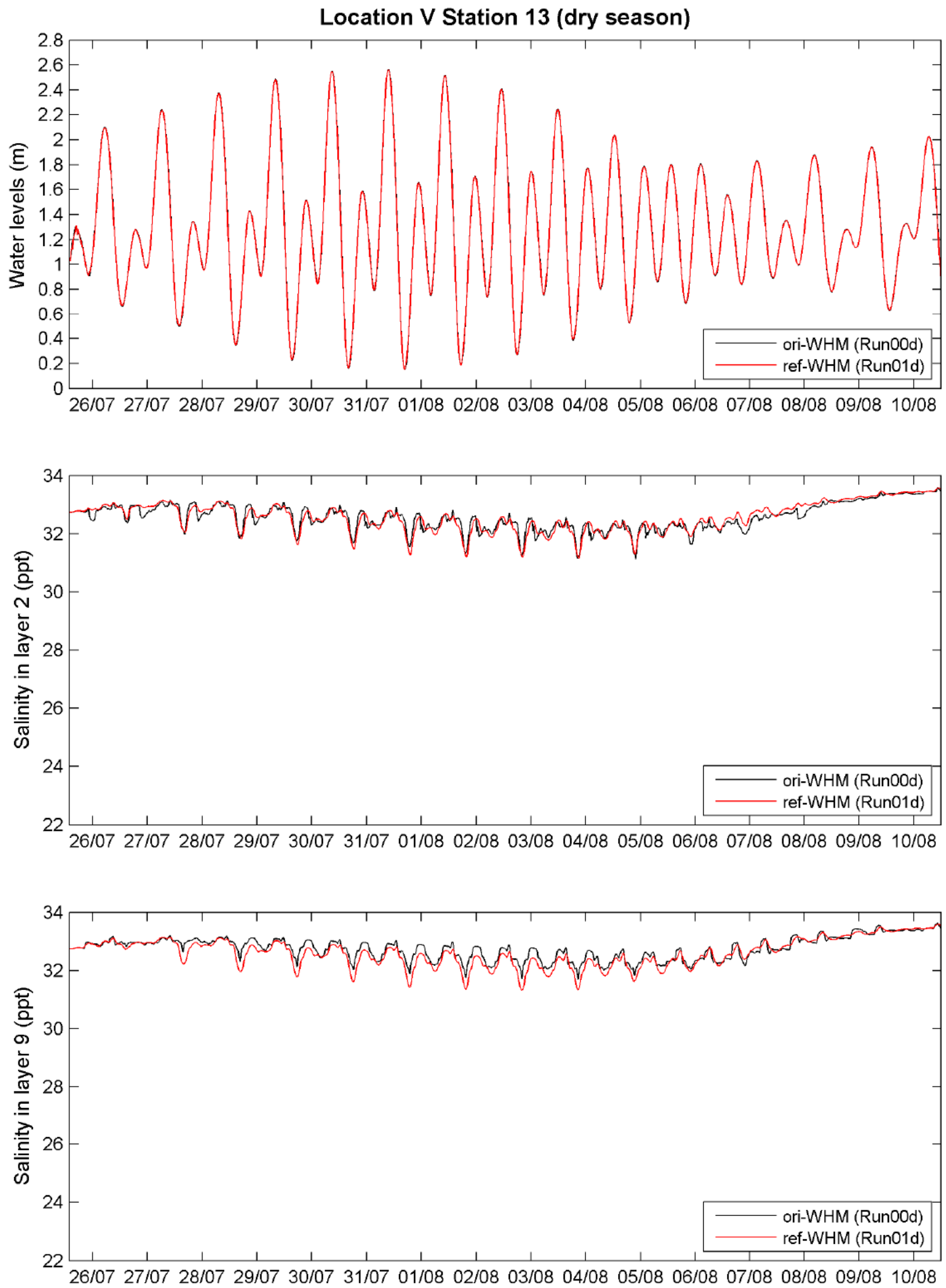
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00d vs. Run01d		
Deltares Delft Hydraulics		

Water level and salinity "validation" for dry season, at location "RO Lok On Pai".



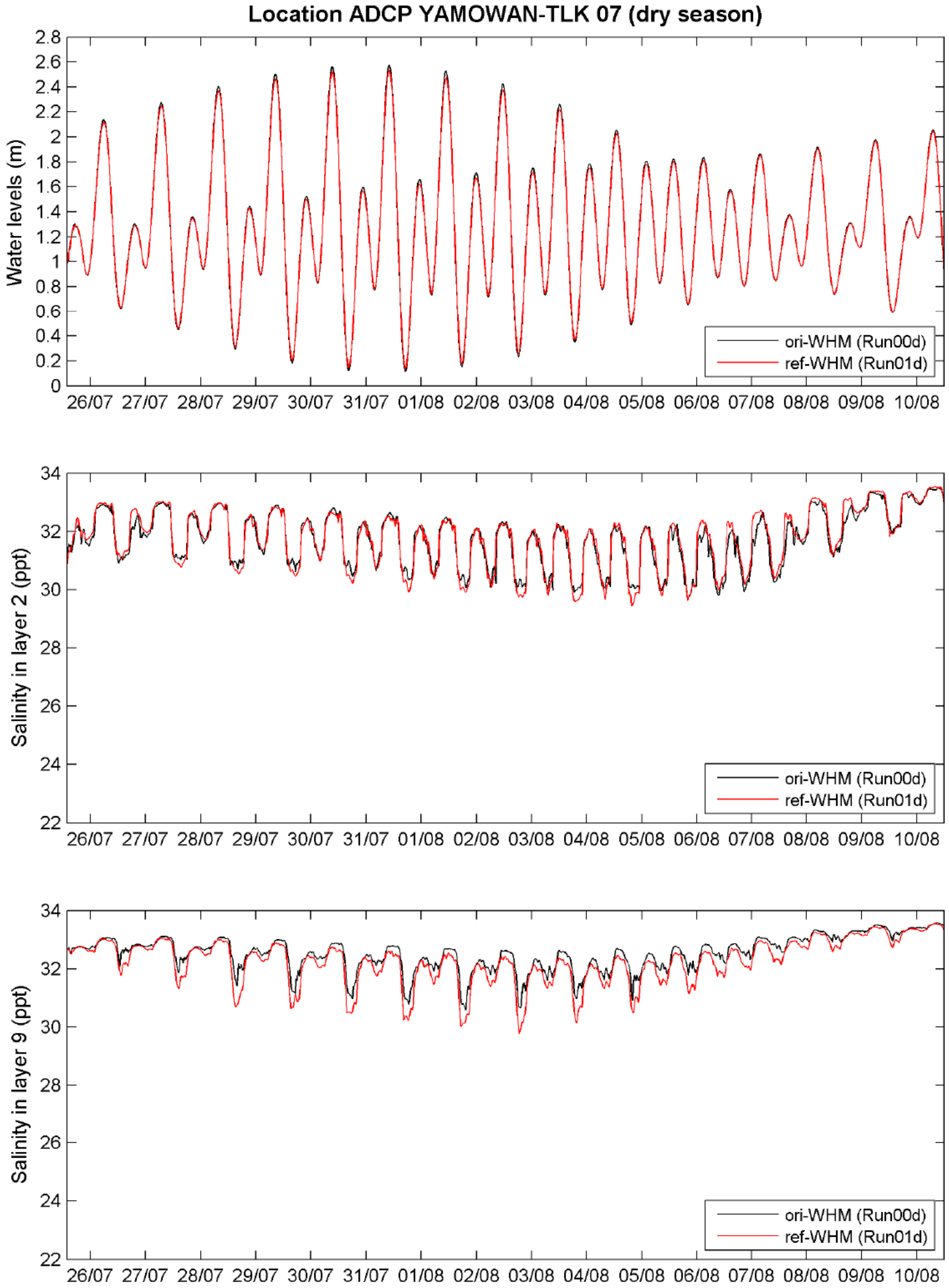
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00d vs. Run01d		
Deltares Delft Hydraulics		

Water level and salinity “validation” for dry season, at location “V station 13”.



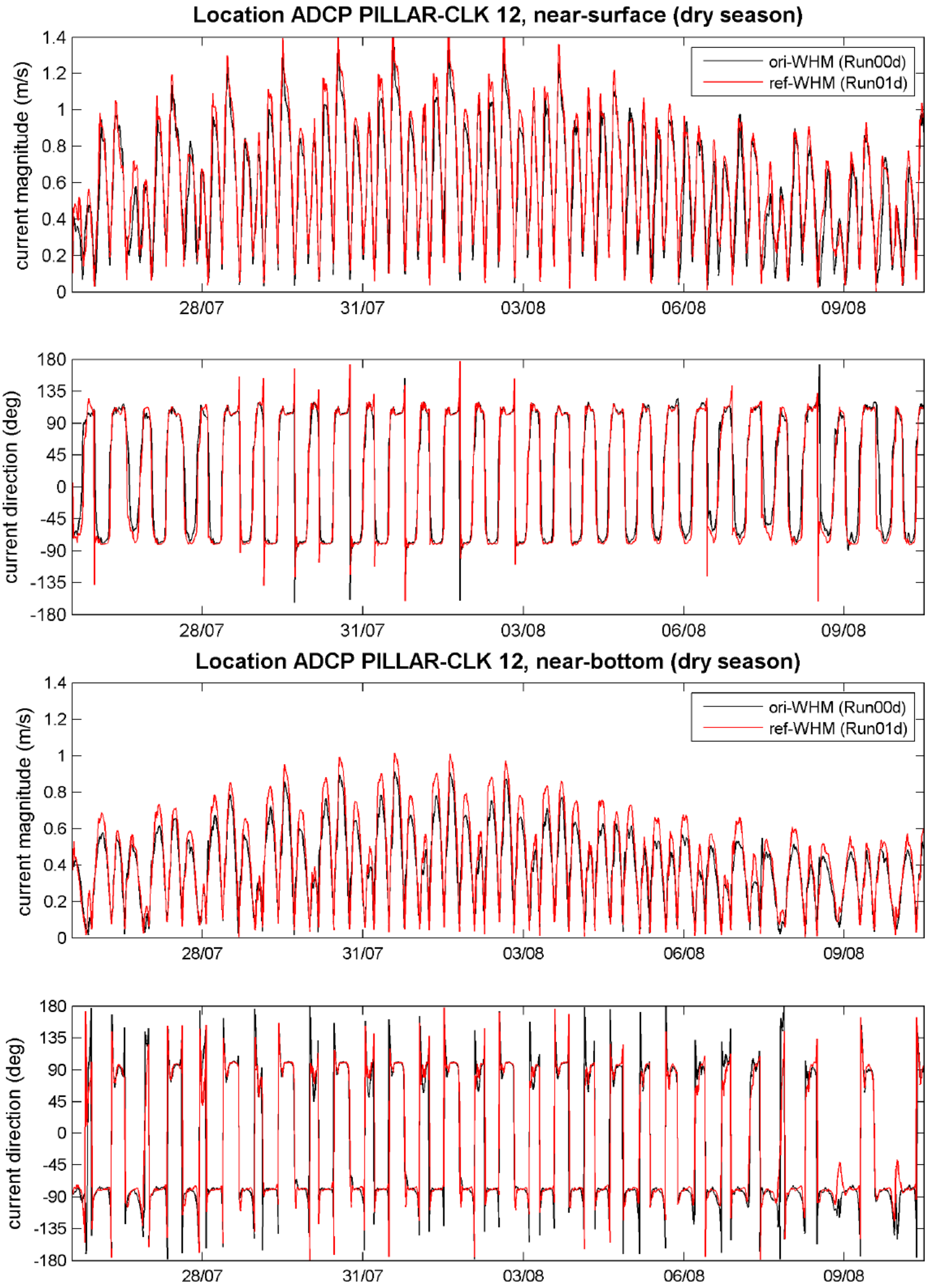
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00d vs. Run01d		
Deltares Delft Hydraulics		

Water level and salinity "validation" for dry season, at location "ADCP Yamowan TLK-07".



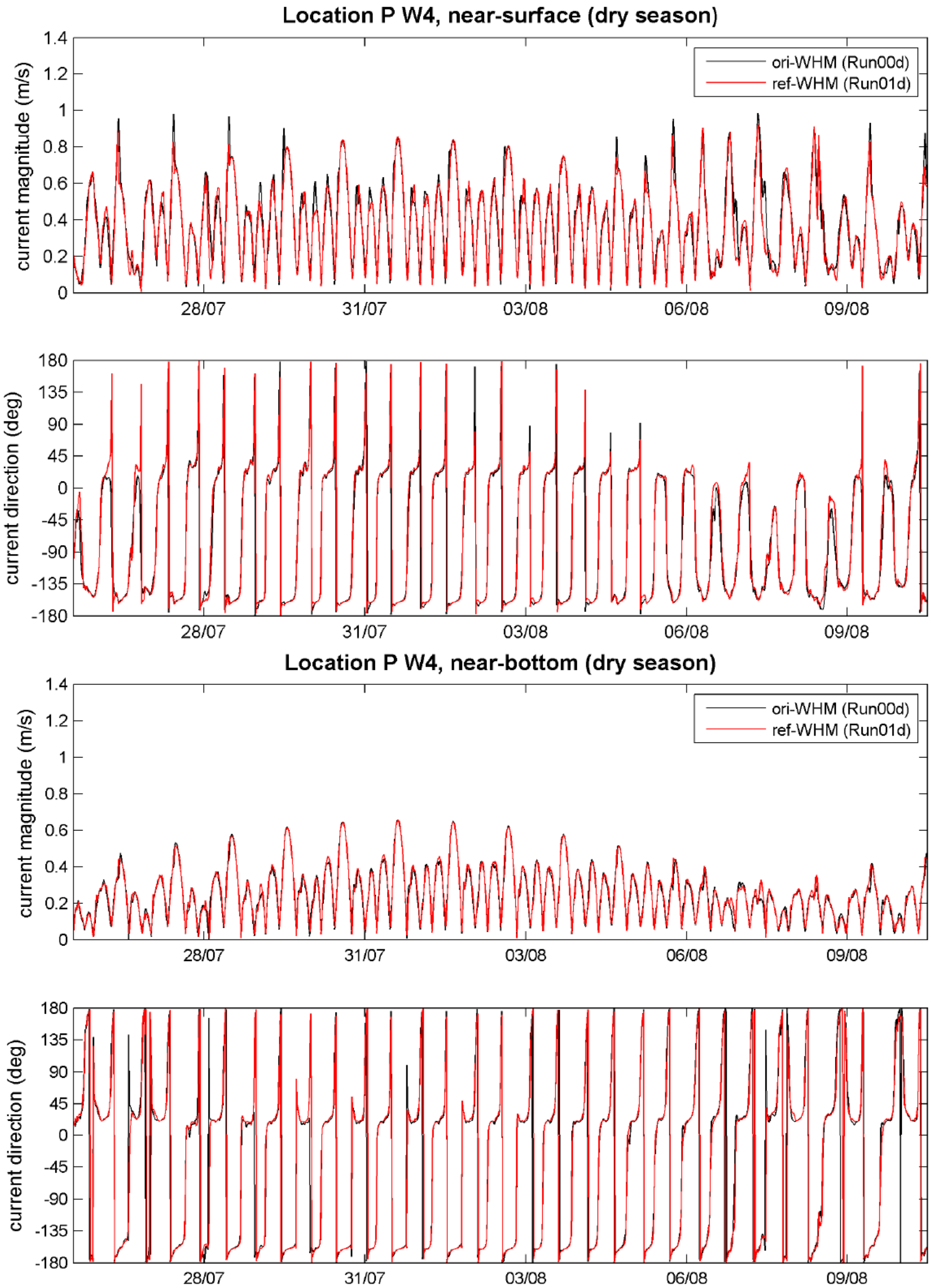
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00d vs. Run01d		
Deltares Delft Hydraulics		

Current magnitude and direction "validation" for dry season, at location "ADCP Pillar CLK-12".



Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00d vs. Run01d		
Deltares Delft Hydraulics		

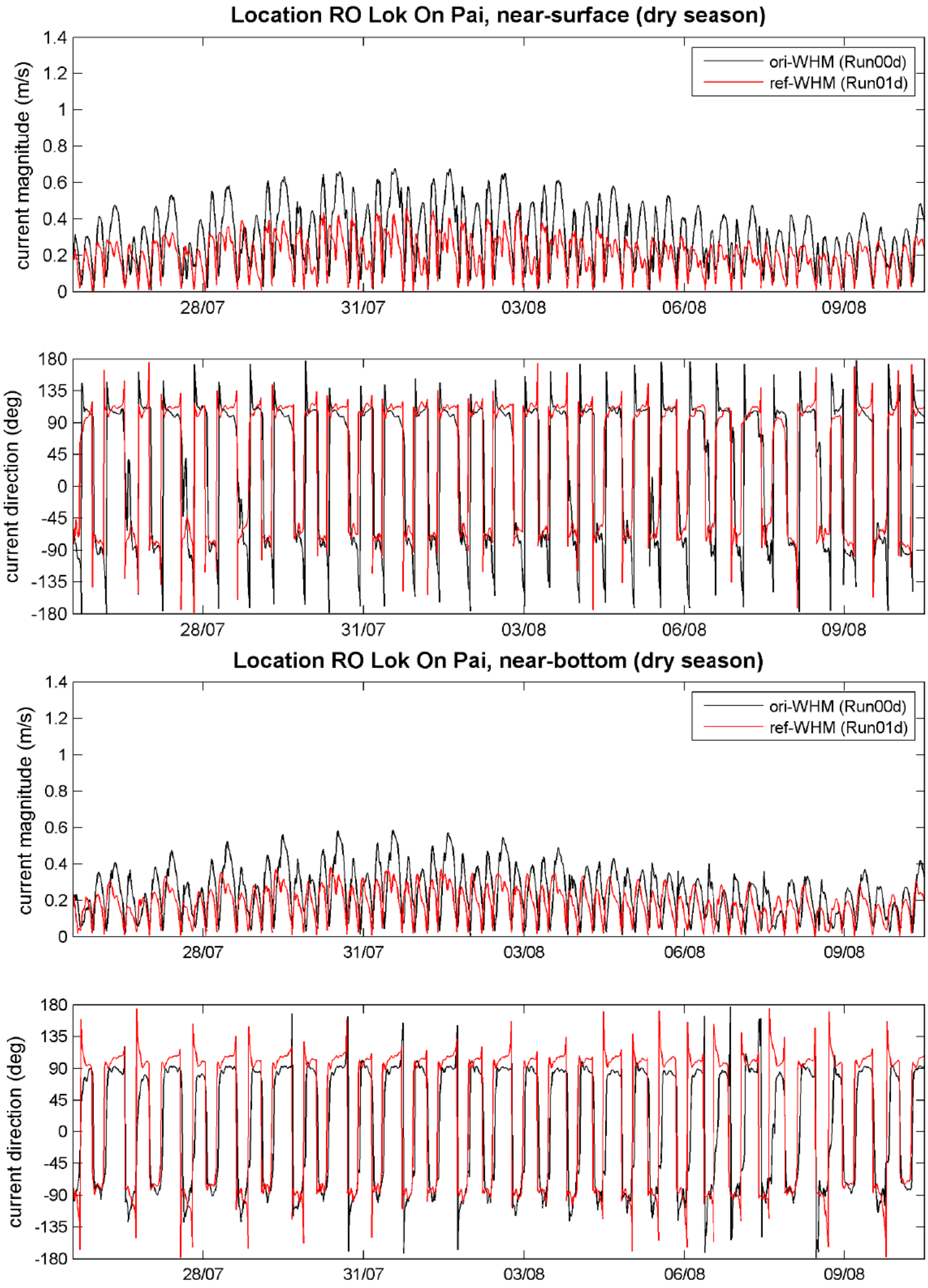
Current magnitude and direction “validation” for dry season, at location “P W4”.



Comparison of Hong Kong model results:
ori-WHM vs. ref-WHM (3x3 DD)
Run00d vs. Run01d

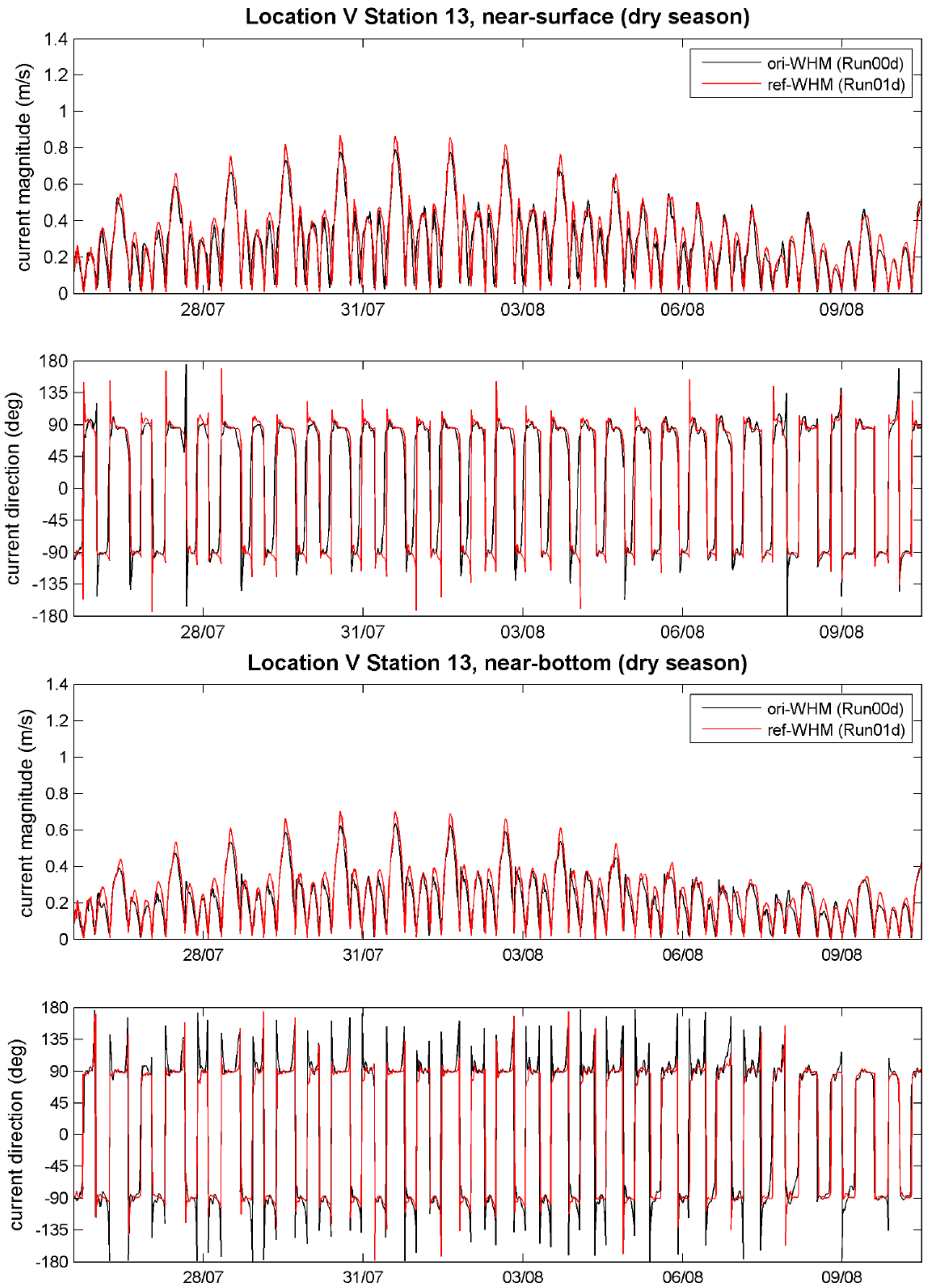
Deltares
Delft Hydraulics

Current magnitude and direction “validation” for dry season, at location “RO Lok On Pai”.



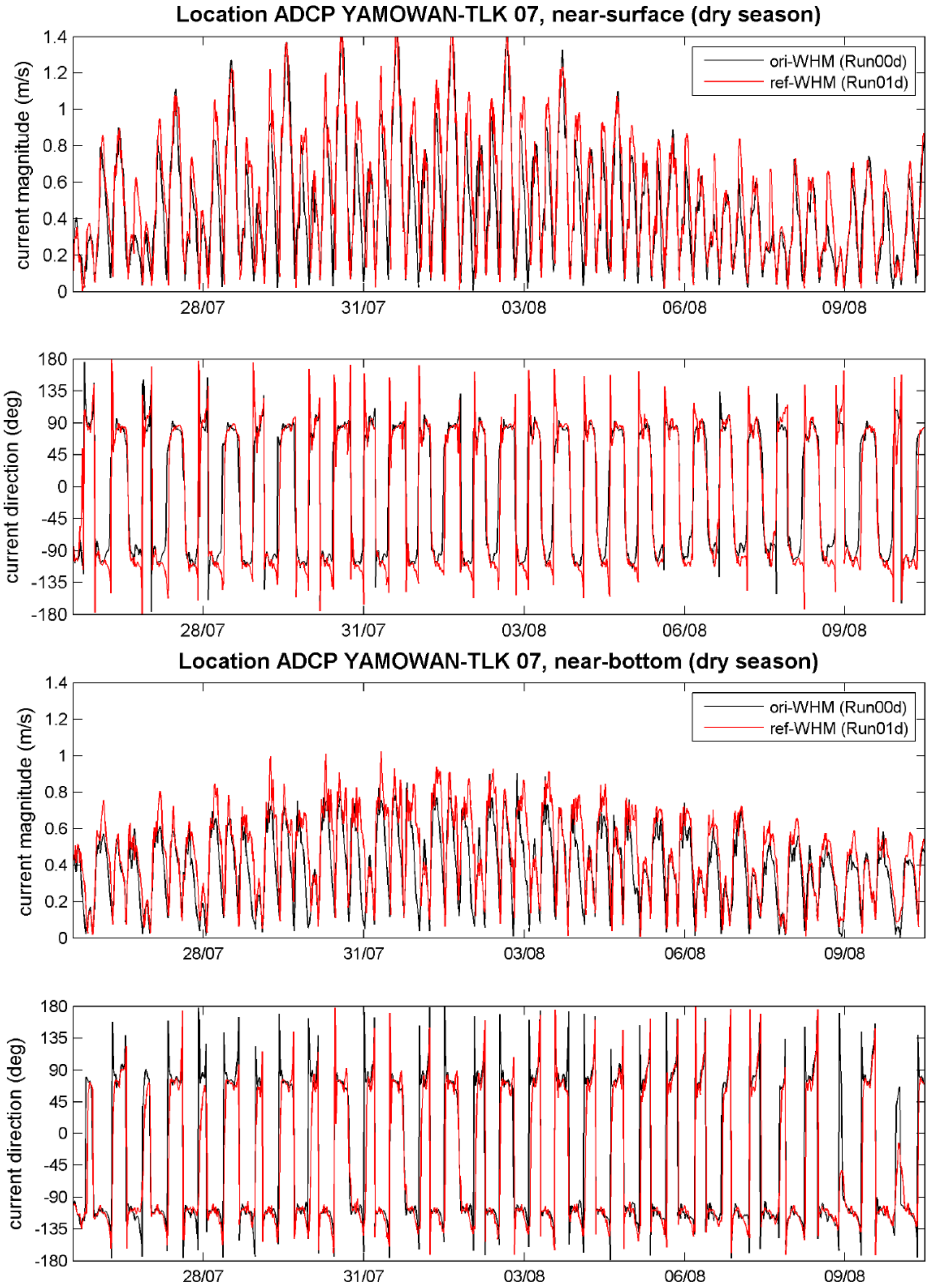
Comparison of Hong Kong model results:
ori-WHM vs. ref-WHM (3x3 DD)
Run00d vs. Run01d

Current magnitude and direction "validation" for dry season, at location "V station 13".



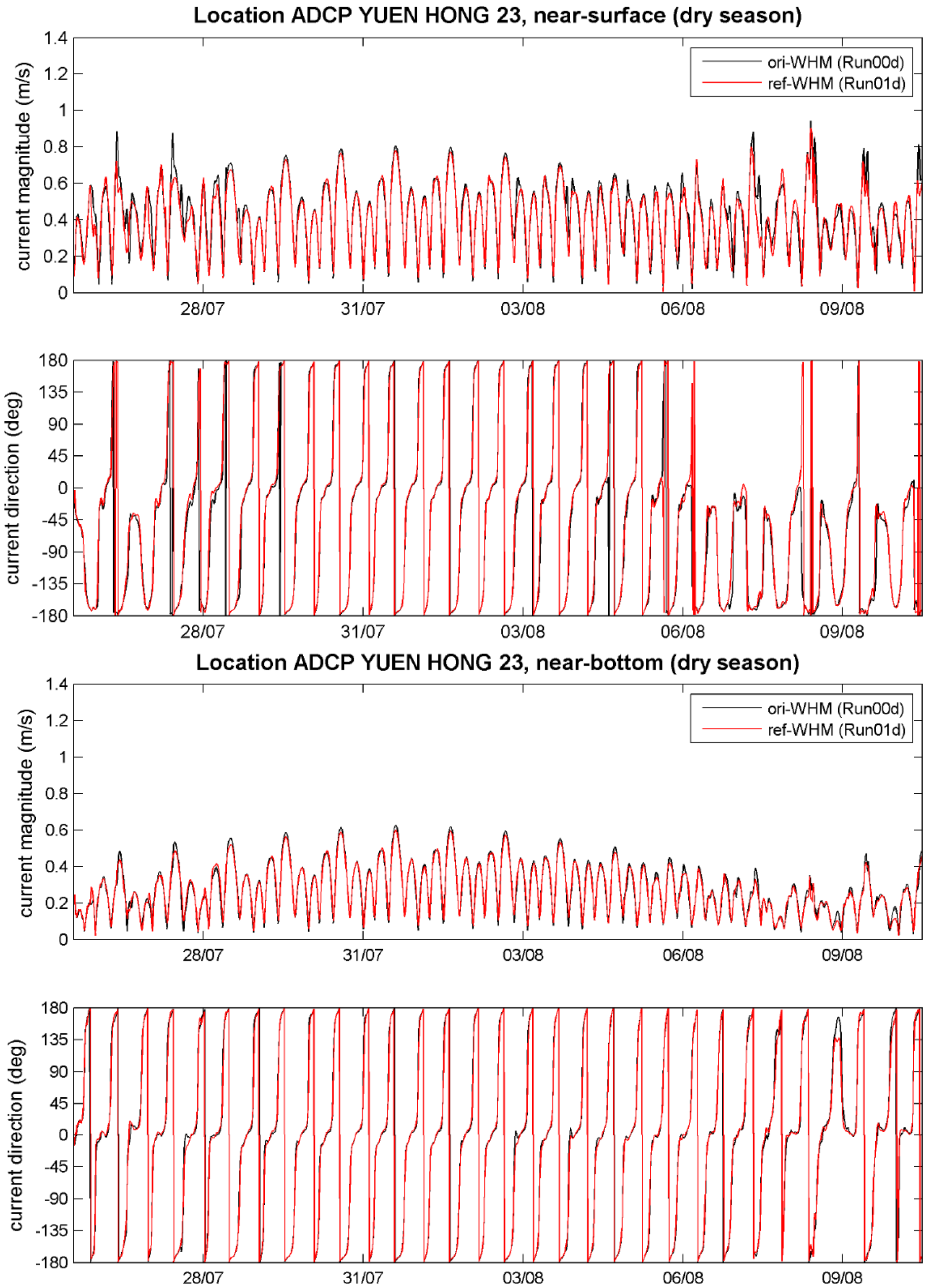
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00d vs. Run01d		
Deltares Delft Hydraulics		

Current magnitude and direction "validation" for dry season, at location "ADCP Yamowan TLK-07".



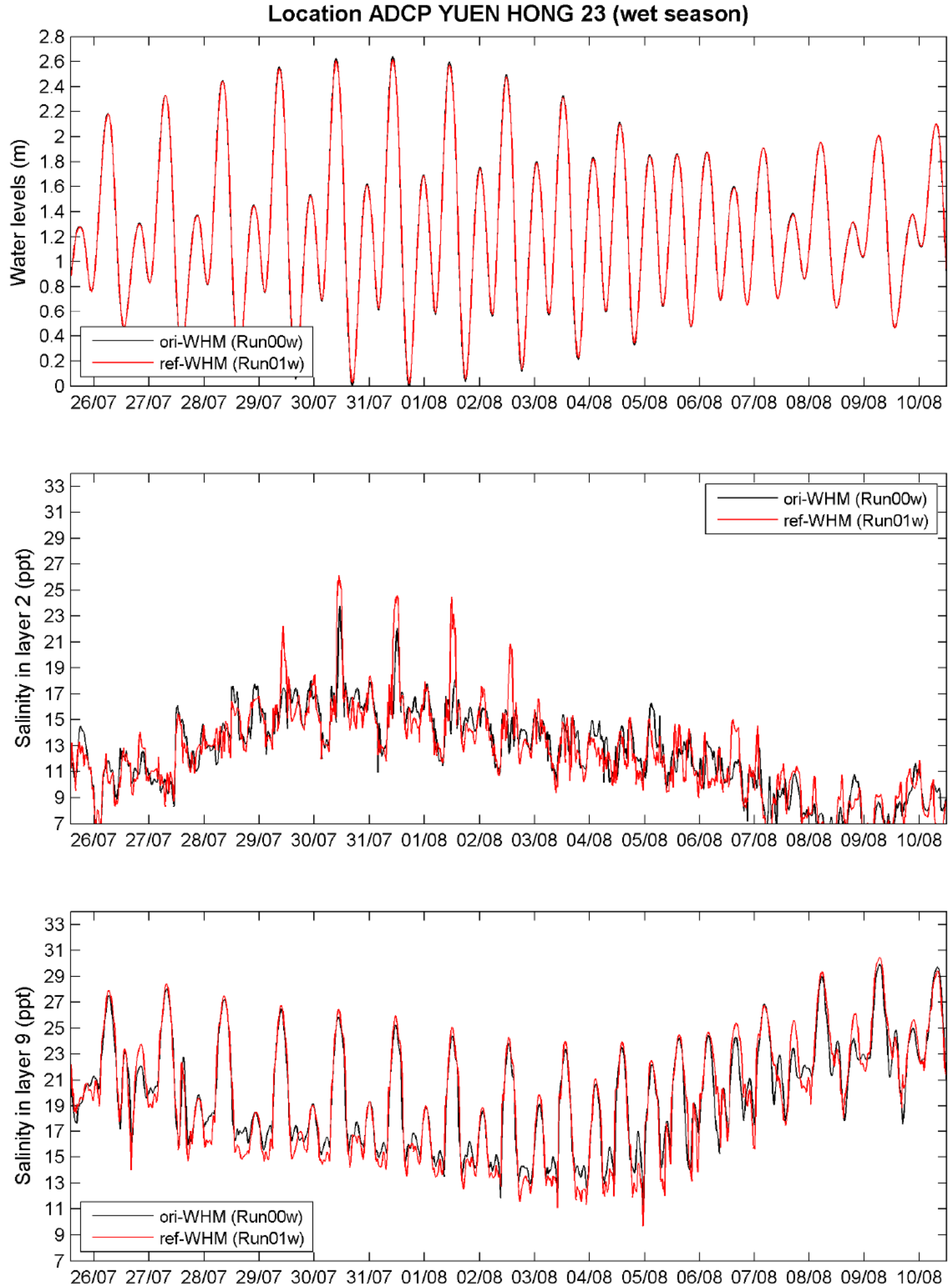
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00d vs. Run01d		
Deltares Delft Hydraulics		

Current magnitude and direction "validation" for dry season, at location "ADCP Yuen Hong 23".



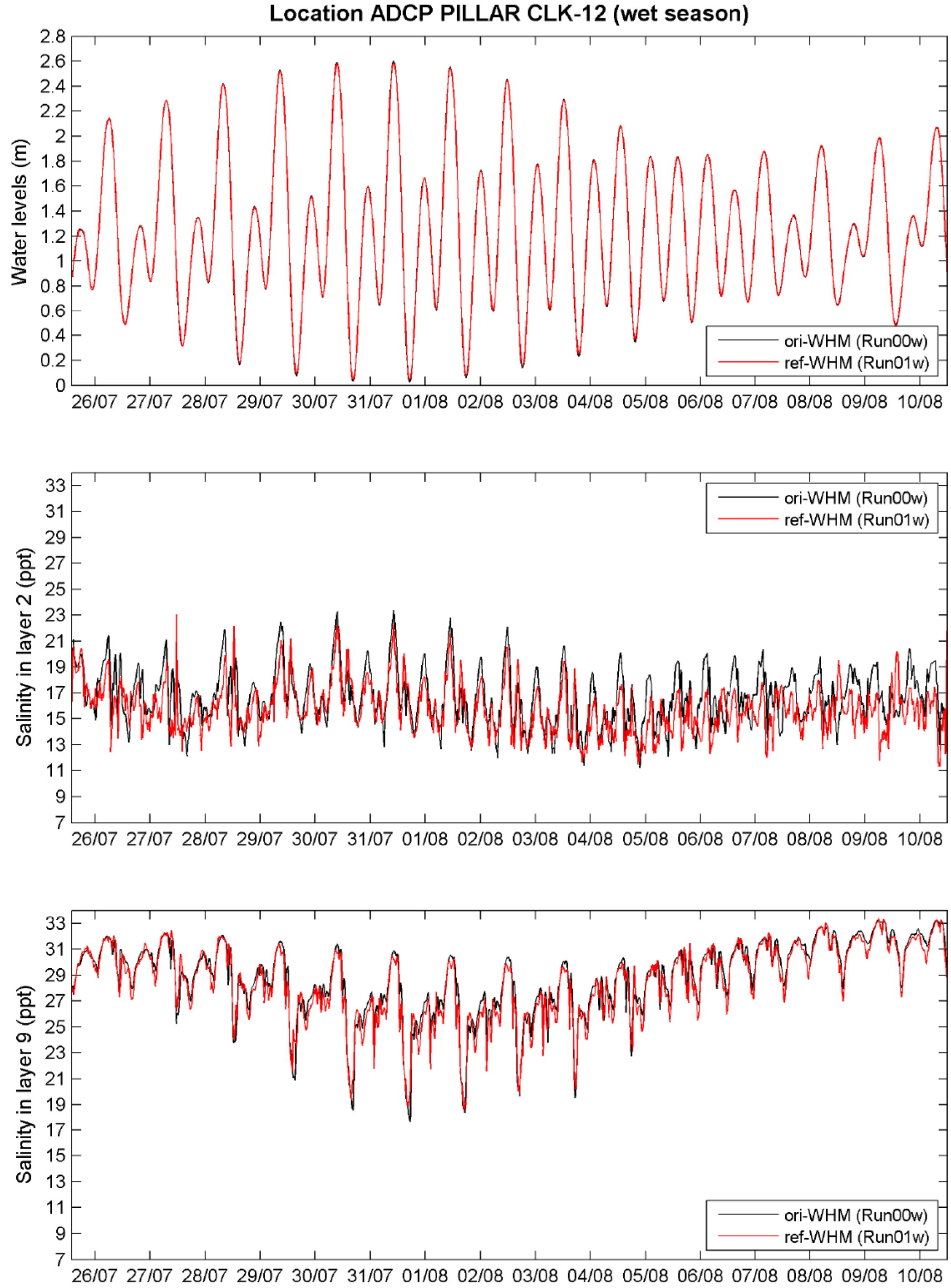
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00d vs. Run01d		
Deltares Delft Hydraulics		

Water level and salinity "validation" for wet season, at location "ADCP Yuen Hong 23".



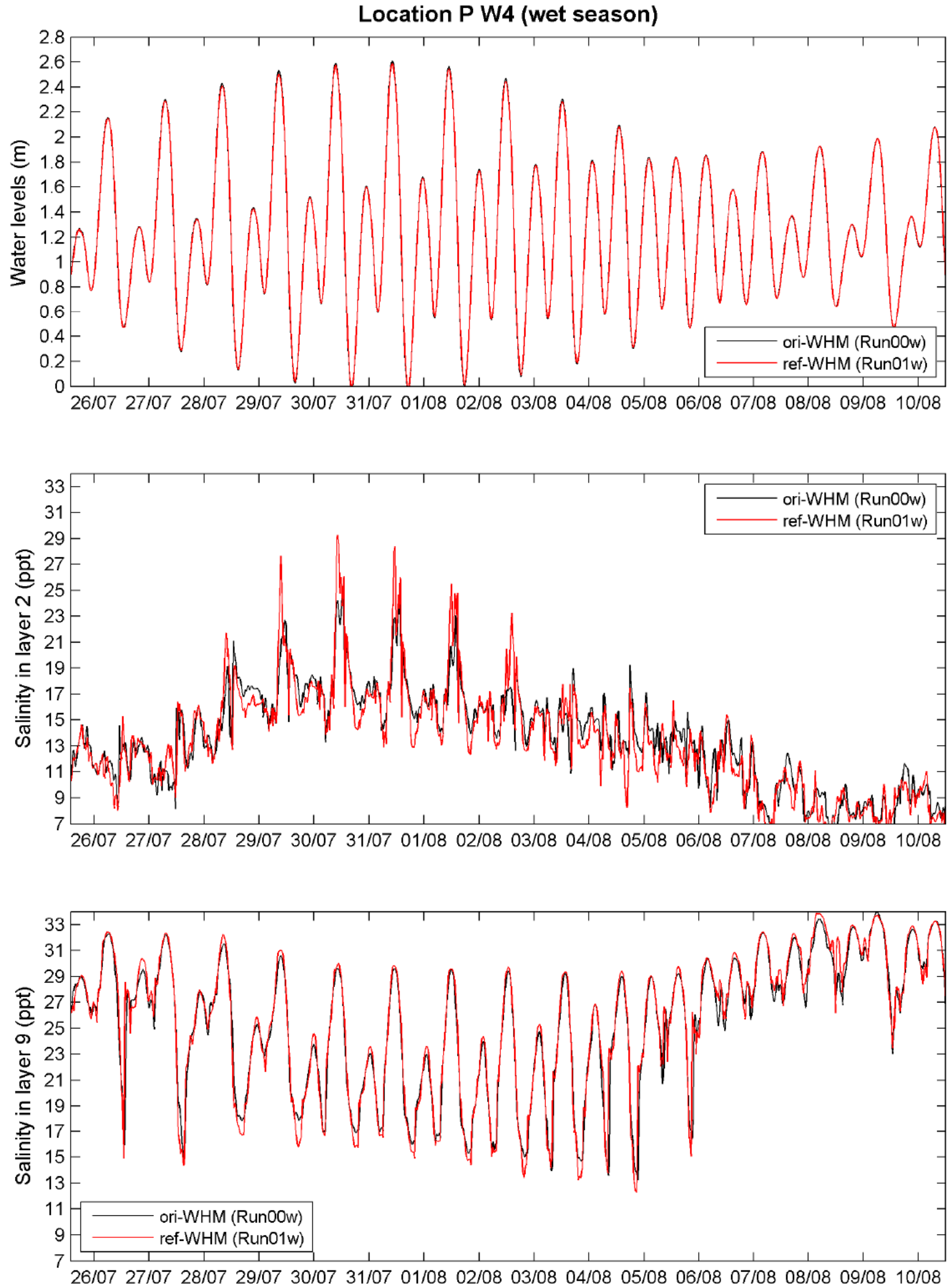
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00w vs. Run01w		
Deltares Delft Hydraulics		

Water level and salinity "validation" for wet season, at location "ADCP Pillar CLK-12".



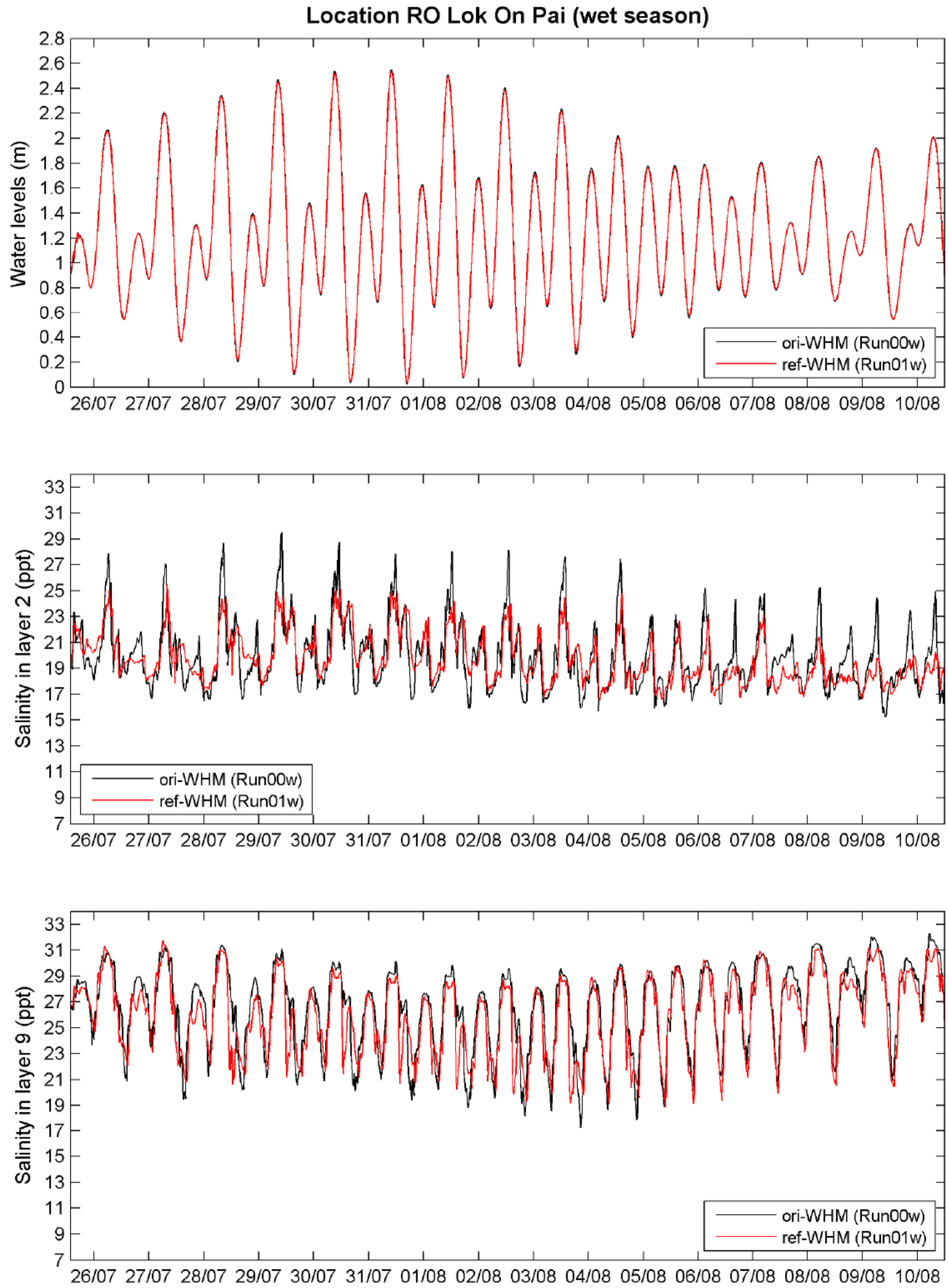
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00w vs. Run01w		
Deltares Delft Hydraulics		

Water level and salinity "validation" for wet season, at location "P W4".



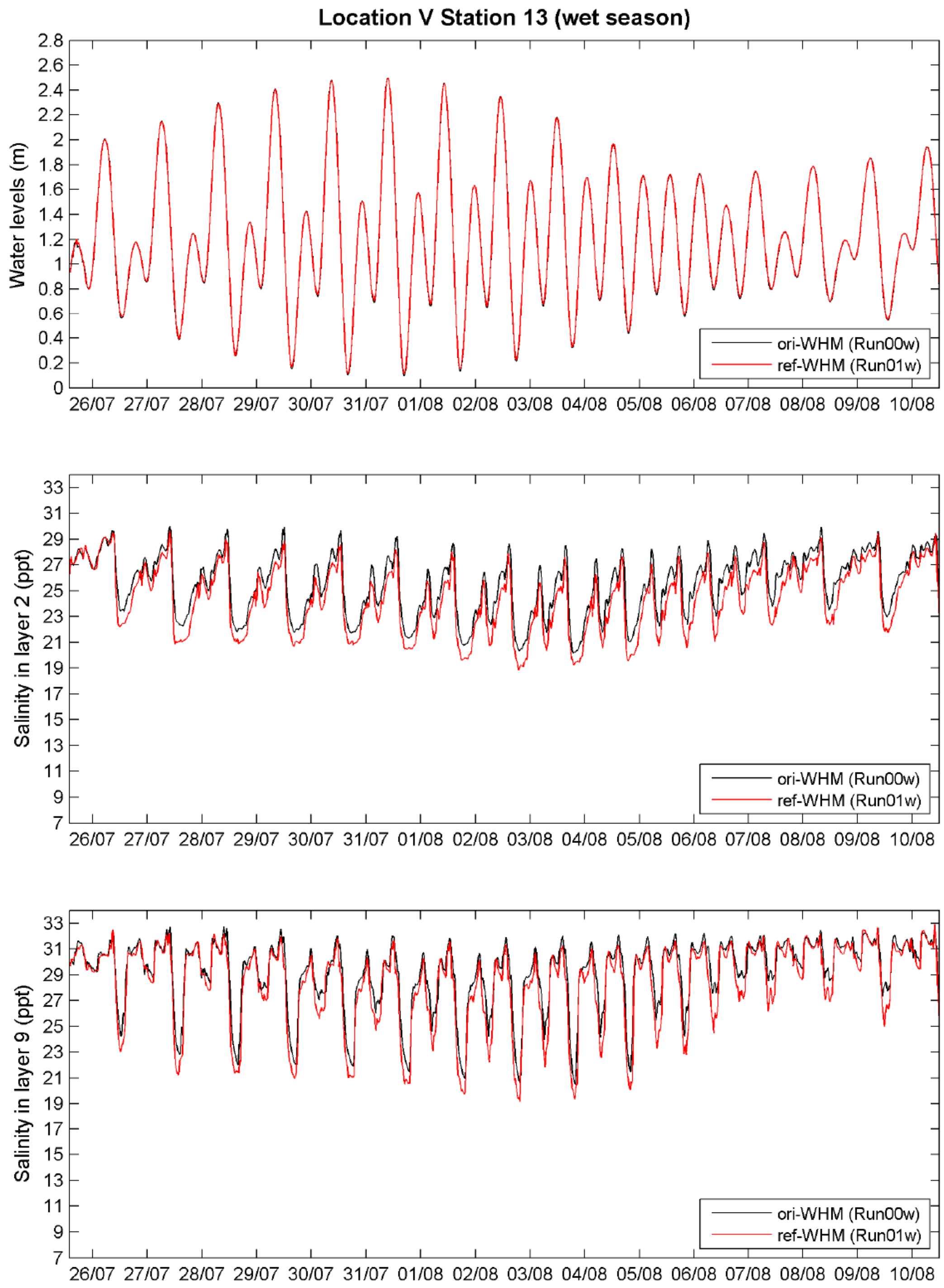
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00w vs. Run01w		
Deltares Delft Hydraulics		

Water level and salinity "validation" for wet season, at location "RO Lok On Pai".



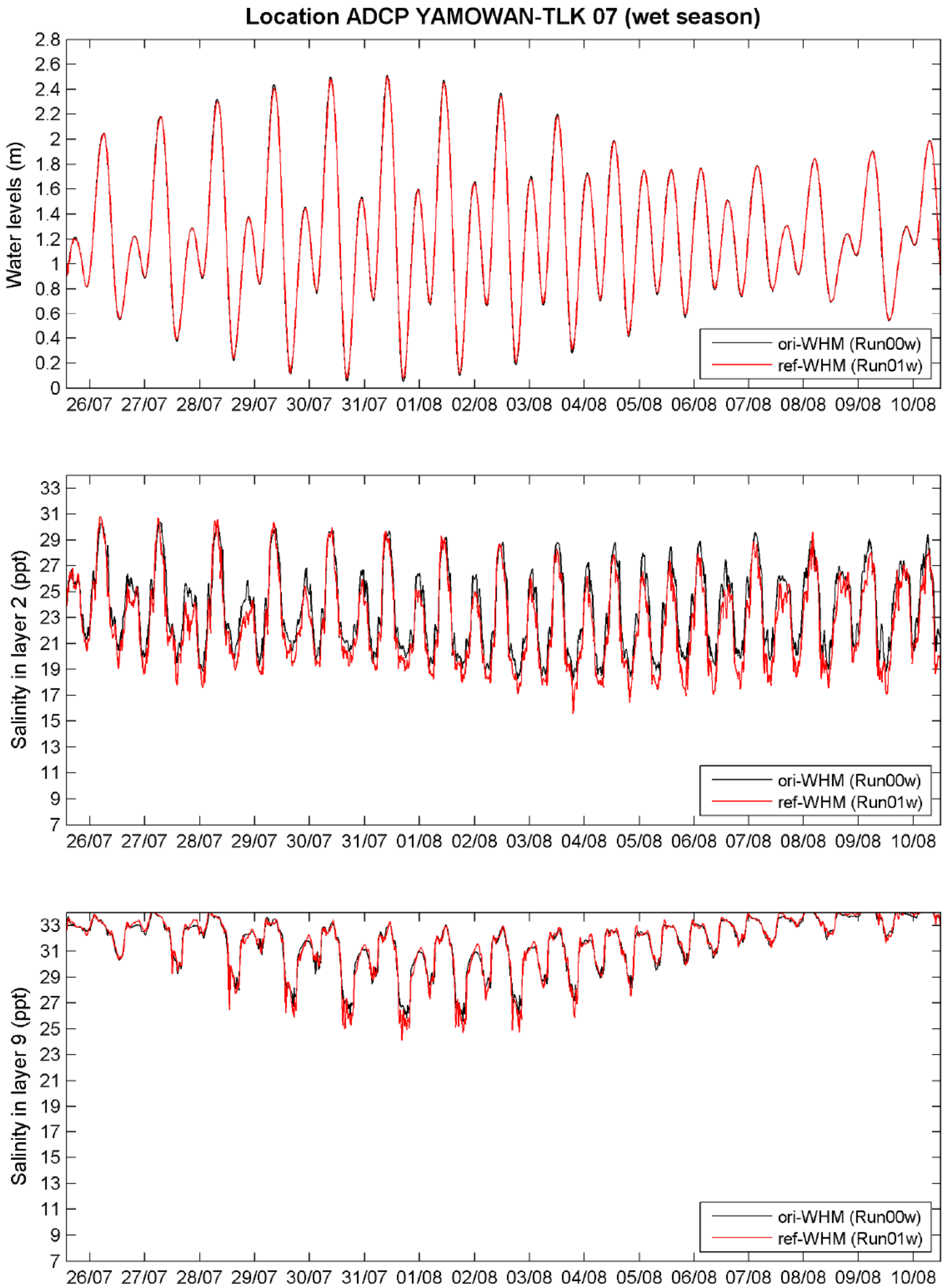
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00w vs. Run01w		
Deltares Delft Hydraulics		

Water level and salinity "validation" for wet season, at location "V station 13".



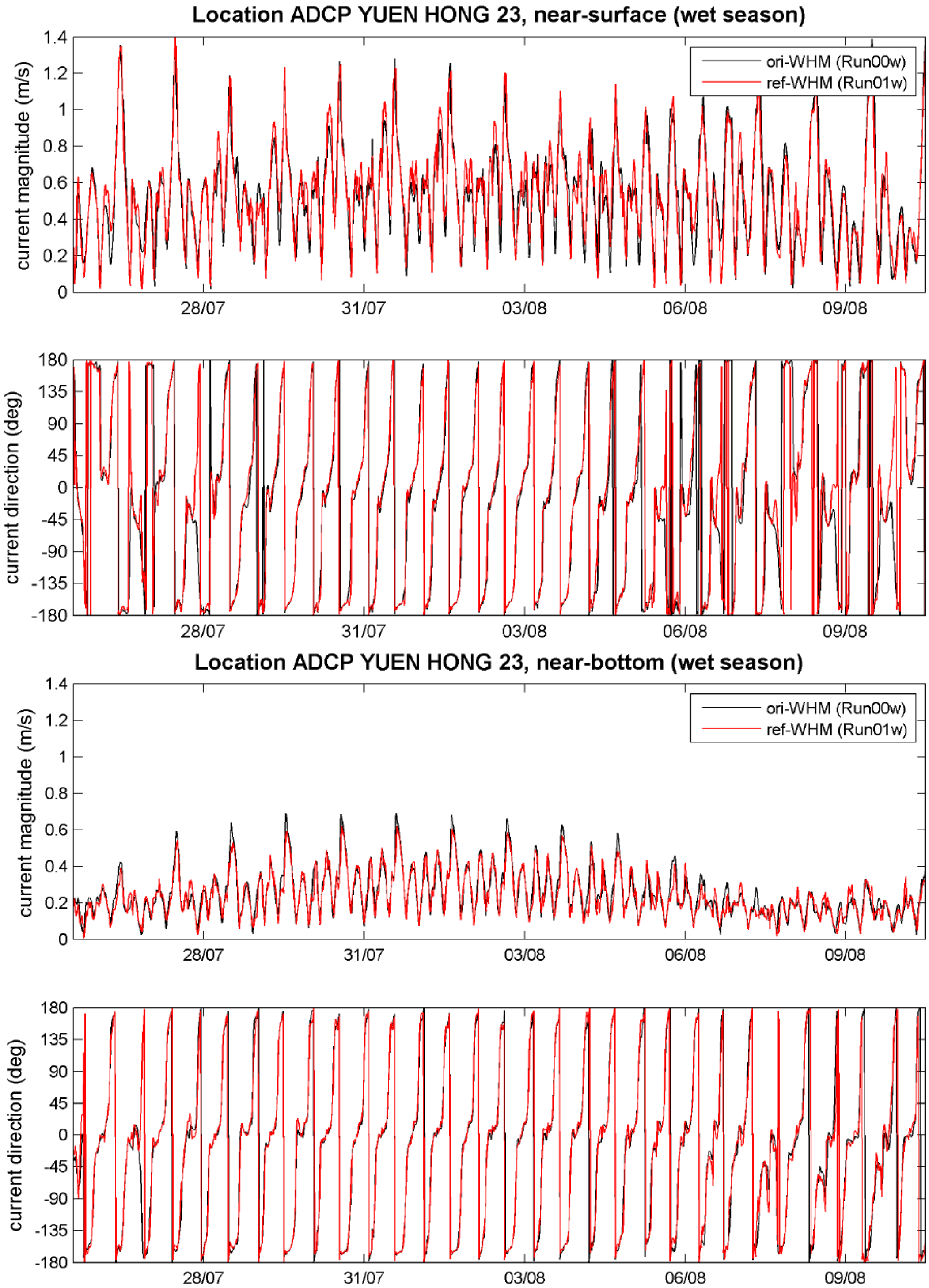
Comparison of Hong Kong model results:
ori-WHM vs. ref-WHM (3x3 DD)
Run00w vs. Run01w

Water level and salinity "validation" for wet season, at location "ADCP Yamowan TLK-07".



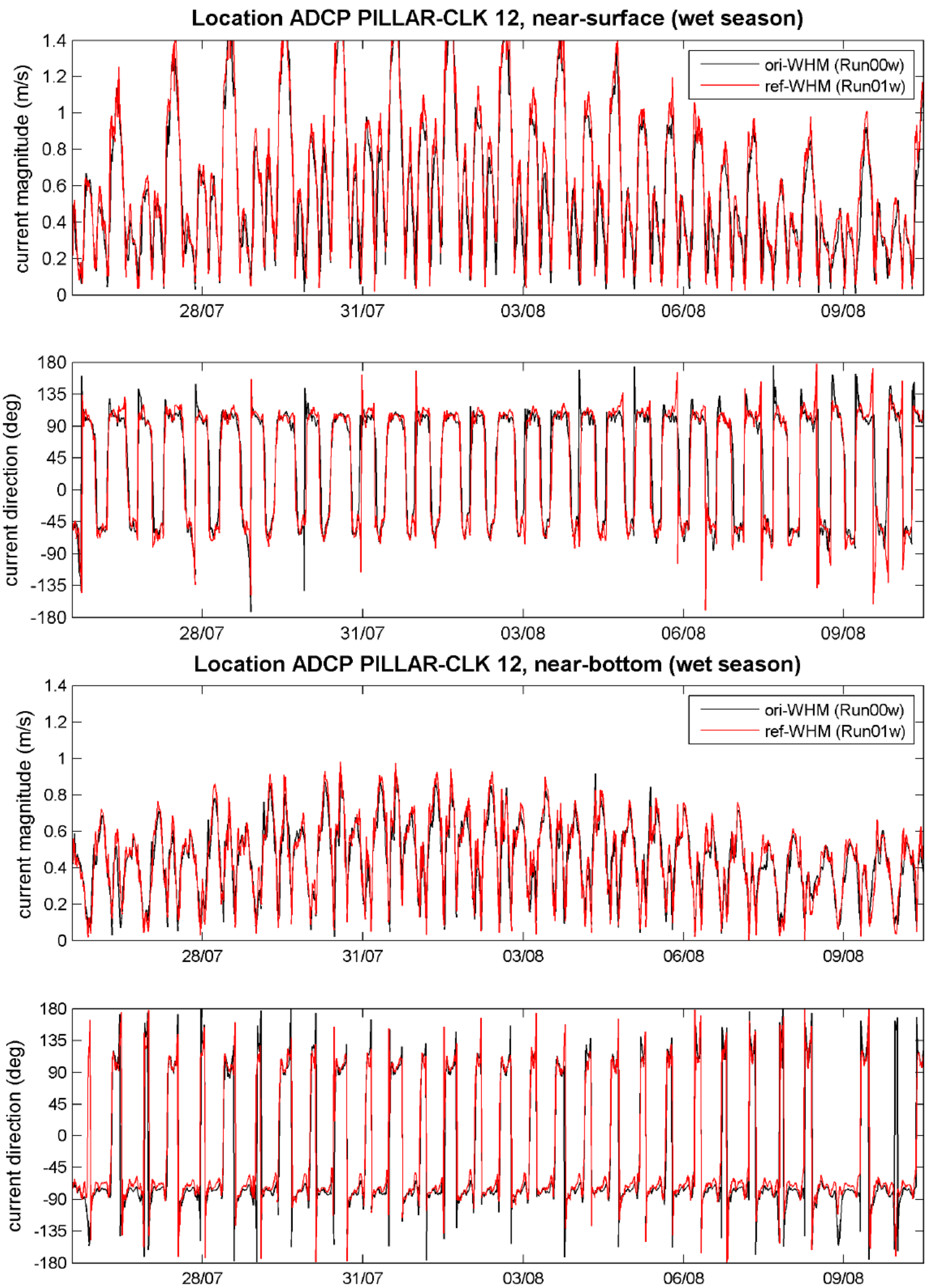
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00w vs. Run01w		
Deltares Delft Hydraulics		

Current magnitude and direction “validation” for wet season, at location “ADCP Yuen Hong 23”.



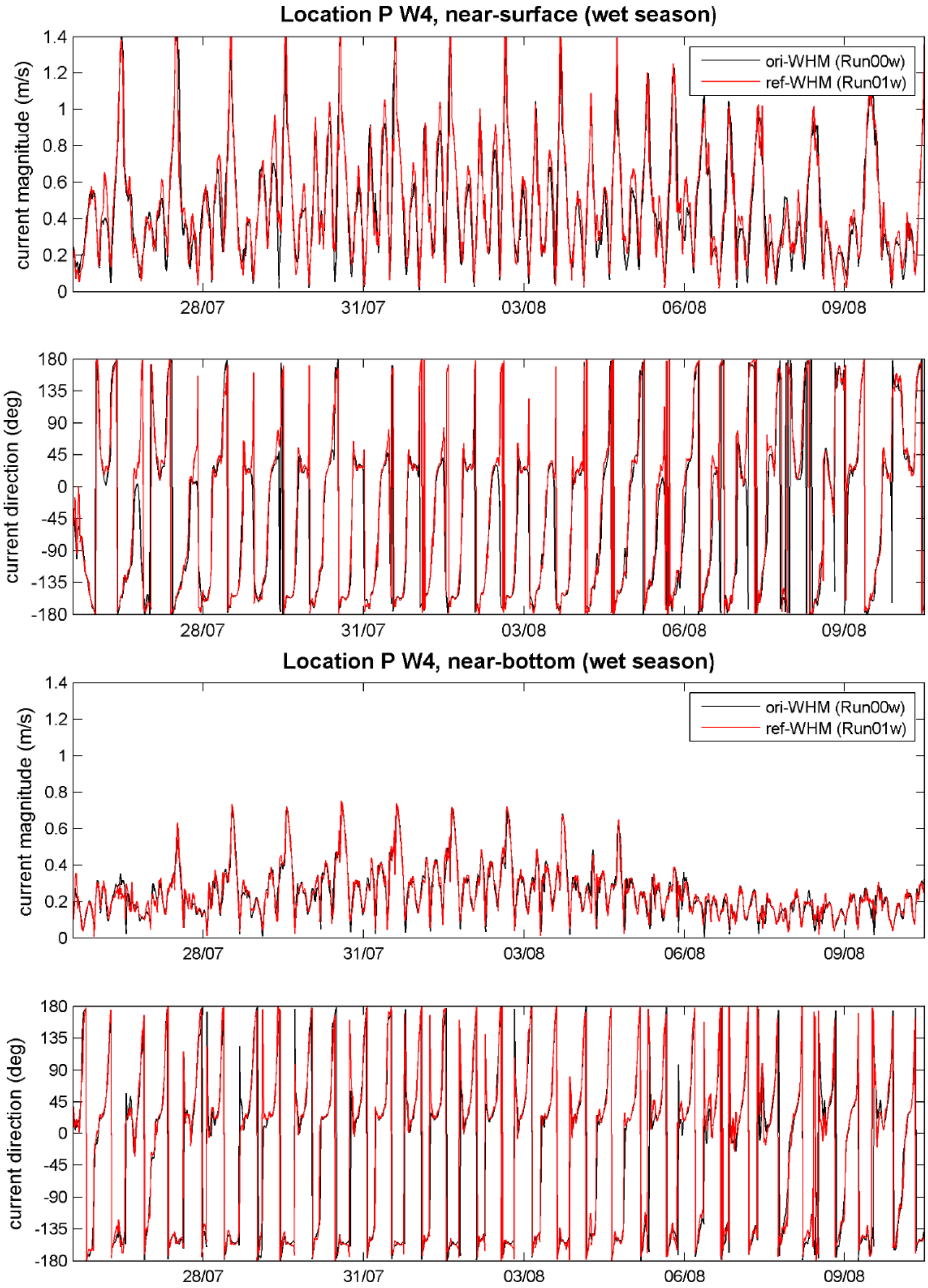
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00w vs. Run01w		
Deltares Delft Hydraulics		

Current magnitude and direction “validation” for wet season, at location “ADCP Pillar CLK-12”.



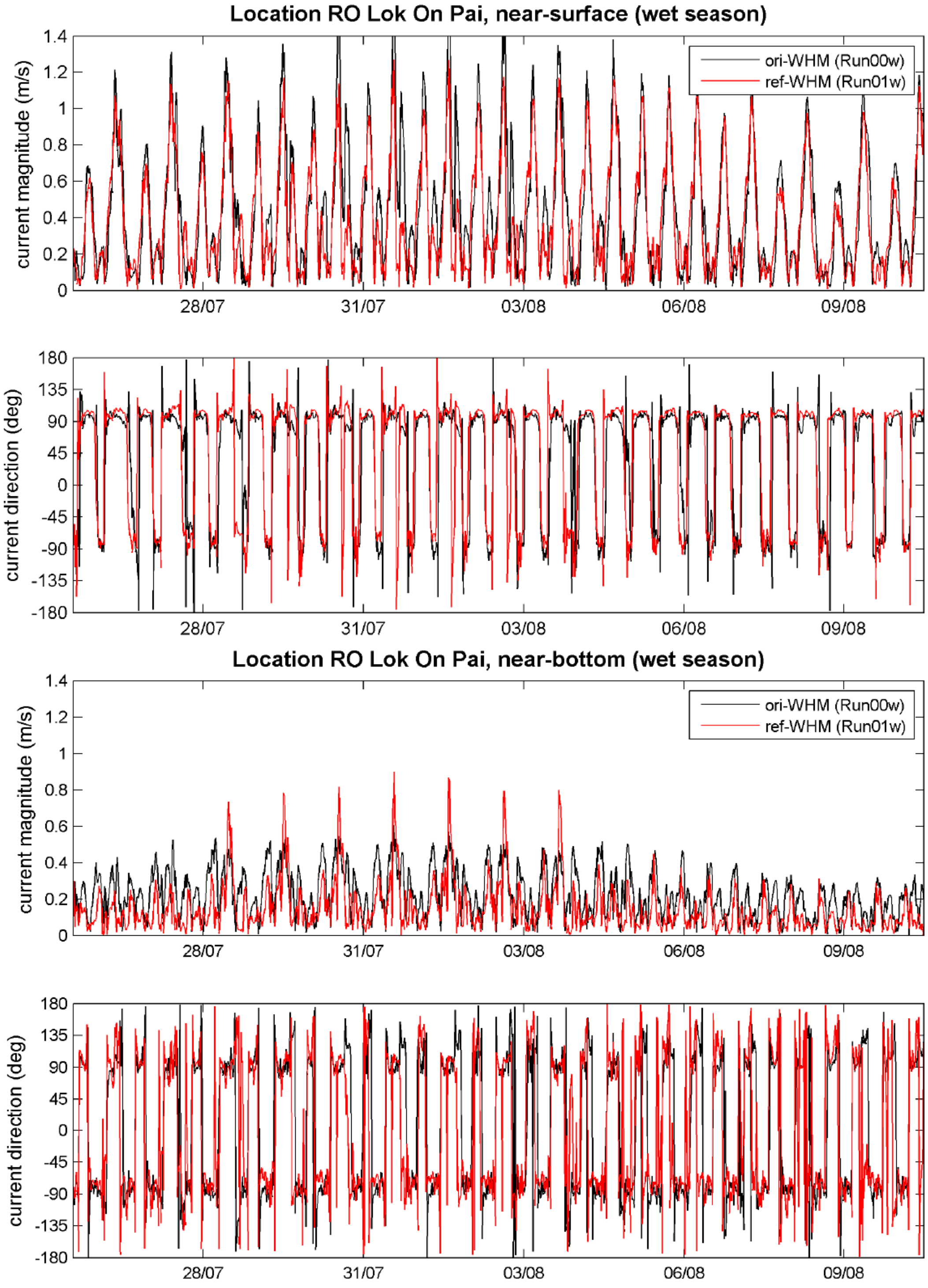
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00w vs. Run01w		
Deltares Delft Hydraulics		

Current magnitude and direction "validation" for wet season, at location "P W4".



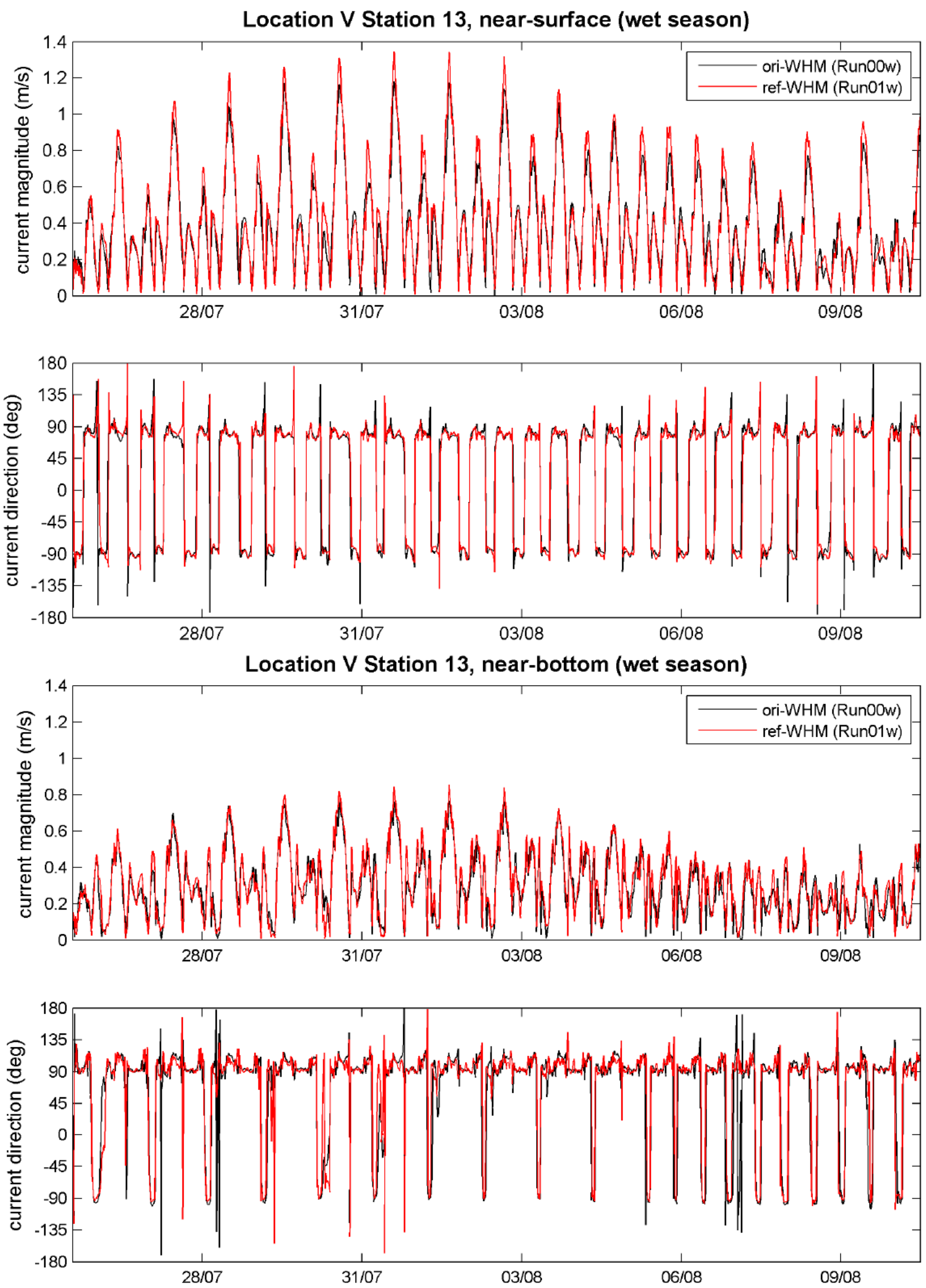
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00w vs. Run01w		
Deltares Delft Hydraulics		

Current magnitude and direction "validation" for wet season, at location "RO Lok On Pai".



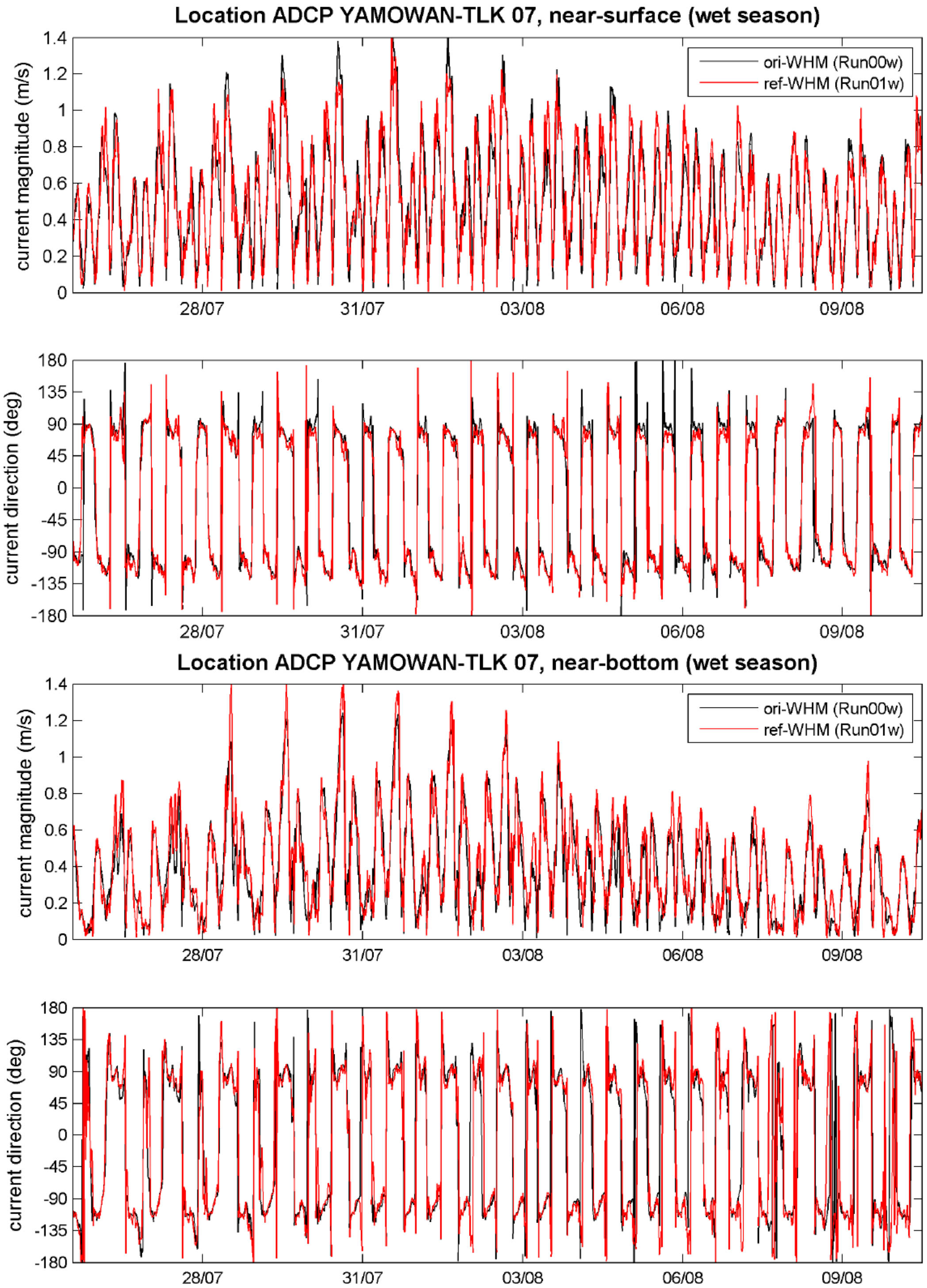
Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00w vs. Run01w		
Deltares Delft Hydraulics		

Current magnitude and direction “validation” for wet season, at location “V station 13”.



Comparison of Hong Kong model results: ori-WHM vs. ref-WHM (3x3 DD) Run00w vs. Run01w		
Deltares Delft Hydraulics		

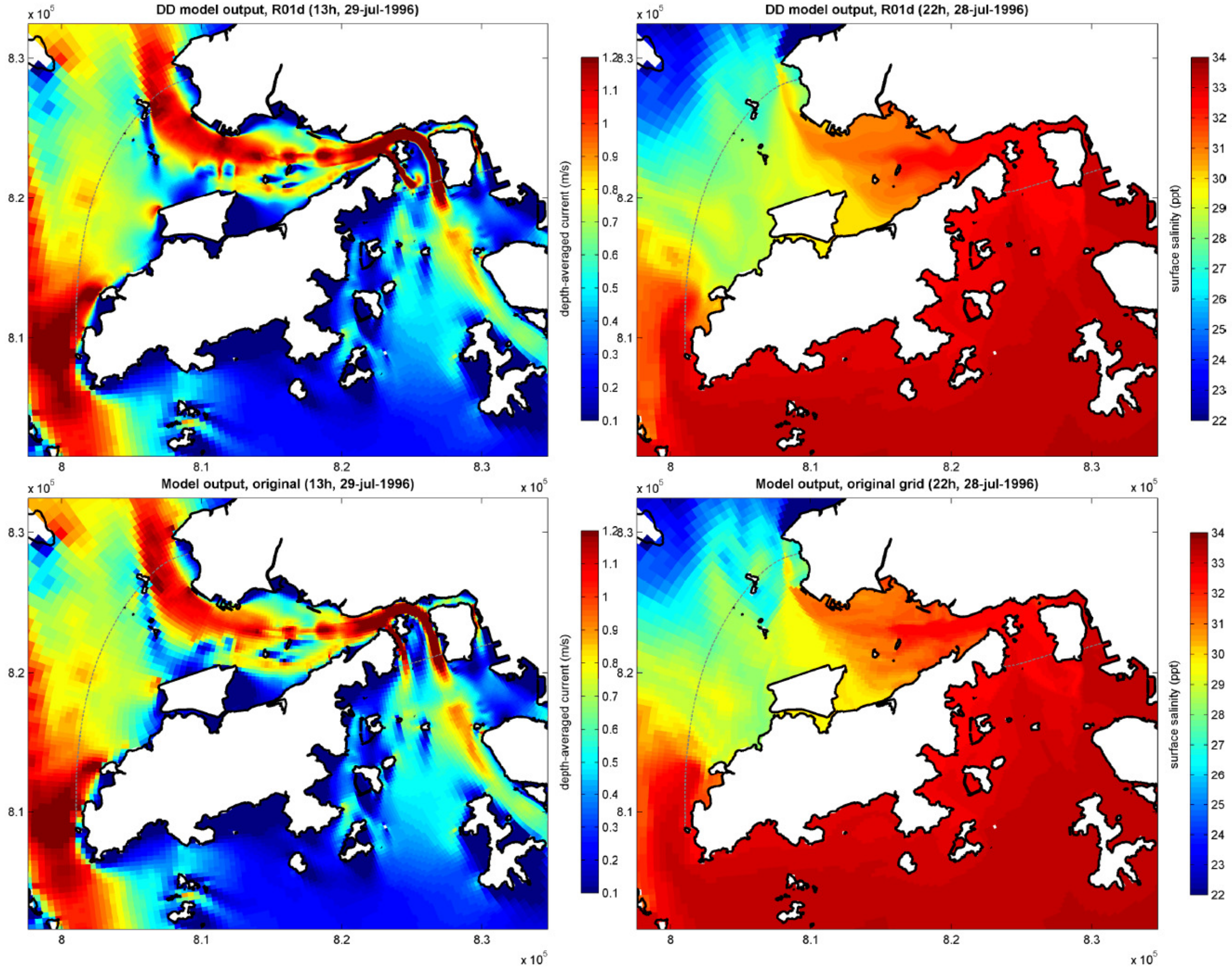
Current magnitude and direction “validation” for wet season, at location “Yamowan TLK-07”.



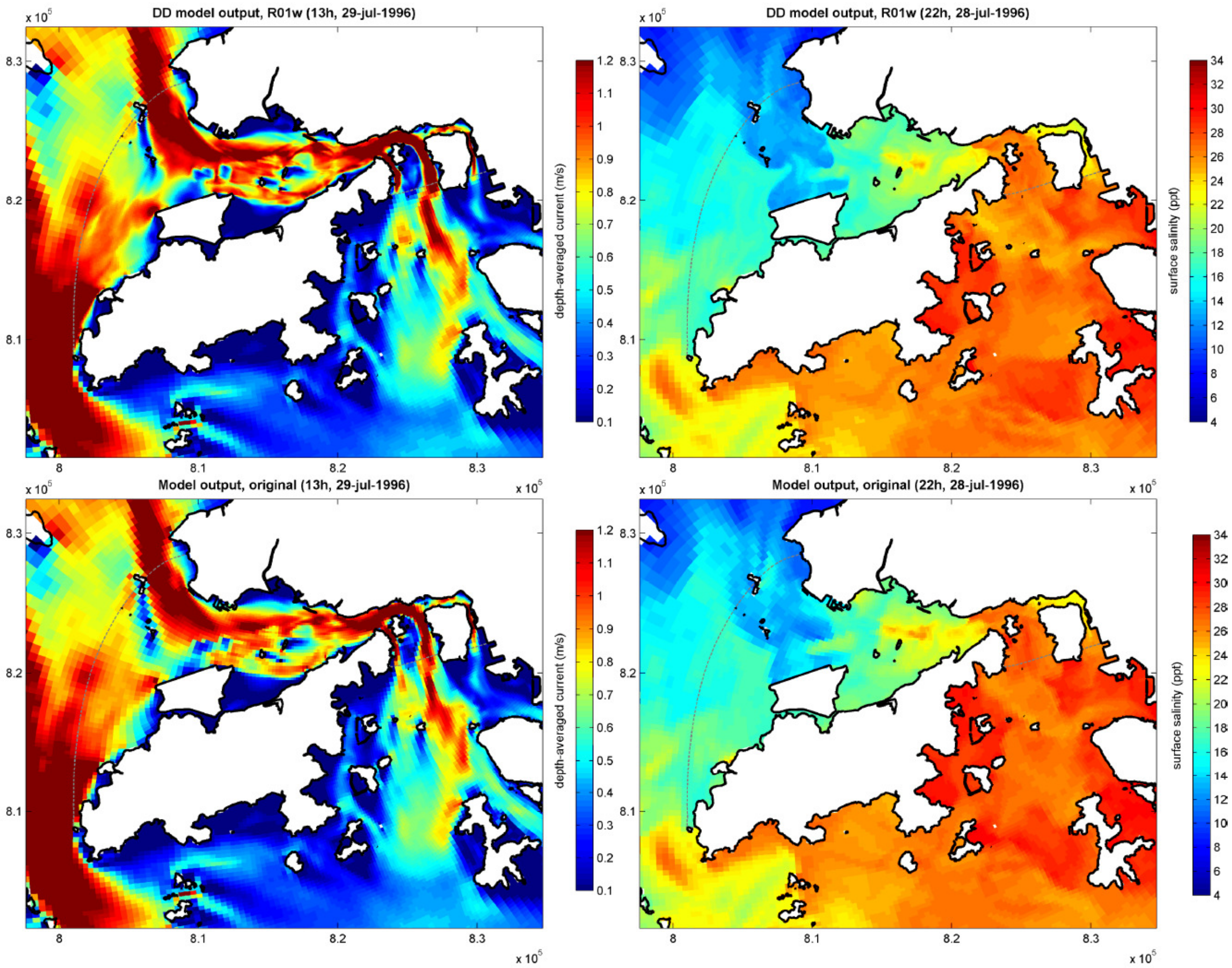
Comparison of Hong Kong model results:
ori-WHM vs. ref-WHM (3x3 DD)
Run00w vs. Run01w

Annex E Model Validation (Comparison Plots)

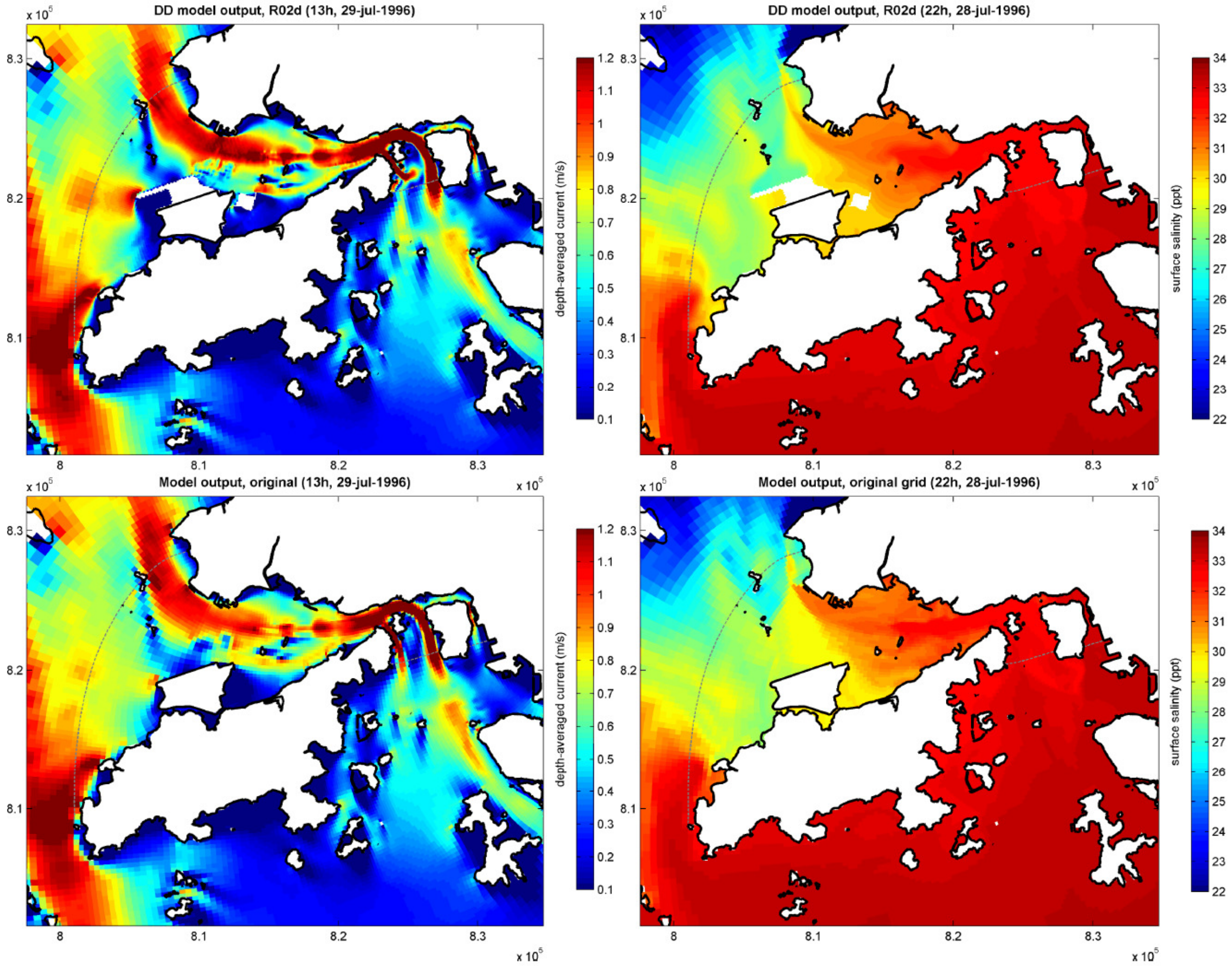
Model Validation (Comparison Plots)



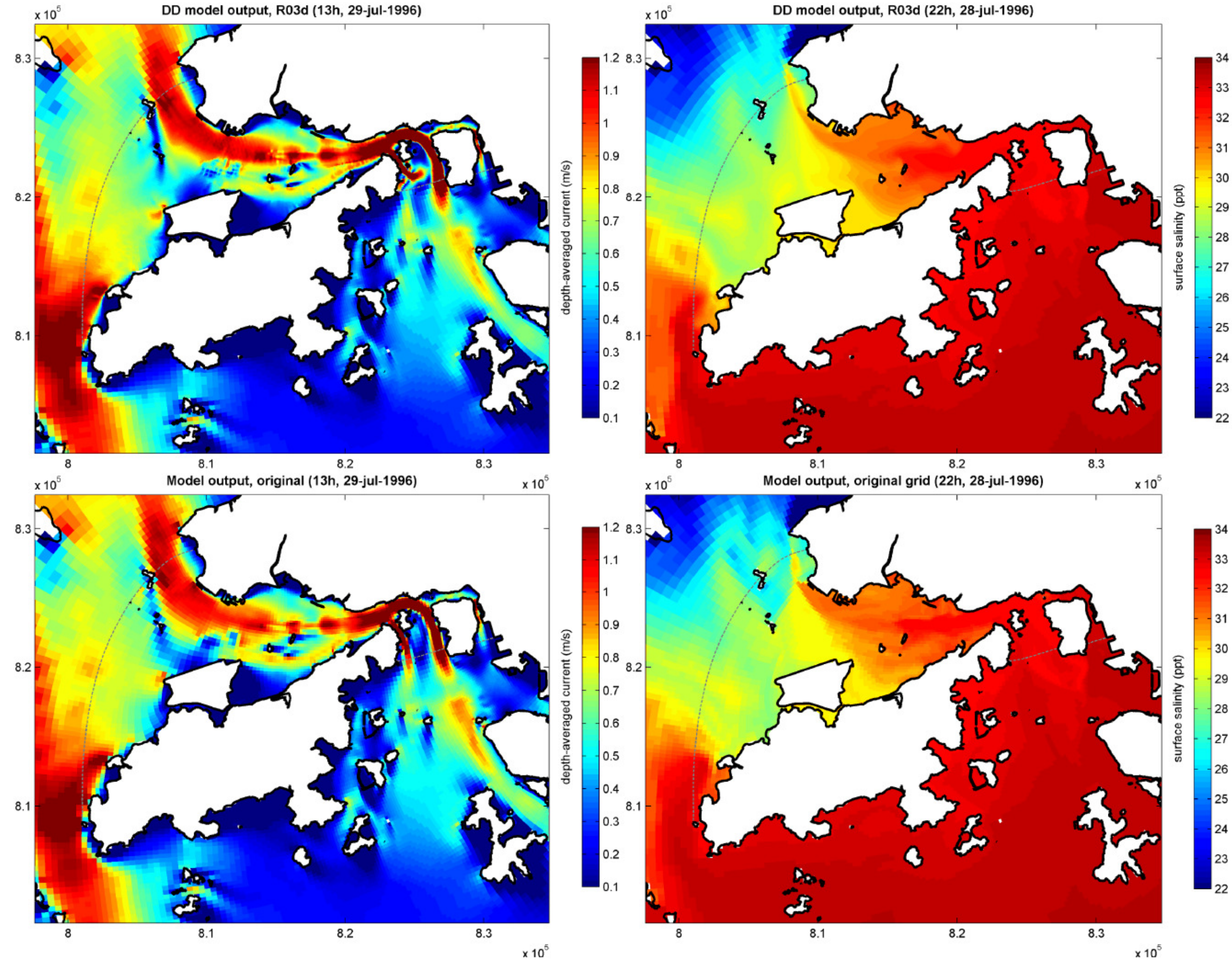
Output comparison between “Run01d” (top) and “Run00d” (bottom). Left panel shows depth-averaged current magnitudes; Right panel shows surface salinities.



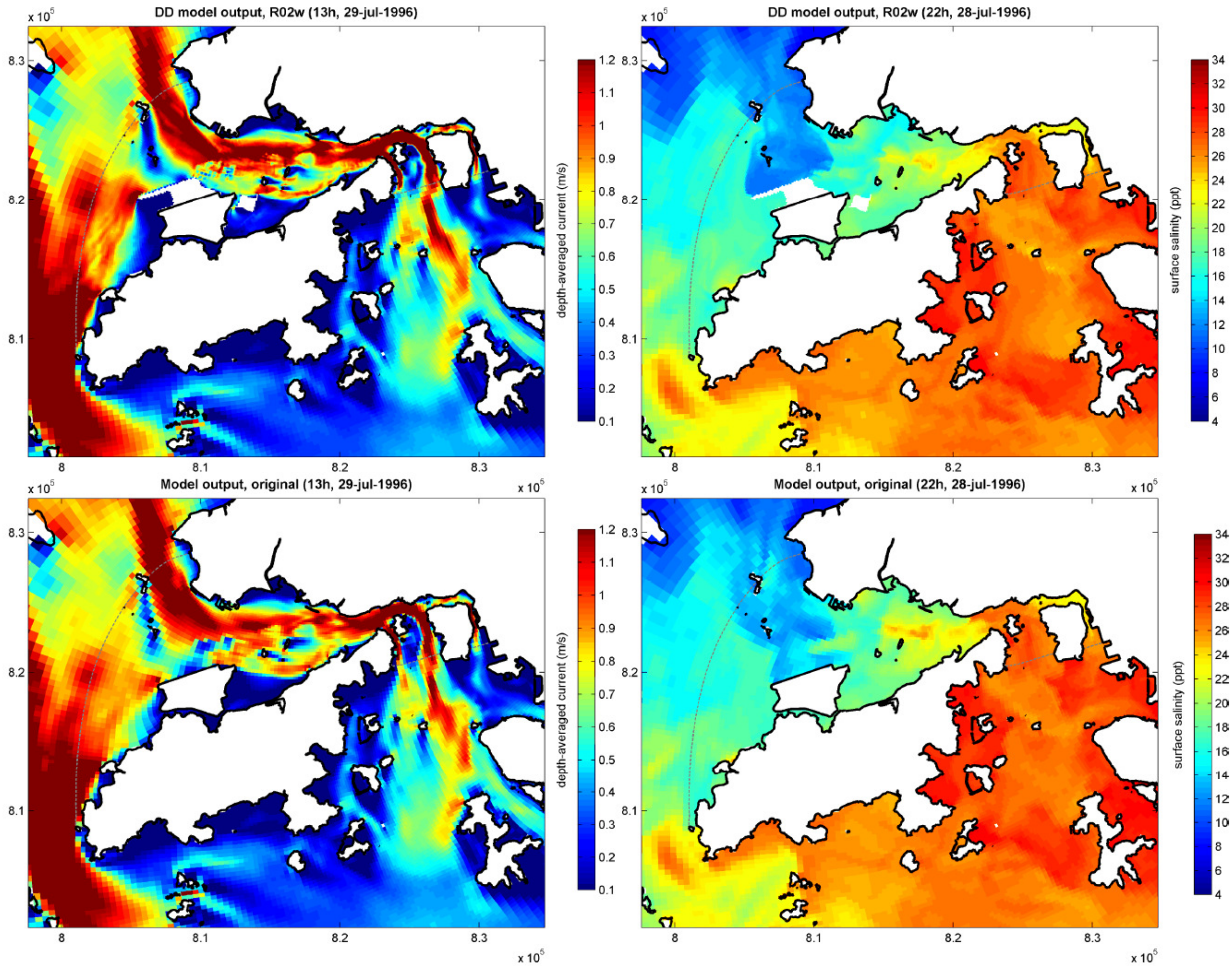
Output comparison between “Run01w” (top) and “Run00w” (bottom). Left panel shows depth-averaged current magnitudes; Right panel shows surface salinities.



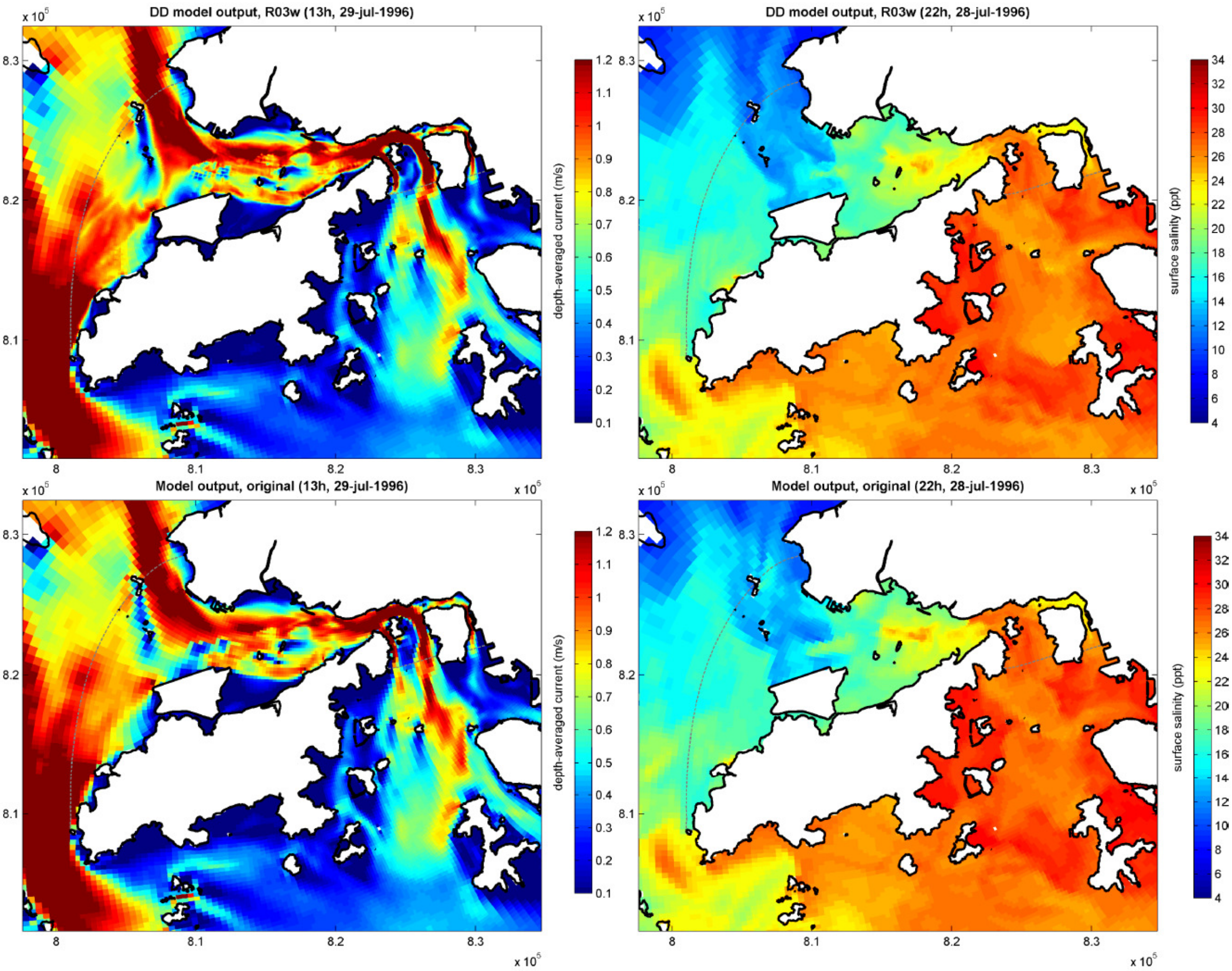
Output comparison for "Run02", dry season scenario. Current magnitudes (left) and Surface salinities (right).



Output comparison for "Run03", dry season scenario. Current magnitudes (left) and Surface salinities (right).



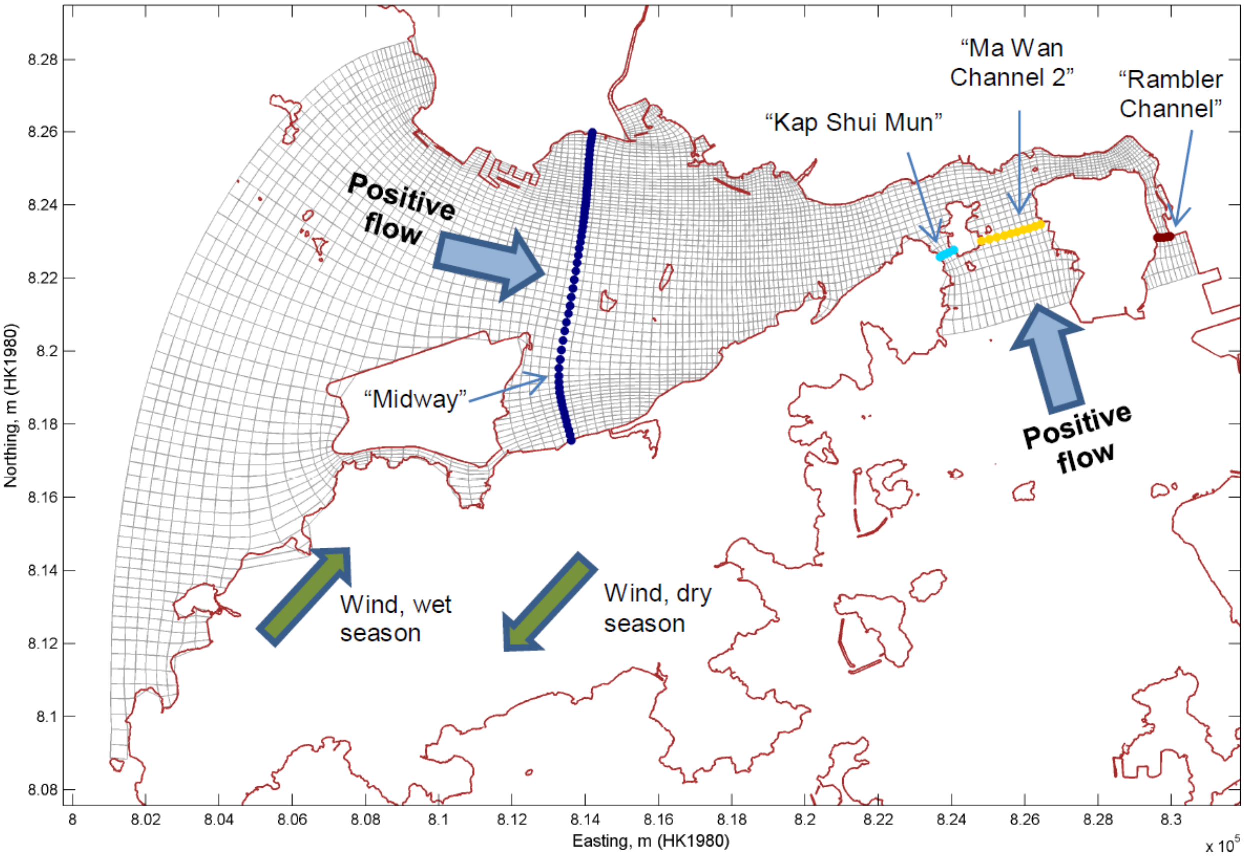
Output comparison for “Run02”, wet season scenario. Current magnitudes (left) and Surface salinities (right).



Output comparison for “Run03”, wet season scenario. Current magnitudes (left) and Surface salinities (right).

Annex F Residual Flow Cross Sections

Residual Flow Cross Sections



Cross-sections used in this section to determine residual discharges. The "intermediate model" grid (see text) is shown in background. Green arrows indicate time- and spatially-constant winds used in each run ("dry" or "wet"). Blue arrows indicate "positive flow" (defined with increasing M,N indices).