# Investigation of WRF configuration for offshore wind resource maps in Japan

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**Abstract**

In Japan, a national project for making offshore wind resource maps is currently conducted by the New Energy and Industrial Technology Development Organization (NEDO). Using the mesoscale model WRF (Weather Research and Forecasting model), which is used for making the maps, several sensitivity tests are performed, changing model configurations regarding the planetary boundary layer (PBL) scheme, four dimensional data assimilation (FDDA), vertical levels, and sea surface temperature (SST). Based on these results, the authors finally determine the WRF configuration which will be actually used to make the offshore wind resource maps in the NEDO project.

**Keyword:** Offshore wind resource assessment, mesoscale model, WRF, wind map, Japan

## 1. Introduction

Since July 2015, the national project for making offshore wind resource maps in Japan has been undertaken by the New Energy and Industrial Technology Development Organization (NEDO). In this project, 500m-gridded offshore wind resource maps are planned to be created for the coastal waters within 30 km from the coast, using the mesoscale model WRF (the Weather Research and Forecasting model). The development target on the map accuracy is within ±5 % in annual mean wind speed at the height of 80 m. The WRF-simulated wind speeds are evaluated in comparison with wind speed measurements from the NEDO offshore meteorological mast located off the coasts of Kitakyushu, Fukuoka Prefecture [1]. This paper describes model sensitivity tests which are carried out to investigate the WRF configuration suitable for making offshore wind resource maps in Japan.

### 2. Data and method

The data used for evaluation of the model configurations are measurements from the offshore meteorological mast at Kitakyushu, shown in Figure 1. On this met mast, cup anemometers are installed at heights from 30 m to 80 m with an interval of 10 m. Here, hourly 10-min average wind speed measurements are used for accuracy verification of WRF-simulated wind speed. The Advanced Research WRF version 3.6.1 are run for two simulation domains with spatial resolutions of 2.5 km and 0.5 km, as shown in Figure 2. Table 1 summarizes the model configurations tested in this study. The tests are conducted in terms of 1) choice of the planetary boundary layer (PBL) scheme, 2) method for applying four dimensional data assimilation (FDDA), 3) configuration of vertical levels, 4) improvement of sea surface temperature dataset, and 5) differences in simulation accuracy between years. The options in each term are described in Table 1. In total, seven WRF simulations are carried out with slightly different model configurations. They are named Case 1 through Case 7 and are compared to each other to find the best model configuration.


Figure 1: NEDO offshore meteorological mast off Kitakyushu City, Fukuoka Prefecture (from NEDO website)

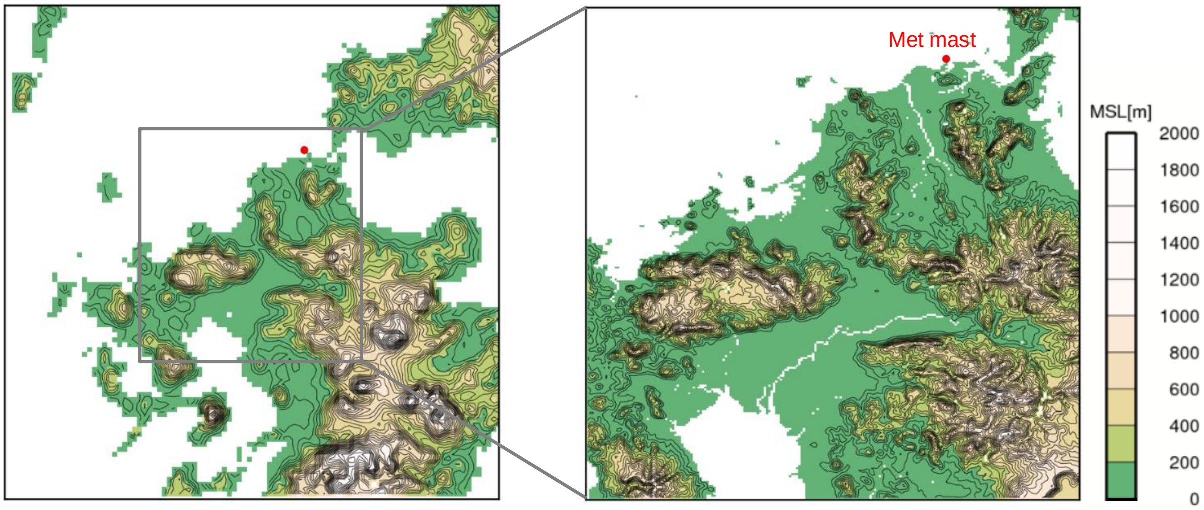


Figure 2: Domains used in WRF simulation (Left: 2.5 km-gridded domain. Right: 0.5 km-gridded domain).

Table 1: Model configuration (Red: options tested in this study)

| | |
|---|---|
| **Model** | Advanced Research WRF (ARW) ver 3.6.1 |
| **Period** | One year for 2013 or 2014 |
| **Input data** | Met: JMA Meso Analysis MANAL (3-houlry, 5 km × 5 km)<br>Soil: NCEL Final Analysis FNL (6-houlry, 1º × 1º)<br>SST: MOSST (daily, 0.05º × 0.05º) or UK Met Office OSTIA (daily, 0.05º × 0.05º) |
| **Grids** | Domain1: 2.5 km × 2.5 km (101 × 101 grids)<br>Domain2: 0.5 km × 0.5 km (201 × 201 grids) |
| **Vertical Levels** | 40 levels (Surface to 100 hPa); Mannual setting (11 m, 38 m, 71 m, 109 m, 151 m, …) or Auto Setting (28m, 97m, 192 m, 311 m, 461 m, …) |
| **FDDA** | Domain1: Enable<br>Domain2: Enable, but excluding below 1,000 m or excluding below the PBL height |
| **PBL options** | MYJ scheme (Mellor-Yamada level 2.5 model), YSU scheme (K-theory with non-local mixing), or MYNN3 scheme (Mellor-Yamada level 3 model) |
| **Other physics options** | Dudhia shortwave scheme<br>RRTM longwave scheme<br>Eta microphysics scheme<br>Mellor-Yamada-Janjic (Eta) TKE PBL scheme<br>Monin-Obukhov (Janjic Eta) surface-layer scheme<br>Noah land surface scheme<br>No cummulus parameterization |

## 3. Results

Table 2 summarizes statistics (bias, root-mean-square-error (RMSE), their relative values to mean wind speed, correlation coefficient (CC), and ratio of observed and simulated standard deviations) on the accuracy of WRF-simulated wind speeds at the height of 80 m. Figure 3 shows monthly and annual biases in the WRF-simulated 80m-height wind speeds. Figure 4 depicts annual biases at each measurement height, meaning vertical profiles of annual bias from 30 m to 80 m.

First, Cases 1, 2 and 3 are compared to examine which PBL scheme has the best accuracy. The YSU scheme (Case 2) exhibits large biases at all heights, as found in Figure 4. The MYNN scheme (Case 3) seems to have a problem in vertical profile, showing large biases at lower heights in spite of the lowest bias at 80 m. Compared to these two cases, the MYJ scheme is found to have high and stable accuracies as a whole. Thus, the MYJ scheme is determined to be used as a PBL option.

Second, the method of how to disable FDDA in the PBL is discussed by comparing Cases 1 and 4. In Case 1, FDDA is disabled below the fixed height of 1 km in the domain 2, because the height of 1 km can be recognized as a mean PBL height. On the other hand, in Case 4, FDDA is disabled below the PBL height calculated by the PBL scheme itself. In this case, the PBL height temporally varies from 0 m to a few kilometers. All the statistics in Table 2, Figure 3 and Figure 4 show that Case 4 is more accurate than Case 1. Accordingly, it is determined to disable FDDA below the PBL height calculated with the PBL scheme.

Table 2: Accuracy comparison of WRF-simulated 80m-height wind speeds among Cases 1 to 7

| | | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 | Case 7 |
|---|---|---|---|---|---|---|---|---|
| **1) PBL** | | MYJ | YSU | MYNN | MYJ | MYJ | MYJ | MYJ |
| **2) FDDA** | | 1km | 1km | 1km | PBLH | PBLH | PBLH | 1km |
| **3) η-level** | | Mannual | Mannual | Mannual | Mannual | Auto | Auto | Mannual |
| **4) SST** | | MOSST | MOSST | MOSST | MOSST | MOSST | OSTIA | MOSST |
| **5) Year** | | 2013 | 2013 | 2013 | 2013 | 2013 | 2013 | 2014 |
| **OBS Ave.** | **(m/s)** | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 6.98 |
| **Bias** | **(m/s)** | 0.39 | 0.50 | 0.37 | 0.24 | 0.28 | 0.45 | 0.2 |
| | **(%)** | 5.6 | 7.1 | 5.3 | 3.4 | 4.0 | 6.4 | 3.3 |
| **RMSE** | **(m/s)** | 2.03 | 2.09 | 2.09 | 1.96 | 1.97 | 2.08 | 2.06 |
| | **(%)** | 29.0 | 29.8 | 29.9 | 28.0 | 28.2 | 29.7 | 29.6 |
| **Correlation** | **( - )** | 0.851 | 0.848 | 0.843 | 0.860 | 0.857 | 0.847 | 0.853 |
| **$SD_{WRF}$ / $SD_{OBS}$** | **( - )** | 0.940 | 0.960 | 0.953 | 0.958 | 0.944 | 0.959 | 1.033 |

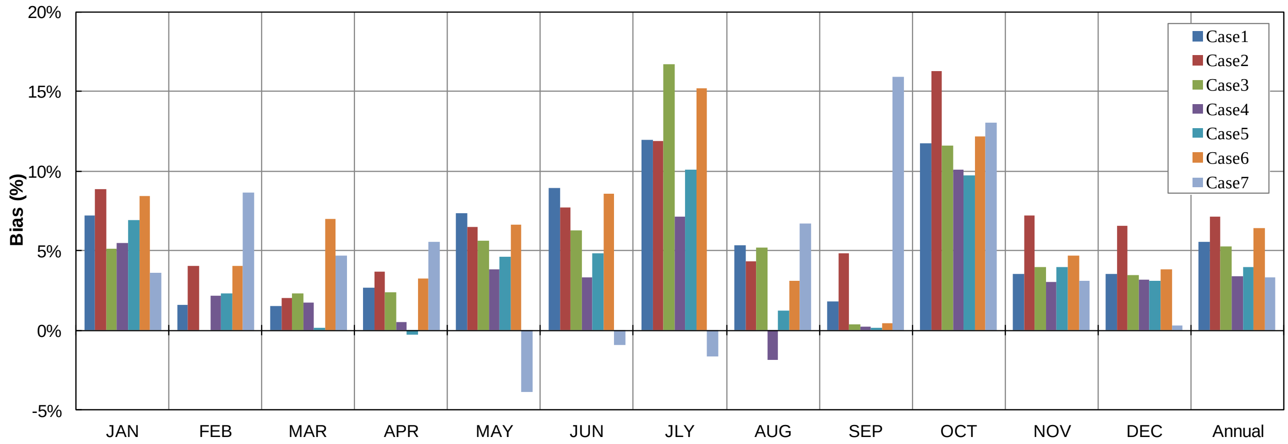


Figure 3: Monthly and annual biases in WRF-simulated 80m-height wind speeds for all cases.

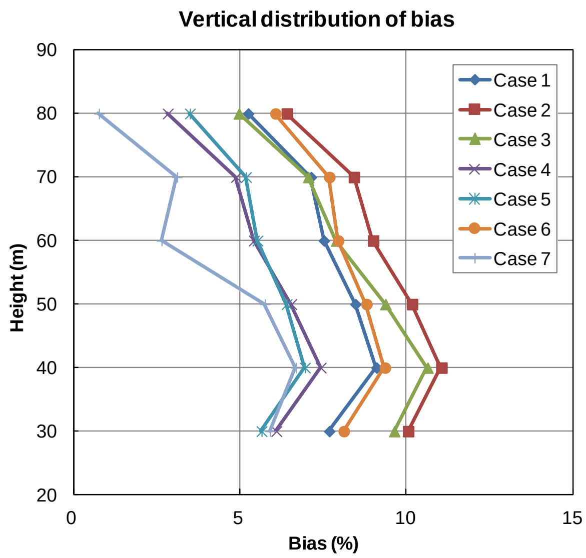


Figure 4: Biases in annual mean wind speed at measurement heights from 30 m to 80 m for all cases.

Third, two cases with manually (Case 4) and automatically (Case 5) configured vertical levels are compared. Heights of the lowest five levels are 11 m, 38 m, 71 m, 109 m and 151 m for Case 4, while they are 28 m, 97 m, 192 m, 311 m and 461 m for Case 5. The differences between these two cases are found to be very small, in spite of the large differences in heights of the lowest five levels. This means that the accuracy of wind speed in the layer from the surface to 80 m does not greatly depend on the configuration of vertical levels. But, since it is also fact that the accuracy of Case 4 is slightly better, further study should be planned to determine how to set up vertical levels manually.

Fourth, two kinds of input data of sea surface temperature are compared. Case 6 uses UK Met Office's Operational Sea Surface Temperatures and Sea Ice Analysis (OSTIA), while Case 5 uses the MODIS (MODerate resolution Imaging Spectroradiometer)-based SST (MOSST), developed by the National Institute of Advanced Industrial Science and Technology (AIST) and Kobe University [2]. MOSST is characterized by the 11-day running average applied in order to interpolate missing values due to cloud coverage. The temporal running average has an advantage that a SST field can maintain a high spatial resolution, which is especially effective for seas with spatially variable SSTs like Japanese coastal waters. As expected, the comparison result shows that Case 5 using MOSST is found to have a higher accuracy than Case 6 using OSTIA.

The afore-mentioned four tests indicate that Case 4 is the best configuration. Finally, the same configuration is tested for another year of 2014 in Case 7. The statistics are found to be almost the same level as those in Case 4. The annual bias is 3.4 % for 2013 and 3.3 % for 2014, indicating that the WRF simulation with the configuration of Case 4 can achieve the development target accuracy of ±5 % for both years.

## 4. Conclusions

Based on the results from the model sensitivity tests in this study, the WRF configuration suitable for offshore wind simulation in Japanese coastal waters are summarized as follows.

1) Mellor-Yamada-Janjic (MYJ) scheme seems to be the best of the PBL schemes.
2) In the domain 2 (0.5km-grid domain), FDDA should be disabled below the PBL height calculated by the PBL scheme.
3) Though there is still room for how to set up vertical levels manually, it is found that the configuration of the vertical levels does not greatly affect the accuracy of simulated wind speed.
4) The use of a new SST product MOSST as input can improve the accuracy of surface wind speed in the WRF simulation.

Though the result is not shown here, effectiveness of the configuration of Case 4, regarded as the best configuration in this study, is confirmed for both 2013 and 2014 at Kitakyushu. In addition, it is also found that the same configuration exhibits an annual bias of 0.6 % for the other NEDO met mast at Choshi. This means that by setting up simulation conditions properly and selecting higher-quality input data, the WRF simulation can achieve a target bias of ±5 % in annual mean wind speed at a hub height (80m) even in Japanese coastal waters, where it is known that the accuracy of mesoscale modelling cannot be higher compared to Europe due to their complex topography and wind climate [3].

The best model configuration found in this study will be used in the ongoing NEDO project for making offshore wind resource maps in Japan.

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