Original Paper

Vertical Flow Simulations Using the Mesoscale Model to Assess Impacts on Soaring Birds around Offshore Wind Turbines

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Vertical velocity of the atmosphere around a floating offshore wind turbine situated in marine areas near Kaba Island, Goto City, Nagasaki Prefecture was predicted using the mesoscale meteorological model that can replicate not only ridge lift but also thermal lift. In addition, the possibility of impacts on soaring birds was investigated using vertical flow. As a result of the simulation, thermal lift and ridge lift of the area were accurately replicated. Around the coast of Kaba Island, ridge lift mainly prevailed, but almost no vertical flow was predicted above the marine waters near the wind turbine. Observations from a pre-construction survey of raptores such as ospreys and falcons revealed these birds frequently soar around the coastal areas of Kaba Island rather than in the waters where the turbine is installed, so the possibility of birds colliding with the turbine or using vertical flow from the turbine is very low.

Key Words

Mesoscale model, Offshore wind turbine, Bird collision, Vertical flow, Thermal lift

長崎県五島市に位置する浮体式洋上風車の設置海域及び近傍の杣島周辺を対象域として、地形風のみならず熱対流も再現可能なメソ気象モデルを用いて大気の鉛直流の発生傾向を予測し、鉛直流を利用する鳥類への影響の可能性について検討した。シミュレーションの結果、対象域の熱対流および地形風が精度よく再現することができた。杣島の海岸線付近においては主に地形風による鉛直流が卓越しているが、設置海域付近は鉛直流がほぼ発生していないことが予測された。一方、対象域に出現するミサゴ・ハヤブサ等猛禽類の事前調査結果によれば、設置海域よりむしろ杣島海岸線付近でソアリング（滑空）行動を頻繁に行っていることから、鉛直流を利用する鳥類が洋上風車へ衝突する可能性は小さいものと考えられた。

キーワード

メソ気象モデル、洋上風力発電、バードストライク、鉛直風、熱対流

1. Introduction

In Japan, a country with huge areas of marine water, offshore wind power is a highly expected source of renewable energy. The Ministry of Environment is now conducting the first demonstration experimental project for floating offshore wind turbine in Japan. Small testing turbine (100 kW) was constructed in 2012, and then an actual testing turbine (2 MW) was constructed in 2013 off the coast of Kaba Island, Goto City in Nagasaki Prefecture¹⁾. In this project, surveys for environmental impact

assessment of birds, marine organisms, etc. have been conducted to study the effects of the floating wind turbine on the environment. Surveys of some species of raptores have been carried out near Kaba Island²⁾.

Bird collisions are considered one major concern with wind turbines. Raptores are known to use vertical air flow³⁾, and in the case of the griffon vulture (*Gyps fulvus*), bird collisions with turbines constructed in the mountains have been reported, when these birds use the vertical flow and soar close to the turbines⁴⁾. Also, replicate experiments with the mesoscale model conducted on an actual onshore wind farm site showed that birds flock at the same point,

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where the simulation showed vertical air flow occurs⁵⁾.

Above the sea, geographical effects can be considered small, but the characteristics of air flow vary with changes in season and distance from the coast. Almost no studies have examined the relationships between vertical flow around the offshore turbines and birds using numerical simulations. Therefore, we analyzed vertical flow for assessing the possibilities of bird impacts around offshore wind turbine in a quantitative and efficient way in this study. The place, time and wind conditions of vertical flow were predicted using a mesoscale meteorological model that can replicate not only ridge lift but also thermal lift, and we examined the possibility of impacts from offshore wind turbine on birds such as raptors that soar mainly with vertical air flow.

2. Area and Methods

The targeted area was near Kaba Island and had an area of 40-km square with installation of a floating wind turbine in the center (Fig. 1). One year of atmospheric vertical flow was calculated using the mesoscale meteorological model WRF (Weather Research and Forecasting), which was designed as a next generation model after NCAR-MM5 and has been widely used around the world. WRF is considered as a valuable tool for not only meteorology but also wind analysis because its dynamic core uses high-order accurate discretization schemes for time and space. This difference in the numerical scheme for the model dynamics, not in the cloud microphysics, allows WRF to use a more detailed vertical velocity field than

Table 1 Calculation conditions and datasets

Model	WRF(ARW) ver. 3.4
Period	1 year (1 Aug 2011 - 31 Jul 2012)
Terrain 1	Horizontal resolution : 3.6 km
Terrain 2	Horizontal resolution : 1.2 km
Terrain 3	Horizontal resolution : 0.4 km
Vertical Layer	35 Layers
Meteorological data	JMA-GSM (Resolution: 20 km) NCEP-FNL (Resolution: 100 km)
Sea Surface Temperature	NCEP-RTGSST (Resolution: 10 km)
Microphysics	WRF Single-Moment 6-class
Radiation (Longwave)	RRTM
Radiation(Shortwave)	Dudhia
Surface Scheme	Pleim-Xiu
Land Surface Model	Pleim-Xiu Land Surface
Planetary Boundary Layer	ACM2 PBL
Cumulus Parameterization	-

MM5⁶⁾. Computational domain was scaled down through 3 steps of nesting. Table 1 shows the main calculations conditions and datasets. The study period was set as one year (August, 2011 - July, 2012), because meteorological observation data was available for validation of the numerical simulation for that period.

3. Validation of Simulation

The simulated results were validated using the wind conditions and temperature data of the wind observation tower set at W2 in Kaba Island (AGL: 40 m) and the wind conditions data recorded from the Doppler Lidar (AGL 150 m) at W1 (Fig. 1). The correlations between the simulated results and the actual data for both wind velocity (Doppler Lidar: BIAS=0.447, RMSE=1.901, R=0.93), wind direction and temperature (BIAS=-1.415, RMSE=1.931, R=0.99) were high (Fig. 2), indicating the simulation results were replicated accurately for the wind and thermal conditions of the data.

4. Results

4.1 Thermal lift replication

Direct cause of thermal lift is the heating effect of solar radiation. Marine water surface has a high reflection (albedo) and high specific heat, so thermal lift does not occur as much as from the ground surface. The model showed that thermal lift occurs above the ground (island) when solar radiation is strong and wind is low.

Stability of the air layer is often determined by potential temperature. Potential temperature is temperature adiabatically converted to standard air pressure (normally 1000 hPa), and is used as a thermodynamically conserved quantity for dry air in many theories. Fig. 3 shows the potential temperature distributions when thermal lift

Fig. 1 Elevation map around the study area

Fig. 2 Comparison between observed data and the results of WRF analysis (30 minutes interval instantaneous value)
Top: Wind velocity [m/s], Middle: Wind direction [Degrees] (Lidar: 150 m AGL) (1 Feb - 14 Feb at W1), Bottom: Ta. [degree C] (Observation tower: 40 m AGL) (One year observation at W2)

occurred in the study area. The horizontal axis in this figure corresponds with the red dashed line at the top of Fig. 4, so the figure shows a N-S cross section that includes the wind turbine. The potential temperature

Fig. 3 Distribution of potential temperature with occurrence of thermal lift (weak wind, sunny)
Vertical axis shows the height [m] and horizontal axis shows the latitude. Shade shows potential temperature [K] and vector shows velocity and direction of wind

above the ground is relatively high compared to above the seawater, indicating an instable stratification state. On the other hand, vertical flow occurred along the coast where the potential temperature was higher relative to the sea, meaning this vertical flow was calculated as thermal lift in the simulation. Above the sea, a relatively low and stable potential temperature is distributed, so considering the thermal characteristics of the environment, thermal lift rarely occurs above the sea.

Meteorological conditions that create thermal lift are limited, so thermal lift seldom occurs. In addition, thermal lift occurs on even fewer occasions in the marine areas where the wind turbine was constructed. Therefore it can be considered that no impacts appear to occur from thermal lift.

4.2 Ridge lift replication

The simulation results when horizontal wind (SE direction) prevails showed that ridge lift occurs following the topography of the land. Upward ridge lift occurred in the windward (SE) side and downward ridge lift occurred in the leeward side (NW), simulated with the model (Fig. 4 (bottom)). Generally speaking, upwind area widened in the northern side of the island when northern winds prevailed, and upwind area widened in the southern area of the island when southern winds prevailed. This correlates with existing reports showing typical air current patterns with the topography (*e.g.* Oke, 1987⁷⁾). Also, when ridge lift occurs, horizontal velocity and vertical wind flow is proportional, this is opposite to the thermal lift that occurs when winds are weak (Fig. 4 (bottom)).

Fig. 4 Examples of vertical flow analysis (Top: thermal lift at low wind, sunny weather; Bottom: ridge lift when South-east wind prevails. Red shade shows up-flow, blue shade shows down-flow, and the vector shows horizontal wind)

5. Discussion

5.1 Annual relationship between vertical and horizontal flow

The monthly frequency of vertical flow was estimated from the results of the simulation for 1 year (Fig. 5 (top)). Classification of the vertical flow was upwind (over +0.5 m/s: Red), still (-0.5 ~ +0.5 m/s: White) and downwind (under -0.5 m/s: Blue). Reference area is the marine area shown with a black spot near Kaba Island in Fig. 1 and Fig. 3 (North of the offshore wind turbine).

As a result, upwind, downwind and still conditions occurred every month in the reference area with upwind prevailing in summer and downwind prevailing in winter. On the other hand, upwind and downwind rarely occurred in the marine areas where the turbine was constructed. Many of the birds used for analysis are diurnal (such as osprey), so the analysis was conducted during the daytime

(9:00-17:00) only.

Also, Fig. 5 (bottom) shows the scatter diagram between horizontal wind velocity [horizontal] and absolute vertical wind velocity [vertical]. In the area where the offshore wind turbine is constructed, no correlation was observed between the horizontal velocity and vertical velocity. Clearly vertical flow did not occur. On the other hand, in the reference area, correlations between horizontal and vertical wind velocity was observed, suggesting on occasions of weak wind around 0-5 m/s, a vertical wind of 0.5 - 1.0 m/s occurs. This result shows that the ridge lift that flows along the coastal cliffs has a larger impact than thermal lift, and the vertical flow occurs when the slope of the approximate equation is large. In other words, the occurrence of vertical flow is accentuated when the slope of the approximate equation is large.

Fig. 6 shows the estimated horizontal distribution of the slope value of the approximate equation of Fig. 5 (bottom) in the surrounding area of the wind turbine site. This shows that vertical flow occurs from the coastal area of Kaba Island to inland areas mainly caused by ridge lift. It appears thermal lift occurs on more occasions above land than sea, but differences in the frequency of occurrence shown in Fig. 6 indicates impacts from ridge lift are dominant.

5.2 Relationship between vertical flow prediction and birds

The impact area of vertical flow from the ridge lift in this marine area, it distributes within 1 km from the coast, but impacts appear considerably minute beyond that distance. This correlates with the results of Fig. 5 (top). That is, impacts from the vertical flow from ridge lift are small beyond 1 km from the coast of Kaba Island. The offshore wind turbine is situated further than 2 km south of the island, so vertical flow does not occur near the wind turbine. Therefore, impacts on birds from vertical flow are small for the offshore turbine.

Vertical flow caused both from thermal lift and ridge lift occurs in the marine area within 1 km of Kaba Island, so birds may use these flow patterns. According to an ornithological survey²⁾ observed from a point on Kaba Island, raptors such as ospreys and falcons soar in the coastal area rather than the wind turbine construction site (Fig. 7), supporting the results of this study. Furthermore, bird observations using marine surveillance radar (Fig. 8) detected flying birds in the bay area at a higher frequency than around the wind turbine construction site, thus further supporting our analysis results.

Fig. 5 Monthly frequency distribution of vertical flow (Top) and scatter diagrams of horizontal wind velocity [horizontal] and absolute vertical wind velocity [vertical] (Bottom) (Left: Reference area, Right: Wind turbine marine site)

Fig. 6 Estimated horizontal distribution for frequency of occurrence in vertical flow (= value of the slope of the approximate equation in Fig. 5 (bottom))

Fig. 7 Soaring routes of observed for raptors that do not migrate (24-26 September 2012)²⁾

Fig. 8 Soaring routes of birds observed by marine surveillance radar (25 September 2012) (Top: 0:00-1:00 AM, Bottom: 0:00-1:00 PM)

6. Conclusion

Based on the mesoscale meteorological model for wind prediction, we showed that ridge lift caused by topography and thermal lift caused by thermal flow can be simulated.

In the coastal areas of Kaba Island, vertical flow caused by ridge lift prevailed, whereas in the sea areas around the offshore turbine, vertical flow did not occur because the area is far from the coast. Raptores such as osprey and falcons were frequently seen to soar catching the vertical flow on Kaba Island. These observations are mostly in the coastal areas correlate well with the simulation results of this study.

Based on the above prediction, the risk of bird collisions with wind turbine in areas where the floating

wind turbine is installed and collision risks due to vertical flow are unlikely because vertical flow caused by either thermal or ridge flow rarely occurs.

In the future, when selecting sites for offshore and onshore wind generation, if there is a possibility of vertical flow occurring, the impact assessment of birds is important. When conducting the environmental impact assessment in such cases, the vertical flow simulation introduced in this study should be effective during consideration of the impacts. Furthermore, accurate evaluations with high resolution and reliability can be achieved by combining other engineering models such as CFD (Computational Fluid Dynamics) with the mesoscale meteorological models that can simulate thermal factors.

In this demonstration experiment, a marine wind observation floating tower was also installed, and the wind conditions were continuously measured. In the future, it may be necessary to compare the actual measured vertical wind flow elements with the simulation results.

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