A Nonlinear Model MASCOT: Development and Application

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Numerical model

Microclimate Analysis System for COmplex Terrain (MASCOT) was developed for the prediction of local wind in complex terrain

Governing Equations

$$\frac{\partial \rho u_j}{\partial x_j} = 0$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial \rho u_j u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j} - \rho \overline{u_i' u_j'}\right)$$

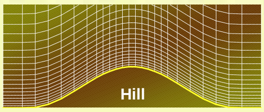
$$\frac{\partial k}{\partial t} + \frac{\partial \rho u_j k}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] - \rho \overline{u_j' u_j'}\frac{\partial u_i}{\partial x_j} - \rho\varepsilon$$

$$\frac{\partial \varepsilon}{\partial t} + \frac{\partial \rho u_j \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] - C_{\varepsilon 1}\frac{\varepsilon}{k}\rho \overline{u_i' u_j'}\frac{\partial u_i}{\partial x_j} - C_{\varepsilon 2}\frac{\rho \varepsilon^2}{k}$$

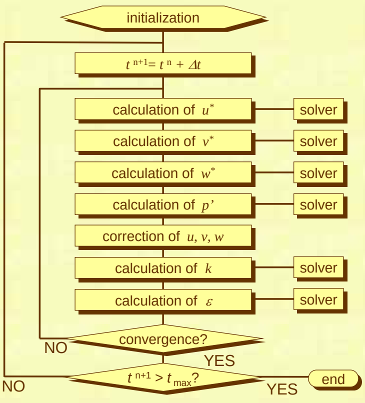
$$\rho \overline{u'_i u'_j} = \frac{2}{3}\rho k \delta_{ij} - 2C_\mu \rho \frac{k^2}{\varepsilon} S_{ij} + 2C_2 \frac{k^3}{\varepsilon^2}(-S_{ik}\Omega_{kj} + \Omega_{ik}S_{kj})$$

(Shih's non-linear k-ε model)

Numerical Methods



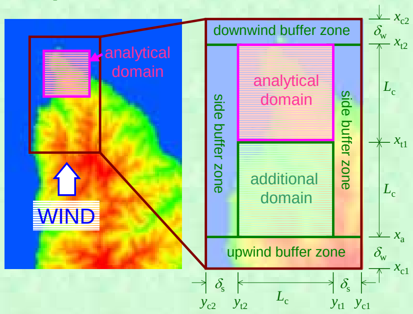
- Arbitrary non-orthogonal coordinate along the terrain surface was adopted.
- Finite Volume Method was used for discretization.
- The ReyTnolds averaged navier-stokes equations were solved by SIMPLE algorithm.
- The Residual Cutting Method was used for the linear equation systems to improve the numerical efficiency.



SIMPLE algorithm

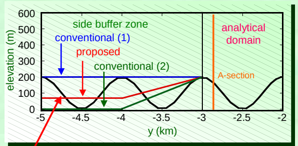
Boundary treatment

Computational domain



- New boundary treatments are proposed, which consist of buffer zones and an additional domain.

Side buffer zone

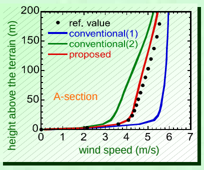


- Proposed method maintains the volume of the terrain in the side buffer zones.

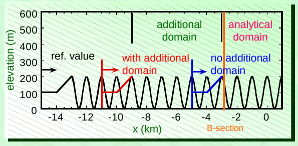
$$\hat{h}(x,y) = \begin{cases} H_{sb}(x) & (y_{c1} \le y < y_{m1}) \\ H_{sb}(x) + \dfrac{2(y - y_{m1})}{\delta_s}[h(x, y_{t1}) - H_{sb}(x)] & (y_{m1} \le y < y_{t1}) \end{cases}$$

$$H_{sb}(x) = \frac{1}{3}\left[\frac{4}{\delta_s}\int_{y_{c1}}^{y_{t1}} h(x,y)dy - h(x, y_{t1})\right]$$

- The proposed method improves the overestimation or the underestimation of the wind speed by conventional ones.

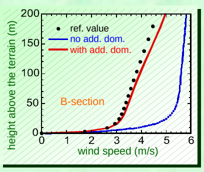


Additional domain



- To account for the effect of the upwind terrain, an additional domain was introduced.

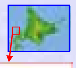
- The case with additional domain shows favorable agreement with the reference value, while the case without additional domain largely overestimates the wind speed.

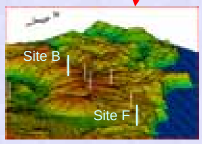


Verification

Experimental setup

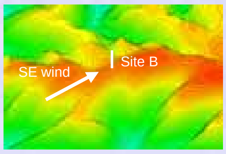
A part of Shakotan Peninsula, north of Japan was chosen and 1:2000 scale wind tunnel test was carried out to verify the model.



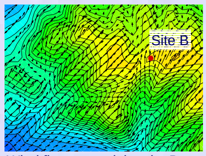


- Typical terrain feature in the coast of the north of Japan
- Very complex and steep cliff along the sea

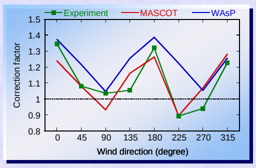
Site B



Terrain around the site B



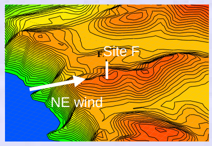
Wind flow around the site B with south westerly wind



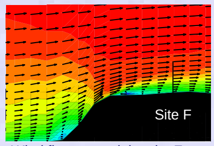
Predicted and measured correction factor at the site B

- When the wind is south westerly, the wind direction is forced to change along the valley.
- The linear model tends to overestimate the wind speed.

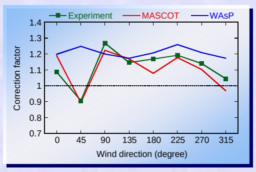
Site F



Terrain around the site F



Wind flow around the site F with north easterly wind



Predicted and measured correction factor at the site F

- With north easterly wind, flow separates at the edge of the cliff and wind speed decreases.
- The linear model overestimates the wind speed remarkably when the flow separation occurs.

Application to Tappi Wind Park

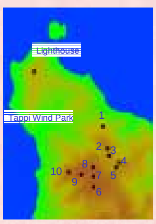
Overview

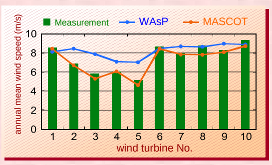
Tappi Wind Park consists of ten wind turbines, all of which are installed on complex terrain.

- The wind speeds and directions at the sites are strongly affected by steep terrain.

Prediction of Annual mean wind speed

Annual mean wind speed for all the turbines are simulated by WAsP and MASCOT using the wind data observed at the lighthouse as a reference value.





- The prediction by MASCOT shows good agreement with the measurement while WAsP overestimates the annual mean wind speed at the turbines No.2-5.

Conclusions

- A nonlinear wind prediction model MASCOT was proposed and verified by wind tunnel test and observation data at Tappi Wind Park.
- New boundary treatments proposed for analysis of wind flow over real terrain give more accurate results than conventional ones.
- Wind tunnel test using real terrain model was carried out to verify the model. MASCOT reasonably predict the flow over complex terrain, while WAsP overestimates the wind speed when flow separates.
- Annual mean wind speeds in Tappi Wind Park predicted by MASCOT give reasonable agreement with those measured at the nacelles, while WAsP overestimates the wind speed at some sites.