MIKE 21

Cyclone Wind Generation Tool

Scientific Documentation

PLEASE NOTE

COPYRIGHT

This document refers to proprietary computer software, which is protected by copyright. All rights are reserved. Copying or other reproduction of this manual or the related programmes is prohibited without prior written consent of DHI A/S (hereinafter referred to as "DHI"). For details please refer to your 'DHI Software Licence Agreement'.

LIMITED LIABILITY

The liability of DHI is limited as specified in your DHI Software License Agreement:

In no event shall DHI or its representatives (agents and suppliers) be liable for any damages whatsoever including, without limitation, special, indirect, incidental or consequential damages or damages for loss of business profits or savings, business interruption, loss of business information or other pecuniary loss arising in connection with the Agreement, e.g. out of Licensee's use of or the inability to use the Software, even if DHI has been advised of the possibility of such damages.

This limitation shall apply to claims of personal injury to the extent permitted by law. Some jurisdictions do not allow the exclusion or limitation of liability for consequential, special, indirect, incidental damages and, accordingly, some portions of these limitations may not apply.

Notwithstanding the above, DHI's total liability (whether in contract, tort, including negligence, or otherwise) under or in connection with the Agreement shall in aggregate during the term not exceed the lesser of EUR 10.000 or the fees paid by Licensee under the Agreement during the 12 months' period previous to the event giving rise to a claim.

Licensee acknowledge that the liability limitations and exclusions set out in the Agreement reflect the allocation of risk negotiated and agreed by the parties and that DHI would not enter into the Agreement without these limitations and exclusions on its liability. These limitations and exclusions will apply notwithstanding any failure of essential purpose of any limited remedy.

CONTENTS

MIKE 21
Cyclone Wind Generation Tool
Scientific Documentation

1   Introduction

The MIKE 21 Cyclone Wind Generation tool allows users to compute wind and pressure data due to tropical cyclone (hurricane or typhoon). Wind and pressure data generated by a tropical cyclone can often be described by simple parametric models based on few parameters like position of the cyclone's eye, radius of the maximum winds, etc… Most of these parameters are generally available from meteorological publications as Best Track data table for each cyclone. Other parameters may need to be derived by the user or adjusted based on wind or pressure measurements.

Several cyclone parametric models are included in the present tool. In addition to that different kind of wind corrections can be applied by the user to reflect the cyclonic wind structure. Wind and pressure data are then computed for different formats of output files allowing the user to easily investigate the cyclonic forcings. Among them space and time varying wind and pressure fields can be obtained for later use in a MIKE hydrodynamic or wind wave generation simulation. In that way cyclonic surges or waves can be computed.

This document presents the different parametric models implemented in the MIKE 21 Cyclone Wind Generation tool (section 2) and the different types of wind correction available (section 3).

2 Parametric Models

2.1 Young and Sobey

Following Young and Sobey (1981) the rotational wind gradient speed V_g at a distance r from the centre of the cyclone, is given by:

$$V_g(r) = V_{max} \cdot \left(\frac{r}{R_{mw}}\right)^7 . exp\left(7\left(1 - \frac{r}{R_{mw}}\right)\right)$$

$$\text{for } r < R_{mw}$$

$$V_g(r) = V_{max} . exp\left((0.0025R_{mw} + 0.05)\left(1 - \frac{r}{R_{mw}}\right)\right)$$

$$\text{for } r \geq R_{mw}$$

(2.1)

where:
- R_{mw} is the radius to maximum wind
- V_{max} is the maximum wind speed

Following the Shore Protection Manual (1984) the pressure p is given as:

$$p(r) = p_c + (p_n - p_c). exp\left(-\frac{R_{mw}}{r}\right)$$

(2.2)

where:
- p_c is the pressure at the storm centre or central pressure
- p_n is the ambient surroundings pressure field or neutral pressure

2.2 Holland

Using parameters already defined in the Young and Sobey model, the pressure p according to Holland (1981) is given as:

$$p(r) = p_c + (p_n - p_c). exp\left(-\frac{R_{mw}}{r}\right)^B$$

(2.3)

B is a shape parameter added by Holland to match different kind storm pressure profiles. Hence it is referred most of the time as the Holland parameter or profile "peakedness". According to Holland the range of B is: $1 < B < 2.5$.

The gradient wind is then given as:

$$V_g(r) = \sqrt{(p_n - p_c)\frac{B}{\rho_A}\left(\frac{R_{mw}}{r}\right)^B exp\left(-\frac{R_{mw}}{r}\right)^B + \left(\frac{r.f}{2}\right)^2} \\ - \frac{r|f|}{2}$$

(2.4)

where ρ_a is the air density and f the Coriolis parameter.

This leads to (neglecting the Coriolis effect):

$$V_{max} = \sqrt{(p_n - p_c)\frac{B}{\rho_A.e}}$$

(2.5)

This can be used to determine the B parameter when the maximum wind speed V_{max} is known:

$$B = \rho_A.e.V_{max}^2/(p_n - p_c)$$

(2.6)

According to Harper et al. (2001) and Phadke et al. (2003), Harper and Holland (1999) suggested however that 'standard' B values might be obtained by:

$$B = 2.0 - (p_c - 900)/160$$

(2.7)

Please note that the central pressure p_c should be expressed in *hPa* only in this empirical formulation *(2.7)* whereas pressure data is expressed in *Pa* anywhere else.

In the Cyclone Wind Generation Tool, the Holland parameter is to be specified by the user based on the available data.

2.3   Holland – Double Vortex

The so-called Holland – double vortex model is based on the parametric model introduced by Holland (1980) and described here above. The Holland – double vortex model includes a secondary vortex following works of Cardone et al (1994, 1996).

The pressure p is therefore given as:

$$p(r) = p_c + \Delta p_1 . exp\left(-\frac{R_{mw1}}{r}\right)^{B_1} + \Delta p_2 . exp\left(-\frac{R_{mw2}}{r}\right)^{B_2} \qquad (2.8)$$

where:

$$\Delta p_1 + \Delta p_2 = p_n - p_c = \Delta p \qquad (2.9)$$

The gradient wind is given by:

$$V_g(r) = \sqrt{\begin{array}{c} \left(\frac{R_{mw1}}{r}\right)^{B_1} . \frac{B_1 \Delta p_1}{\rho_A} . exp\left(-\frac{R_{mw1}}{r}\right)^{B_1} \\ + \left(\frac{R_{mw2}}{r}\right)^{B_2} . \frac{B_2 \Delta p_2}{\rho_A} . exp\left(-\frac{R_{mw2}}{r}\right)^{B_2} \\ + \left(\frac{r.f}{2}\right)^2 \end{array}} - \frac{r|f|}{2} \qquad (2.10)$$

The Holland – double vortex parametric formulation is used in the model developed by the Marine Modeling Unit (MMU) of the James Cook University.

2.4 Rankine

The modified Rankine vortex model uses the following velocity distribution:

$$V_g(r) = \begin{cases} V_{max} \cdot \left(\frac{r}{R_{mw}}\right) & \text{for } 0 \le r < R_{mw} \\ V_{max} \cdot \left(\frac{R_{mw}}{r}\right)^X & \text{for } r > R_{mw} \end{cases} \qquad (2.11)$$

The shape parameter *X* is used to adjust the wind speed distribution in the radial direction. Typical values of *X* are in the range of 0.4 to 0.6.

3 Wind Correction

3.1 Geostrophic Correction

In order to obtain surface winds, a boundary layer wind speed correction can be applied to the gradient wind. The near-surface wind, V_{10}, is usually obtained by the following relation (Harper et al., 2001):

$$V_{10}(r) = K_m . V_g(r) \tag{3.1}$$

As mentioned by Harper et al, (2001) different values for the parameter K_m are available in the literature. These values can be entered in the Cyclone Wind Generation Tool using a constant type of geostrophic correction.

A speed-dependent formulation for K_m is also proposed by Harper et al. (2001) and seems widely used in Australia. This has been implemented in the Cyclone Wind Generation Tool as the 'Harper et al.' geostrophic correction type where the K_m factor is computed as:

$$K_m = \begin{cases} 0.81 & for\ V_g < 6\ m/s \\ 0.81 - 2.96\ 10^{-3}(V_g - 6) & for\ 6 \leq V_g < 19.5 \\ 0.77 - 4.31\ 10^{-3}(V_g - 19.5) & for\ 19.5 \leq V_g < 45 \\ 0.66 & for\ V_g > 45\ m/s \end{cases} \tag{3.2}$$

3.2 Forward Motion Asymmetry

Cyclonic winds circulate clockwise the Southern Hemisphere. The wind field is asymmetric so that winds are typically stronger to the left of cyclone's track and lower to the right due to the contribution of the cyclone movement.

Following Harper et al. (2001) the forward motion asymmetry is taken into account in the Cyclone Wind Generation Tool at surface level by the following general relationship:

$$V_{10}(r, \theta) = K_m . V_g(r) + \delta_{fm} . V_{fm} . cos(\theta_{max} - \theta) \tag{3.3}$$

The proportion of the added forward cyclone speed V_{fm} can be adjusted using the correction factor δ_{fm} (typically 0.5 or 1).

The maximum intensity is added along an assumed line of maximum winds defined by the angle θ_{max} measured relative to the cyclone movement direction. In the Southern Hemisphere θ_{max} is commonly taken as 115° (corresponding to the rear left quadrant) but values around 65° (front left quadrant) is also employed in more recent studies (see Harper et al., 2001 for references). Opposite values shall be selected in the Northern Hemisphere.

In the MIKE 21 Cyclone Wind Generation tool, the cyclone movement direction and the cyclone speed are computed based on the position of the centre of the storm given in the Best Track Data table.

3.3   Wind Inflow Angle

All the parametric wind models introduced previously assume a circular wind flow pattern which does not represent the observed surface wind directions. Frictional effects cause the inflow of winds towards the centre of the storm. The inflow angle β is typically of the order of 25° but decreases towards the storm centre.

Sobey et al. (1977) proposed the following empirical formulation which has been implemented in the Cyclone Wind Generation Tool:

$$\beta = \begin{cases} 10\,\dfrac{r}{R_{mw}} & \text{for} \ \ 0 \leq r < R_{mw} \\[2mm] 10 + 75\left(\dfrac{r}{R_{mw}} - 1\right) & \text{for} \ \ R_{mw} \leq r < 1.2\,R_{mw} \\[2mm] 25 & \text{for} \ \ r \ \geq 1.2\,R_{mw} \end{cases} \tag{3.4}$$

4 References

/1/   Harper and Holland, 1999:
An updated parametric model of the tropical cyclone, pp. 893–896.

/2/   Harper, B.A., Hardy, T.A., Mason, L.B., Bode, L., Young, I.R., Nielsen, P., 2001:
Queensland climate change and community vulnerability to tropical cyclones,
Ocean hazards assessment - Stage 1, report, Department of Natural Resources
and Mines, Queensland, Brisbane, Australia, 368 p.

/3/   Holland, G., 1980:
An analytic model of the wind and pressure profiles in hurricanes, Monthly
weather review, volume 108, pp. 1212-1218

/4/   Phadke, A.C., Martinoa, C.D., Cheung, K.F, and Houston, S.H., 2003:
Modeling of tropical cyclone winds and waves for emergency management,
Ocean Engineering, Volume 30, Issue 4, March 2003, pp. 553-578.

/5/   Sobey, R.J., Harper, B.A., Stark, K.P., 1977:
Numerical simulation of tropical cyclone storm surge, Research Bulletin CS-14,
Dept Civil and Systems Engineering, James Cook University.

/6/   Thompson, E. and Cardone, V., 1996:
Practical modelling of hurricane surface wind fields, Journal of Waterway, Port,
Coastal, and Ocean Engineering, July/August 1996.

/7/   Young, I.R. and Sobey, R.J., 1981:
The numerical prediction of tropical cyclone wind-waves, James Cook University
of North Queensland, Townville, Dept. of Civil & Systems Eng., Research
Bulletin No. CS20