Minimising Processing Time when Reconstructing Tropical Cyclone Wind Fields using GIS

M. L. Puotinen[1,2]

[1]Institute for Conservation Biology and Law and [2]School of Earth and Environmental Sciences, University of Wollongong, Wollongong, NSW 2522
Telephone: +61 2 4221 3589
Fax: +61 2 4221 4250
Email: marji@uow.edu.au

1. Background

Tropical cyclones (TCs) can generate extreme wind and wave conditions, which may threaten human lives and infrastructure as well as disrupt both land and marine ecosystems. Reconstructing the spread of extreme TC conditions is thus useful for a range of purposes. In an interesting twist, a recent study in the Caribbean demonstrated that ocean cooling caused by the nearby passage of a TC reduced the severity of coral bleaching due to temporary relief of persistent high sea surface temperatures from high winds and surface pressure changes (Manzello et al 2007). This poses the question of how often this interaction occurs under current climates, and the extent to which the increased storminess predicted for future climates could offset the increased bleaching also predicted. Initial steps to address this question require data of the spread and intensity of TC winds across the entire world’s tropical oceans at a fine resolution (1 km) over a 23 year time period (1985-2007) on an hourly basis.

Direct measurements of TC winds during an event are rare because instruments fail and it is difficult to predict the location of a TC track to situate instruments accordingly. Thus, models are commonly used to reconstruct the spread of extreme winds given basic TC characteristics which are routinely recorded by world meteorological agencies. This most often based on the relatively well understood TC wind – pressure profile (Holland 1980), whereby wind speeds are estimated using equations based on TC central pressure, translation speed and distance from the TC center (eye). These equations can be implemented in raster GIS to reconstruct TC wind fields– for example for the entire world at a coarse resolution (~0.1 degree pixel - Berz et al 2001) or for a local region at a fine resolution (1 km, Australia’s Great Barrier Reef – Puotinen 2007).

As the basic characteristics of a TC (and the resulting wind field) can vary considerably from hour to hour, a separate TC wind field must be constructed for each time step. A current implementation of this model (within ArcInfo workstation’s Arc Macro Language [AML] – Puotinen 2007) requires 0.00003 seconds per pixel per time step to run. Thus, processing time quickly mounts when running it for many hours of TCs over a large study area represented at a fine resolution. For example, running the current AML for the entire world’s tropical oceans at high spatial (1 km) and temporal (1 hour) resolution for the period 1986 to the 2007 would require 413,351 iterations each comprised of 414,720,000 pixels, which would take approximately 176.3 years to complete. So – clearly work is needed to minimize processing time. This paper describes some preliminary steps taken to do so via a case study of a typical severe TC which crossed Australia's Great Barrier Reef in March 2005 (TC Ingrid – see Fabricius et al 2008).

2. How to speed it up?

2.1 Reducing the number of iterations needed

TCs often change intensity as they move along their track. This means that TC positions are often recorded in meteorological databases when they are incapable of generating extreme winds. Thus, if non-extreme wind conditions are not of interest, a proportion of iterations are unnecessary as all values in the wind field grid will be below the threshold (gale force winds, 17m/s). To test this for the case study, a spreadsheet was created implementing the TC wind field equations for maximum possible conditions (at the boundary of the TC eye wall). For TC Ingrid, 16% of the hourly positions could be eliminated (16%) on this basis. Applying this to the world scenario would eliminate 66,136 iterations and thus save 28 years of processing.

2.2 Reducing the number of cells in the grid to be processed

Clearly, though, the size of the raster grid for which winds are estimated must be dramatically reduced. Following on from above, the distance to which each TC position is capable of generating gale force winds can be calculated in a spreadsheet for basic TC characteristics. This can then be used as a lookup table for all TCs from which to automatically generate a buffer beyond which gale force winds are not possible. This buffer can be used to create a raster mask to limit processing to cells where extreme winds are possible, and the mask's boundary coordinates can be used to define a local grid appropriate to each TC. Doing this makes a dramatic difference to processing time (from 176 years to 86 days), as shown in Table 1.

Basin	Number of recorded eye positions	Estimated number of 1 hourly eye positions	Extent - World		Extent - local	
			Time (days) - world grid NO MASK	*Time (days) - world grid WITH MASK*	*Time (days) - subgrid NO MASK*	*Time (days) subgrid WITH MASK*
Australia	7,267	56,450	8,789	6,591	16	12
Atlantic	13,210	102,615	15,976	11,982	29	21
E Pacific	13,474	104,666	16,295	12,221	29	22
Indian	5,561	43,198	6,725	5,044	12	9
S Pacific	3,010	23,382	3,640	2,730	6	5
W Pacific	10,690	83,040	12,928	9,696	23	17
TOTAL	53,212	413,351	64,354	48,265	115	86

Table 1. Effect of using a subgrid and a mask on processing times.

2.3 Further work

Tests revealed that ~70% of each iteration is spent resolving equations within an Arc-Info GRID DOCELL loop. Eliminating the loop increased processing time. Minimising the number of temporary variables written within the loop had little effect. One idea is to trial a vector implementation whereby all calculations are done within the attribute table of a grid of the study area represented as points. If done in ArcGIS (possibly accessing MapObjects directly via VBA), the buffer could be a temporary selection to which processing is applied, eliminating the need to write the mask. Another alternative is to solve the equations in GRASS GIS, which could be run on a supercomputer.

3. Acknowledgements

The original AML described in this work was created for MP’s PHD which was supported by James Cook University, the Australian Institute of Marine Science, the Great Barrier Reef Marine Park Authority, and the Cooperative Research Centre for the Ecologically Sustainable Development of the Great Barrier Reef. Technical support was provided by the Spatial Analysis Laboratories within the School of Earth and Environmental Sciences at the University of Wollongong.

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