Chapter Eleven

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11. Ready Reckoner

11.1 Introduction

This chapter provides a ready reference for various parameters and information related to tropical cyclones.

11.2 Unit conversion

Multiply the line unit by the indicated number to get the column unit; for example, on the first line inches multiplied by 12 gives 1 ft in the second column. Only conversions to higher values are shown. Take care to convert to the degree of accuracy of the original observation only; for example a ship estimate of 20 kt based on sea state should convert to 10 ms⁻¹, a literal transformation to 10.256 ms⁻¹ is incorrect.

SI length units are identified by an asterisk

Length								
	mm*	in	ft	m*	km*	mi	nm	°lat
mm*	1	25.4	304.8	1000	10 ⁶	1.61x10 ⁶	1.85x10 ⁶	1.11137x10 ⁸
in		1	12	39.37	39370	63360	72913	4.38x10 ⁶
ft			1	3.28	3281	5280	6080	364320
m*				1	1000	1609	1853	1.11137x10 ⁵
km*					1	1.609	1.853	111.137
mi						1	1.15	69
nm							1	60
Time	Time							
		se	c	miı	ר ו	hour		day

sec	1	60	3.6x10 ³	8.64x10 ⁴
min		1	60	1.44x10 ³
hour			1	24

Speed						
	km h ⁻¹	mph	kt	ms ⁻¹		
km h⁻¹	1	1.61	1.85	3.6		
mph		1	1.15	2.24		
kt			1	1.95		

Conversion from °C to °F

 $^{\circ}F = (1.8 \times ^{\circ}C) + 32$

Conversion from °K to °C

 $^{\circ}C = ^{\circ}K - 273.15$

11.3 Beaufort scale

Several versions of the Beaufort wind scale exist. They mostly vary by small degrees. The following is adapted from Pielke (1991) and Dunn and Miller (1964) following work by Black and Adams (personal communication), and using information provided by R. Simpson (personal communication).

Beaufort Force	Estimated 10-min averaged wind (kt) at 19m [*] .	Description
0	Calm	Sea glassy. Appearance of being covered by oil.
1	1-3	Slight ripple.
2	4-6	Slight ripple. Isolated brief whitecaps. Unable to determine direction.
3	7-10	Gentle Breeze: Surface like wrinkled paper. Small. well defined whitecaps of uniform size but few in number. White crests disappear quickly. First able to tell direction but with difficulty.
4	11-16	Moderate Breeze: Small foam patches. Number of

		breaking crests increase slightly and are a little larger. First able to tell direction with confidence. Wrinkle texture of surface is very evident.
5	17-21	Fresh Breeze: Size and number of whitecaps and foam patches increase significantly. Whitecaps on most wave crest. Very short streaks may appear in foam patches.
6	22-27	Strong Breeze: Well defined short streaks in foam patches. Small whitecaps on most wave crests. Occasional medium-size foam patch or breaker. Isolated green patches of short duration. Foam patches, short streaks, and whitecaps (white water) cover 5-7% of sea surface.
7	28-33	Moderate Gale: Medium-size breaking crest. Dense foam patches and accompanying short streaks are numerous. Average length of streaks equal to diameter of average foam patch. Small green patches occasionally visible.
8	34-40	Fresh Gale - Tropical Cyclone: Streaks more numerous and occasionally longer. Some streaks may appear unassociated with breaking waves or foam patches. Area covered by whitecaps stabilises at 7- 10%. Occasional large foam patch. Small green patches continually visible with occasional moderate- size green patch.
9	41-47	Strong Gale: Streaks readily apparent between foam patches. Streak length varies from patch size to occasional regions of long, nearly continual streaking. Streaks, patches, and breaking waves cover 15-20% of sea. 50% of foam patches are green.
10	48-55	Storm Force: Wind streaks become the most obvious surface feature and are continuously or nearly so. Well-defined, thinly breaking waves form on long crestlines, often preceded by short breaking wavelets giving a step-like appearance. Occasional large foam patches are quickly fragmented and elongated into streaks. Sea covered 2-25% by white water.
11	56-63	Streaks are well-defined, parallel, thin, close together, and continuous with very short capillary wavelets cutting across and perpendicular to streaks, giving sea surface a 'shattered glass' effect in certain areas. Some large breaking crests may take on 'rolling' or

		'tumbling' appearance. Sea covered 30-40% by white water.
12	64-69	Hurricane Force: Sea may occasionally be obscured by spray and take on a murky appearance. Large, curved, breaking crests have undulating effect on steaks, giving churning appearance. Streaks appear to thicken and become milky or pale green.
13	70-75	Surface features generally become murky. Streaks and foam patches begin to sole their sharp definition and appear to smudge, thicken, or merge together. Frequent, extremely large, almost semicircular crests outlined by thinly breaking waves with occasional groups of large foam patches after entire crest breaks.
14	76-80	Quantity of spray increases. Streaks thicken and appear to have more depth. Previous crisp, shattered glass appearance now appears blurred. Most features appear to be a submerged rather than a surface phenomenon, owing to obscuration. Very short capillary wavelets which cut across streaks give surface a stressful appearance as though undergoing compression. Sea surface 50% white.
15	81-85	Sea appears flatter and entire surface takes on a whitish/greyish cast. Streaks organise somewhat into broader, diffuse bands. All features lose some definition and appear submerged. Surface 50-55% white.
16	86-90	Many thin streaks are partially obscured and those which can be seen may appear as bands spaced farther apart. Occasional cloud below aircraft blots out or obscures surface. Sea appears almost flat. Whitish cast covers 60-65% of surface.
17	91-95	Breaking waves and foam patches appear as diffuse, white, puffy areas. Streaks become fuzzy bands. Surface 70-80% white.
18	96-100	Cloud, spray, and foam patches merge into large, white, indefinable areas historically referred to as 'white sheets'. Surface features have only rough boundary definition.
19	101-105	Isolated large, white puffs. Only strongest features of previously seen thick streaks remain to be observed

		and result gives impression of only a very few widely scattered and non-parallel streaks or wide bands. Whitish and greenish cast covers 100% of surface.
20	106-110	Foam patches, bands, and whitecaps merge into large indefinable areas or white sheets. Variations in brightness are less distinct but still result in churning appearance.
21	>110	Sea 100% white and green. Only slight variation in whiteness is apparent.

* The standard height for ship observations is 19m, rather than the 10m used for land.

11.4 Useful tropical cyclone parameters

11.4.1 Tropical cyclone severity scales

The **Saffir Simpson Hurricane Scale** (Simpson and Riehl, 1981) was developed to provide a sliding scale of damage potential for hurricanes, including that arising from storm surge. A similar scale, though adapted for local conditions is used in Australia. Global adoption of such scales is strongly recommended.

	Maximum Sustained Winds			
Hurricane or Severe Tropical Cyclone	Saffir-Simpson	Australian Scale		
	Level (1-min mean, kt)	(10 min mean, km h ⁻¹)		
1	64-83	63-90		
2	84-96	91-125		
3	97-113	126-165		
4	114-135	166-225		
5	>135	>225		

Some of the tables from the main text are also listed on the following pages for convenience.

11.4.2 Gust factors

Gust factors defined by the ratio of peak 2-s wind to the mean wind at 10 m elevation for various exposures and averaging times and in wind speeds of at least hurricane force.

Parentheses give an indication of the range in gust factors. From Atkinson (1974), Spillane and Dexter (1976) and Padya (1975).

	OCEAN	FLAT GRASSLAND	WOODS/CITY
1-min Mean	1.25 (1.17-1.29)	1.35 (1.29-1.45)	1.65 (1.61-1.77)
10-min Mean	1.41 (1.37-1.51)	1.56 (1.51-1.70)	2.14 (1.89-2.14)
10-min Mean over Ocean	1.41	1.31	1.11

11.4.3 Dvorak intensity relationship

Empirical relationship between the current intensity number (CI), the Maximum sustained 1min Wind Speed (MWS, kt), and the central pressure (hPa) in tropical cyclones. The central pressure values for the western North Pacific are from Shewchuk and Weir (1980).

Τ.

		Central	Pressure
CI	MWS (kt)	(Atlantic)	(NW Pacific)
0.0	<25		
0.5	25		
1	25		
1.5	25		
2	30	1009	1000
2.5	35	1005	997
3	45	1000	991
3.5	55	994	984
4	65	987	976
4.5	77	979	966
5	90	970	954
5.5	102	960	941
6	115	948	927

6.5	127	935	914
7	140	921	898
7.5	155	906	879
8	170	890	858

11.5 Useful constants

9.6.1 Universal constants

Avogadro's Number,	N _A	6.02247x10 ²⁶ kmol ⁻¹
Base of Natural Logarithms,	е	2.71828
Boltzmann's Constant,	k	1.381x10 ⁻²³ J K ⁻¹ molecule ⁻¹
Gravitational Constant		6.673x10 ⁻¹¹ Nm ² kg ⁻¹
Pi	π	3.1415927
Planck's Constant,	h	6.6262 x10 ⁻³⁴ J s ⁻¹
Speed of Light,	с	2.998x10 ⁸ ms ⁻¹
Speed of Sound in Air at 0°C		340 ms ⁻¹
Stefan-Boltzmann Constant,	σ	5.6696x10 ⁻⁸ W m ⁻² K ⁻⁴
Universal Gas Constant,	R	8.3143x10 ³ J K ⁻¹ kmol ⁻¹
9.6.2 The Earth		
Angular Velocity,	Ω	7.292x10 ⁻⁵ s ⁻¹
Gravitational Acceleration at the surface,	g	9.81 ms ⁻²
Radius: Mean, Equatorial Polar	R _E	6370 km 6379 km 6357 km
Volume		1.083x10 ²¹ m ³
Surface Area		5.1x10 ¹² m ²

Mass	5.988x10 ²⁴ kg
Mean Density	5.529x10 ³ kg m ⁻³
Mean Distance to Moon	3.8x10 ⁵ km
Mean Distance to Sun	1.49x10 ⁸ km
Orbital Speed around Sun	2.977x10 ⁴ ms ⁻¹
Azimuthal Speed at Equator	465 ms ⁻¹
Solar Irradiance	1.38x10 ³ W m ⁻²

9.6.3 The Atmosphere

Density of dry air at 0°C and 1000 hPa		1.29 kg m ⁻³
Gas Constant: Universal For Dry Air,	R _d	8.31436x10 ³ J K ⁻¹ kmol ⁻¹ 287 J K ⁻¹ kg ⁻¹
Mass of Atmosphere		5.3x10 ¹⁸ kg
Molecular Weight of Dry Air		28.966 kg kmole ⁻¹
Specific Heat of Dry Air: at Constant Pressure, at Constant Volume,	C _p Cv	1004 J K ⁻¹ kg ⁻¹ 717 J K ⁻¹ kg ⁻¹
Standard Sea Level: Pressure, Temperature, Density, Speed of Sound, 9.6.4 Water	ρ _s T _s ρ _s c _s	1013.28 hPa 288.16K 2.225 kg m ⁻³ 331.3 ms ⁻¹
Density of Water	(0°C)	1.0x10 ³ kg m ⁻³
Density of Ice	(0°C)	0.917x10 ³ kg m ⁻³
Gas Constant for Vapour,	R _v	461.5 J K ⁻¹ kg ⁻¹
Molecular Weight of Water Vapor		18.016 kg kmol ⁻¹
Specific Heat: Water Vapour: Constant Pressure		1810 J K ⁻¹ kg ⁻¹

Constant Volume	1350 J K ⁻¹ kg ⁻¹
Liquid Water at 0°C	4218 J K ⁻¹ kg ⁻¹
lce at 0°C	2106 J K ⁻¹ kg ⁻¹
Latent Heat:	2.5x10 ⁶ J kg ⁻¹
Vaporisation at 0°C	2.25x10 ⁶ J kg ⁻¹
Vaporisation at 100°C	3.34x10 ⁵ J kg⁻¹
Fusion at 0°C	2.83x10 ⁶ J kg⁻¹
Sublimation at 0°	

11.6 Derived parameters

11.6.1 Definition of terms

b	empirical constant
Cg	gravity wave phase speed
Cp	specific heat of dry air at constant pressure
C ₁ , C ₂	empirical constants
е	base of natural logarithm
f	Coriolis parameter
h, H	atmospheric scale height
I	inertial frequency
k	unit vector perpendicular to the earth surface
L	latent heat of condensation
L _r	Rossby radius of deformation
In	natural logarithm
M _a	absolute angular momentum
Ν	Brunt Vaisala frequency, total number in population sample
р	air pressure
p _c	central (minimum) pressure of a tropical cyclone
p _n	representative environmental pressure for a tropical cyclone
q	specific humidity
R	universal gas constant

R _d	gas constant for dry air
R _o	Rossby number
r	radius
r _m	radius of maximum winds
Т	temperature
t	time
u	wind component, either zonal or radial
V	velocity
V	wind component, either meridional or azimuthal
Vg	geostrophic wind
v _m	maximum wind speed
х	empirical parameter
Z	height above the earth surface
д	gradient operator
д	partial derivative
!	factorial
ζ	relative vorticity
θ	potential temperature
θ_{e}	equivalent potential temperature
λ	latitude, azimuthal angle
ρ	air density
Σ	summation convention
σ	standard deviation
Ω	earth angular velocity

11.6.2 Derived parameters

Angular Momentum:

$$M_a = rv + \frac{f_o r^2}{2}$$

where f_0 is evaluated at the cyclone centre (Holland, 1983)

Brunt Vaisala Frequency (Static Stability):

$$N^2 = g \frac{\partial ln\theta}{\partial z}$$

Coriolis Parameter:

$$f = 2\Omega sin(\lambda)$$
$$= 14.584 sin(\lambda) s^{-1}$$

Divergence:

General:
$$D = \nabla \cdot \mathbf{v}$$

Cartesian: $D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$
Cylindrical: $D = \frac{1}{r} \left(\frac{\partial r u}{\partial r} + \frac{\partial v}{\partial \lambda} \right)$

Equation of State:

$$\rho = pRT$$

Equivalent Potential Temperature:

$$\theta_E \approx T_E \left(\frac{1000}{p}\right)^{R_d/C_p}$$
$$T_E = T e^{L_q/C_p T}$$

Inertial Frequency (Inertial Stability):

$$I^{2} = (f_{o} + \zeta)(f_{o} + \frac{2v}{r})$$

Mean:

$$\bar{x} = \frac{\sum x}{N}$$

Poisson Distribution: The discrete probability distribution

$$p(x) = \frac{\lambda^x e^{-\lambda}}{x!}$$

which has the properties of mean = $\lambda\,$ and standard deviation, σ = $\lambda^{\frac{1}{2}}$

Potential Temperature:

$$\theta = T(\frac{p_o}{p})^{R/C_p}$$

Rossby Number:

$$R_o = \frac{v}{fr}$$

Rossby Radius of Deformation:

$$L_R = \frac{c_g}{\zeta + f}$$
$$= \frac{\sqrt{gh}}{\zeta + f}$$
$$= \frac{NH}{I}$$

Standard Deviation:

$$\sigma = \sqrt{(\overline{x^2} - \bar{x}^2)}$$

Thermal Wind:

Geostrophic:
$$f \frac{\partial v_g}{\partial lnp} = -R\nabla T$$

Cylindrical:
$$\left(\frac{2v}{r} + f\right) \frac{\partial v}{\partial lnp} = -R \frac{\partial T}{\partial r}$$

Vorticity:

General:
$$\zeta = k \cdot \nabla \mathbf{x} \mathbf{V}$$

Cartesian: $\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$
Cylindrical: $\zeta = \frac{1}{r} \left(\frac{\partial rv}{\partial r} - \frac{\partial u}{\partial \lambda} \right)$

Wind Balance:

Gradient:
$$v = \frac{-fr}{2} \pm \sqrt{\left(\frac{r\partial p}{\rho\partial r} + \frac{f^2r^2}{4}\right)}$$

Cyclostrophic: $v = \pm \sqrt{\frac{1}{\rho r \partial r}}$

For cyclones, the positive (negative) root is used in the northern (southern) hemisphere

Wind Profiles: (Holland, et al, 2010)

Knowledge of radial wind profiles has become quite complex. This is best understood by consulting the reference at:<u>http://nldr.library.ucar.edu/repository/assets/osgc/OSGC-000-000-001-080.pdf</u>

Wind/Pressure Relationships:

Recent research into wind-pressure relationships have shown involvement of storm motion, size & latitude. The following equations are taken from (Knaff and Zehr, 2007):

$$MSLP = 23.286 - 0.483V_{srm} - \left(\frac{V_{srm}}{24.254}\right)^2 - 12.587S$$
$$- 0.483\phi + P_{env}, \tag{7}$$

where V_{srm} is the maximum wind speed adjusted for storm speed, S (i.e., = V_{500}/V_{500c}) is the normalized size parameter (see below), and ϕ is latitude (in degrees). V_{500} is the mean tangential wind at 500km from the cyclone centre and V_{500c} is defined below.

$$V_{500c} = V_{\max} \left(\frac{R_{\max}}{500}\right)^x,\tag{4}$$

where x, the shape factor, and R_{max} , the radius of maximum winds in kilometers, are functions of latitude (ϕ) in degrees and intensity (V_{max}) in knots:

$$x = 0.1147 + 0.0055V_{\text{max}} - 0.001(\phi - 25)$$
 and
(5)
 $R_{\text{max}} = 66.785 - 0.09102V_{\text{max}} + 1.0619(\phi - 25).$ (6)

11.7 Tropical cyclone records

Recording records is a difficult task, because of the extreme nature of the event and the tendency for observing equipment to break. The following records are backed up by good analysis methods and are considered to be reasonably reliable.

11.7.1 Global records

These records have been taken from <u>http://wmo.asu.edu/#cyclone</u> and from tropical cyclone records. Visit the page for the sources for these records and also any recent updates.

Tropical Cyclone Characteristic	Value	Date (D/M/Y)	Length of Record	Tropical Cyclone	Latitude/ Longitude
Most Intense - by Central Pressure (World and Eastern Hemisphere)	870mb (25.69")	12/10/1979	1951- present	Typhoon Tip in the Northwest Pacific Ocean	16°44'N, 137°46'E
Most Intense - by Central Pressure (western hemisphere)	882mb (26.05")	19/10/2005	1951- present	Hurricane Wilma in Caribbean Sea	17°18'N, 82°48'W
Most Intense - by Maximum Sustained Surface Wind	95m/s (185 kt, 215 mph)	12/9/1961	1945- present	Typhoon Nancy in the Northwest Pacific Ocean	15°30'N, 137°30'E
Maximum Surface Wind Gust for Tropical Cyclone	113.2 m/s (253mph; 220 kt	1055 UTC, 10/4/1996	1949- present	Barrow Island, Australia	20°49'S, 115°23'E
Northern Hemispheric Maximum Surface Wind Gust for Tropical Cyclone	94.4 m/s (211.3 mph; 183.5 kt	2235 UTC, 30/9/2008	1949- present	Pinar del Rio, Cuba	22°34'N, 83°40'W
Fastest Intensification	100mb (976 to 876 mb) in just under 24 hours	22- 23/9/1983	1951- present	Typhoon Forrest in Northwest Pacific Ocean	18°0'N, 136°0'E
Highest Storm Surge	13m (42 feet)	5/3/1899		Tropical Cyclone Mahina; Bathurst Bay, Queensland, Australia	14°15'S, 144°23'E
First Identified South Atlantic Hurricane		28/3/2004	1966- present	Tropical Cyclone Catarina; state of Santa Catarina, Brazil	approximate ly 27°S, 48°W
Largest Tropical Cyclone (winds from center)	Gale winds [17m/s, 34 kt, 39mph] extending 1100km (675 mi) from center	12/10/1979	1945- present	Typhoon Tip in Northwest Pacific Ocean	16°44'N, 137°46'E
Smallest Tropical Cyclone (winds from center)	Gale winds [17m/s, 34kt, 39mph] extending 50km (30 mi) from center	24/12/1974	1956- present	Tropical Cyclone Tracy near Darwin, Australia	12°12'S, 130°00'E
Longest Lasting Tropical Cyclone	31 days	10/8/1994- 10/9/1994	1945- present	Hurricane / Typhoon John in Northeast & Northwest Pacific	

				Basins	
Longest Distance Traveled by Tropical Cyclone	13280 km (7165 st. mi.)	10/8/1994- 10/9/1994	1961- present (satellite era)	Hurricane / Typhoon John in Northeast & Northwest Pacific Basins	
Smallest eye	6.7km (4 mile)	24/12/1974	1956- present	Tropical Cyclone Tracy at Darwin Australia	12°12'S, 130°00'E
Largest eye	90km (56 mile)	21/2/1979	1956- present	Tropical Cycle Kerry, Coral Sea	17°30'S, 154°06'W

Largest Rainfall of Tropical Cyclones	Value	Date (D/M/Y)	Length of Record	Tropical Cyclone	Latitude/ Longitude
12 hr	1.144m (45.0")	7- 8/1/1966	1966- 1990	Tropical Cyclone Denise in South Indian Ocean	21°14'S, 55°41'E
24 hr	1.825m (71.8")	7- 8/1/1966	1966- 1990	Tropical Cyclone Denise in South Indian Ocean	21°14'S, 55°41'E
48 hr	2.467m (97.1")	7- 9/4/1958	1952- 1980 & 2004- present	Unnamed Tropical Cyclone In South Indian Ocean	21°00'S, 55°26'E
72 hr	3.930m (154.7")	24- 27/2/2007	1968- present	Tropical Cyclone Gamede in South Indian Ocean	21°12'S, 55°39'E
96 hr	4.869m (191.7")	24- 27/2/2007	1968- present	Tropical Cyclone Gamede in South Indian Ocean	21°12'S, 55°39'E
10-day	5.678m (223.5")	18- 27/1/1980	1968- present	Tropical Cyclone Hyacinte in South Indian Ocean	21°12'S, 55°39'E

11.7.2 Regional Records

When printing this file include your regional records here.

11.8 Trivia corner

Hurricane Rubble: Surge and waves from Hurricane Bebe at Funafuti Atoll (8°S, 179°E) during 21 October, 1972 raised a permanent rubble rampart 3.5 m high, 37 m wide and 18 km long (Maragos et al., 1973).

Hot Air: A localised region of extremely warm stratospheric air with 240 hPa temperature anomaly of 18° attained over a distance of 13 km at the end of a cloud band *outside* the eye of Tropical Cyclone Kerry, February 1979, Coral Sea (Holland et al., 1984); measured by 747 with meteorologist in the cockpit, caused a major scare as the jet engines lost substantial power; in a similar incident in Western Australia a jet descended to 3 km altitude before regaining engine power.

Best Ship Observations: Caught in a typhoon in the western North Pacific during 26 September 1935, officers of the Japanese Imperial Navy collected the first, and possibly still the most comprehensive set of observations of the surface structure of a tropical cyclone (Arakawa and Suda, 1953).

Best Book Title: "An Attempt To Develop The Law of Storms By Means of Facts, Arranged According To Place and Time; and Hence To Point Out A Cause For The Variable Winds With The View To Practical Use In Navigation" (Reid, 1838).

Meteorology: This word seems to have been introduced to the language by Rear Admiral FitzRoy (1862), who begged his readers to accept the "abbreviation" from the then accepted meteorologic or meteorological.

Cyclone=Coiled Snake: Piddington (1855) first coined the term cyclone based on the Greek word, $\kappa \nu \kappa \lambda \delta \zeta$ or coil of a snake, which indicated the characteristic circular and centripetal air flow.

Typhoon=Big Wind: The derivative of the word typhoon seems to have arisen from very appropriate Mandarin word *t'ai fung* for great wind.

Hurricane=Angry God: The derivative of the word hurricane comes from *Huracan*, or "God of Evil" used by the Central American Tainos tribe (Anthes, 1982).

Cock-Eyed Bobs: Contrary to popular belief, tropical cyclones are not referred to as Willy Willys in Australia. This name refers to dust devils. However, old timers on the Australian west coast often used the colourful name Cock-Eyed Bob to refer to severe tropical cyclones.

Divine Wind: In the 13th century, a Mongol fleet, possibly the largest fleet ever assembled up to that time, was destroyed by a typhoon on its way to what would have been a successful invasion of Japan. This great fortune for Japan gave rise to the term *kamikaze*, for Divine Wind.

Friend or Foe: Clement Wragge, the Australian forecaster who started the convention of naming tropical cyclones, occasionally named a particularly severe one after politicians with whom he was displeased.

Coincidences? The TCM-90 Field experiment was initiated following a less than good series of forecasts for Typhoon Abby; the Project Manager was Bob Abbey. The Director of the field experiment in Guam was Russ Elsberry; several months later Guam was badly damaged by Supertyphoon Russ.

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