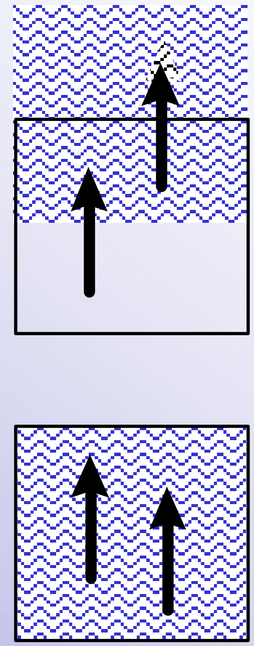
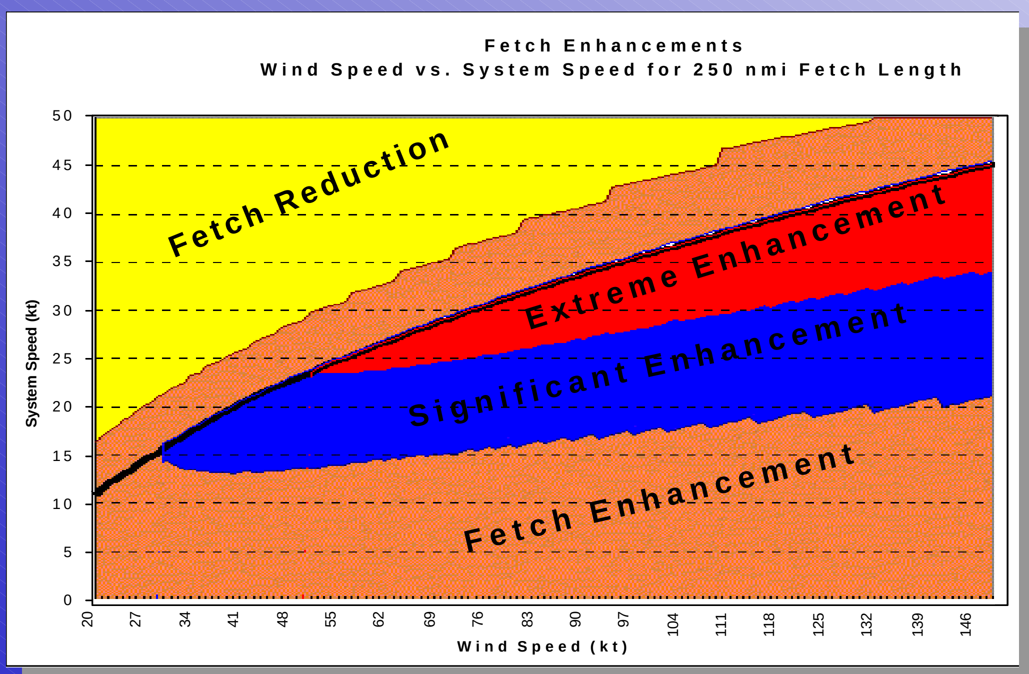
TRAPPED-FETCH WAVES

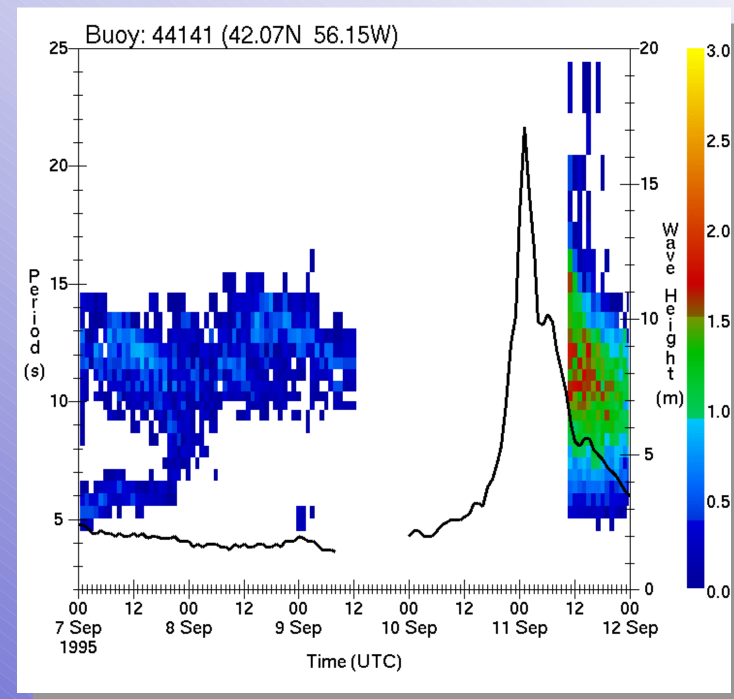
The Theory from an
Observational Perspective

Peter J. Bowyer
Allan W. MacAfee



Canadian
Hurricane
Centre



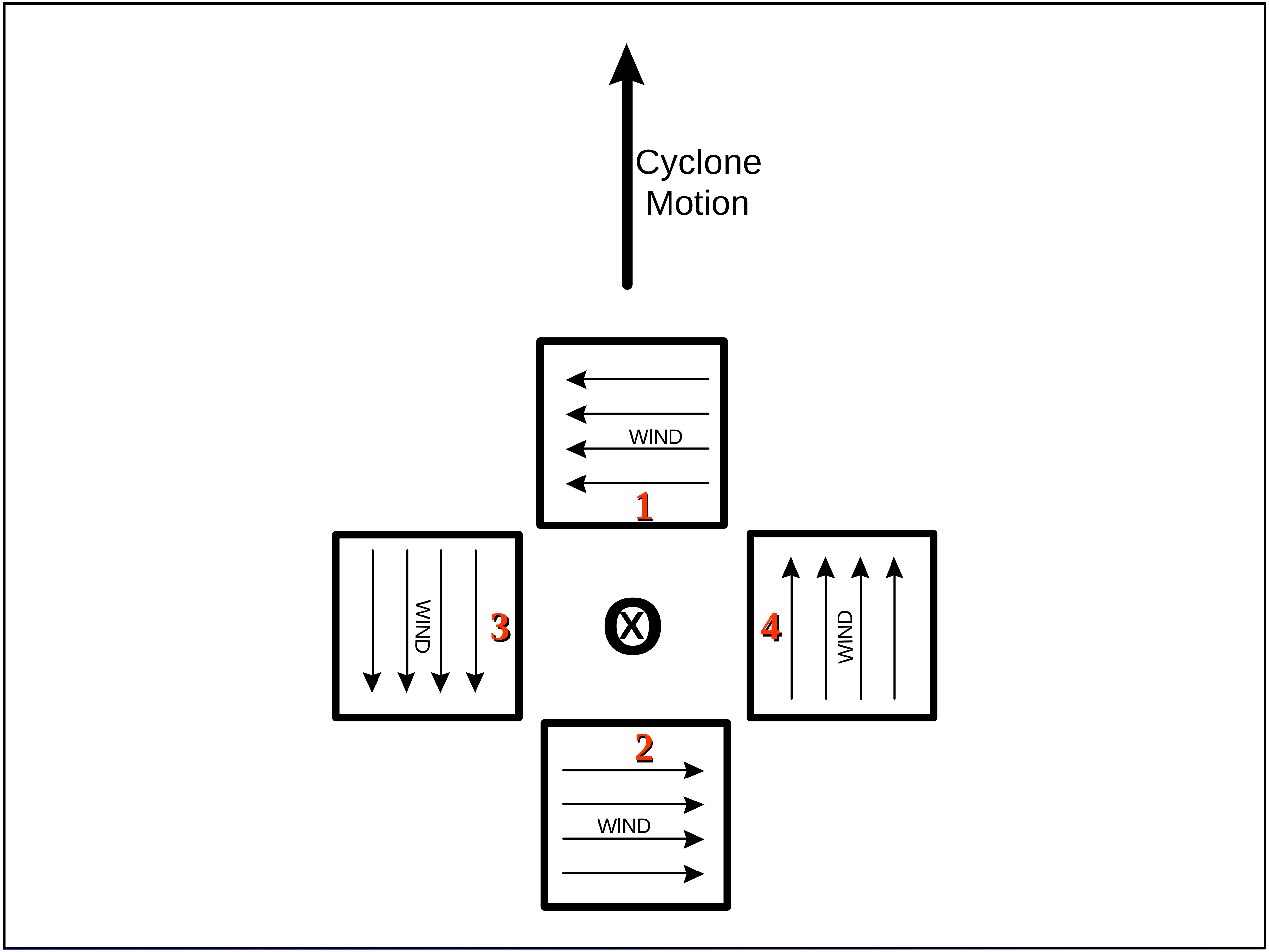


Canadian Hurricane Centre

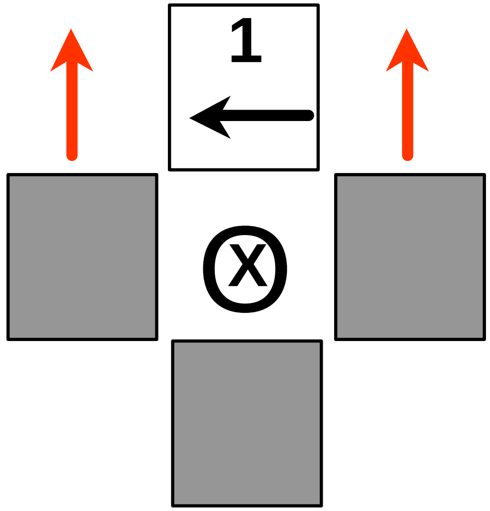
BACKGROUND

Since 1990 a significant number of TCs have moved through eastern Canadian waters, accompanied by extreme waves (H_{SIG} 13-17 m and/or H_{MAX} 25-30 m) generated by a dynamic ("trapped") fetch (Bowyer & MacAfee)

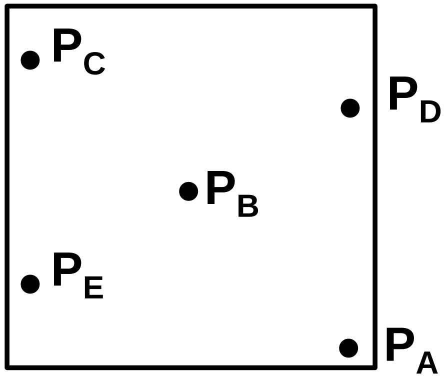
1995 – Interest in trapped-fetch waves spawned
2000 – Basic theory & model developed
2003 – Theory & model significantly refined
2004 – Papers submitted to WAF (awaiting 2nd review)


Cyclone
Motion
WIND
1
WIND
3
X
4
WIND
2
WIND

Winds Perpendicular to Fetch Motion

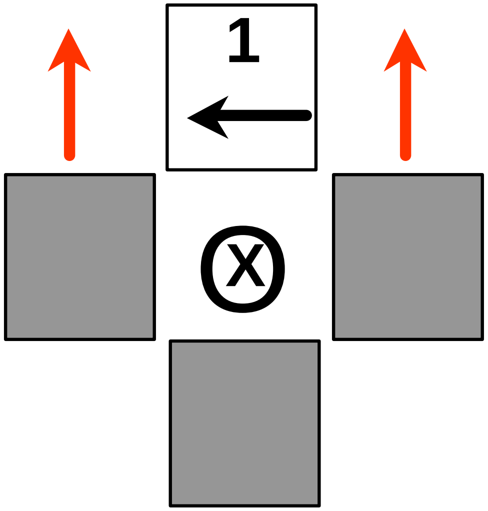


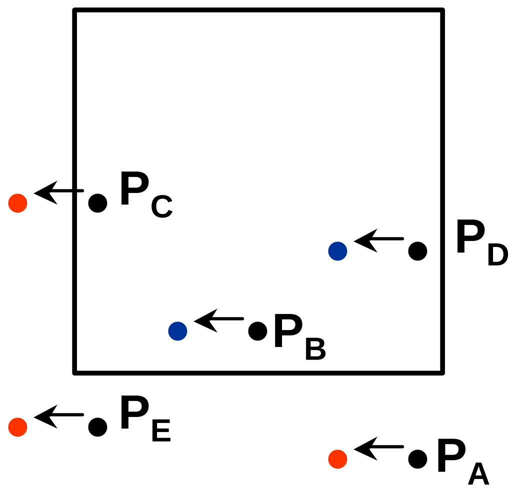
Which waves will remain in the fetch the longest?



Time T_0

Winds Perpendicular to Fetch Motion



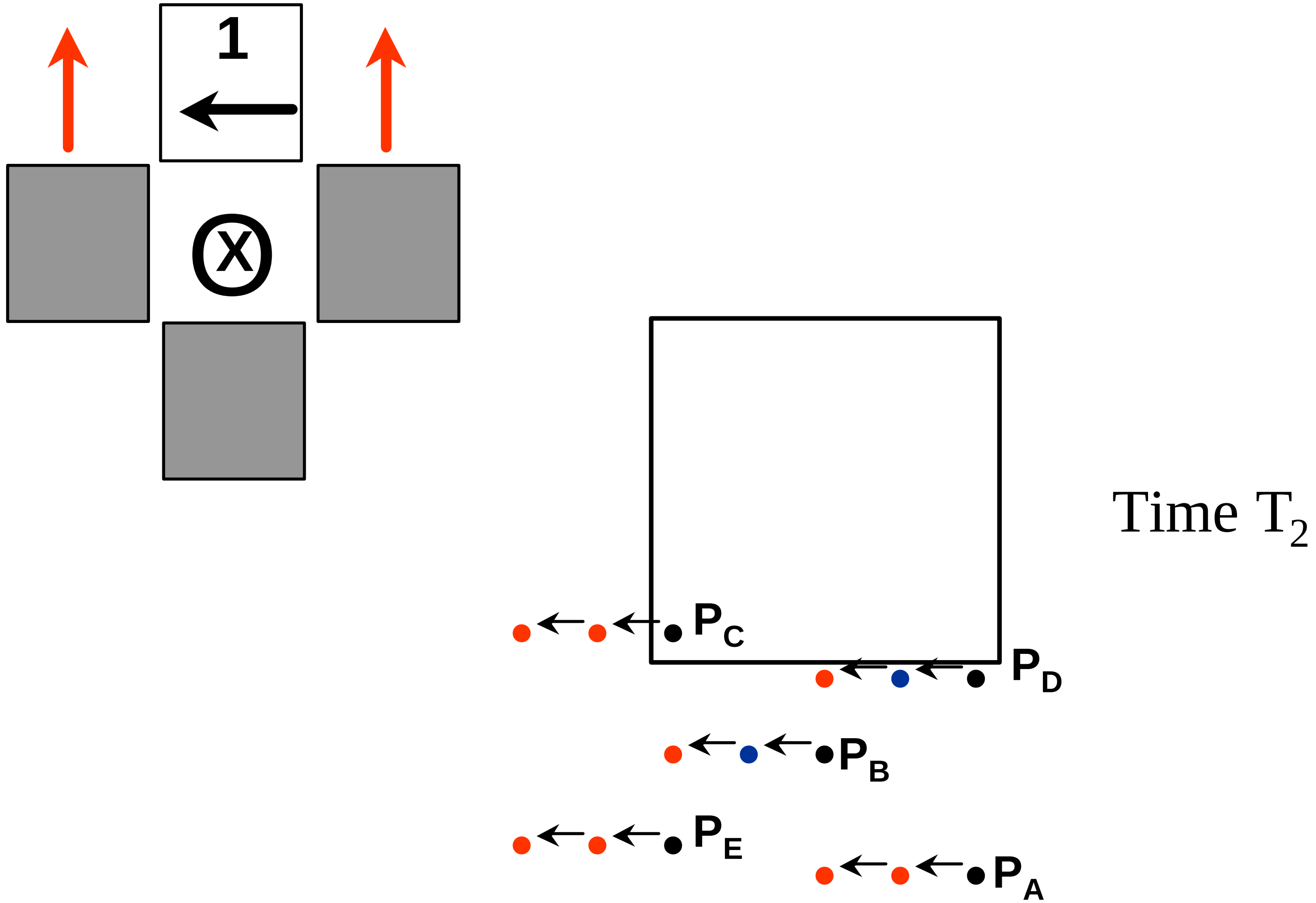


Time T_1

Waves from P_A & P_C & P_E grew for less than 1 time-step before moving outside the fetch

Waves from P_B & P_D have grown for 1 time-step

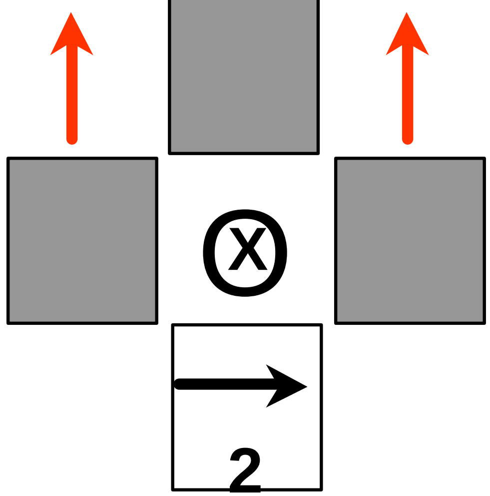
Winds Perpendicular to Fetch Motion



Waves from P_B moved outside the fetch after 1 time-step

Waves from P_D grew for almost 2 time-steps

Winds Perpendicular to Fetch Motion



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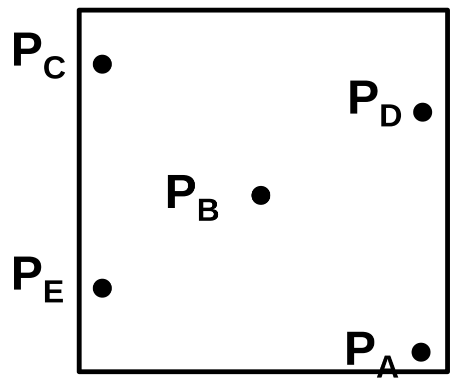
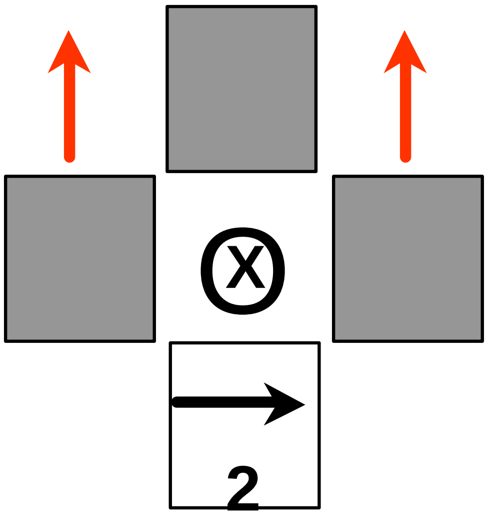


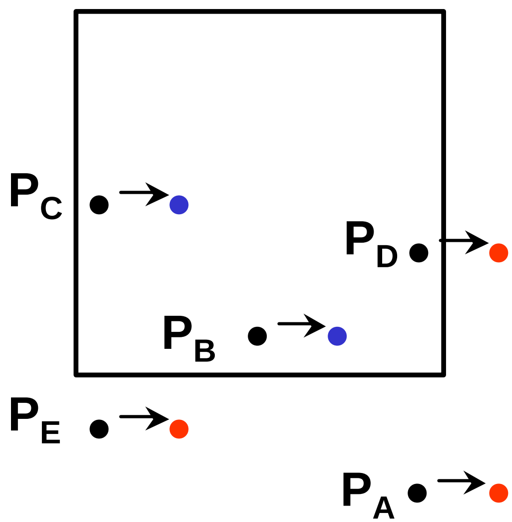
Time T_0

Winds Perpendicular to Fetch Motion



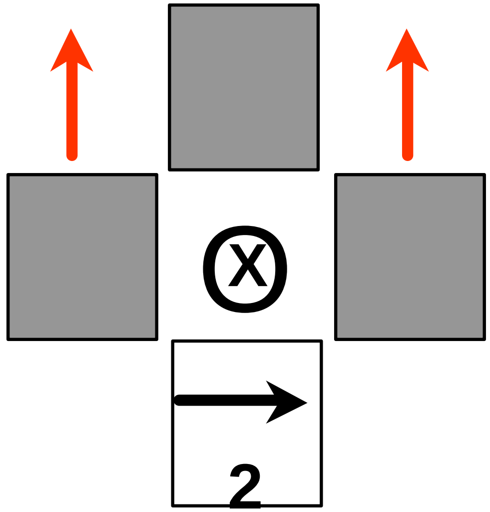
Waves from P_A & P_D & P_E grew for less than 1 time-step before moving outside the fetch

Waves from P_C & P_B have grown for 1 time-step

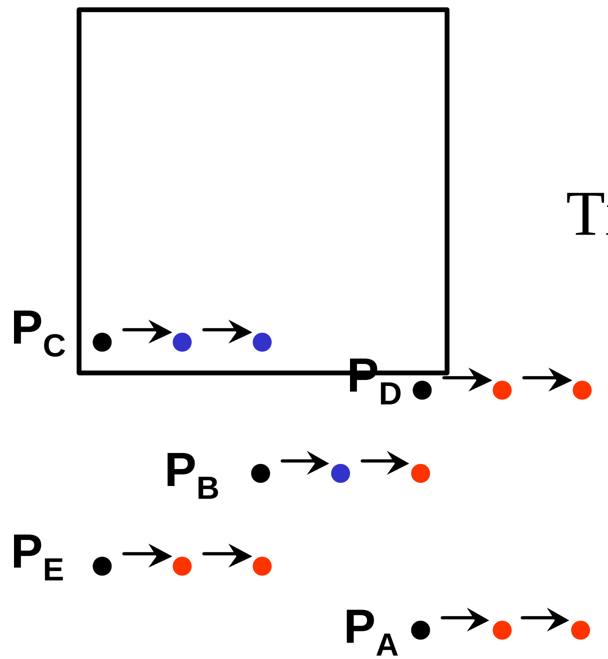


Time T_1

Winds Perpendicular to Fetch Motion



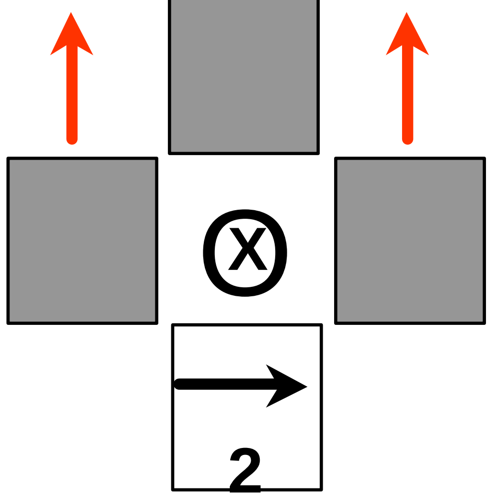
Time T_2



Waves from P_B moved outside the fetch after 1 time-step

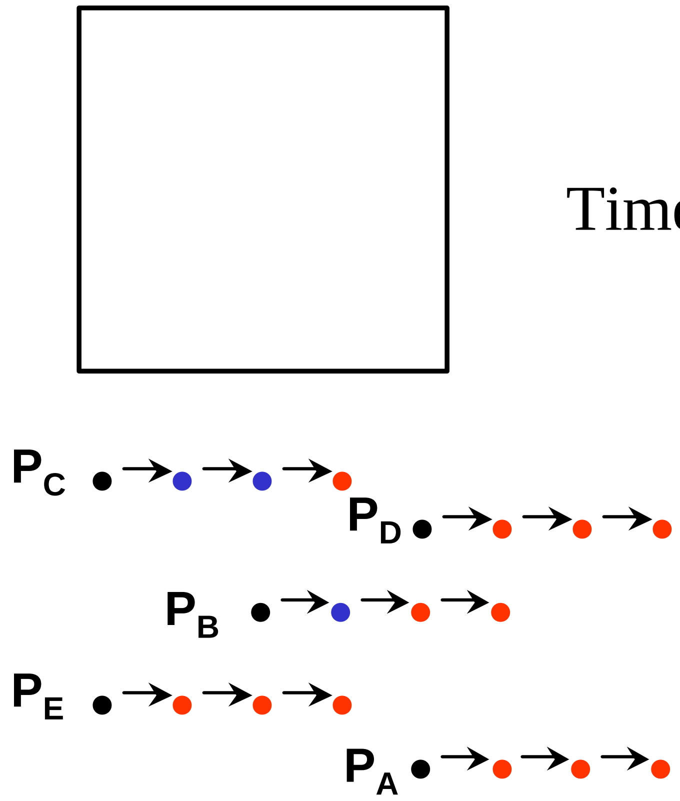
Waves from P_C have grown for 2 time-steps

Winds Perpendicular to Fetch Motion

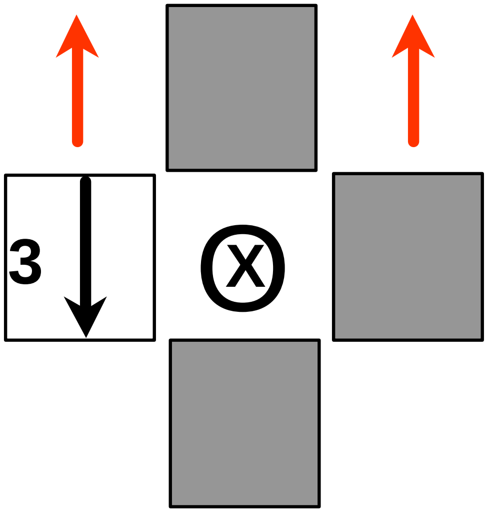


Waves from P_C grew for more than 2 time-steps before moving outside the fetch

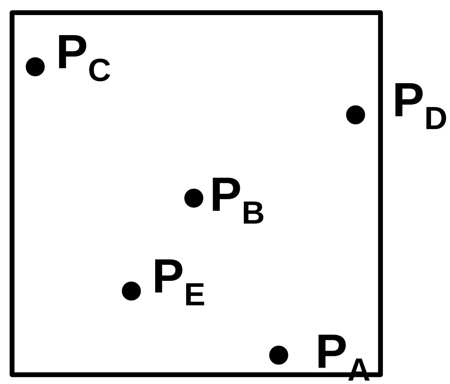
Time T_3



Winds Opposing Fetch Motion

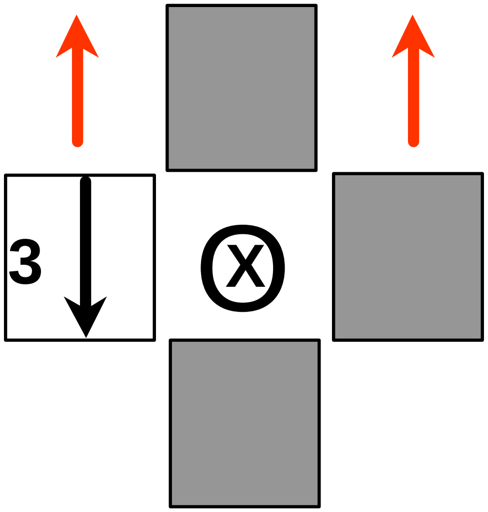


Which waves will remain in the fetch the longest?



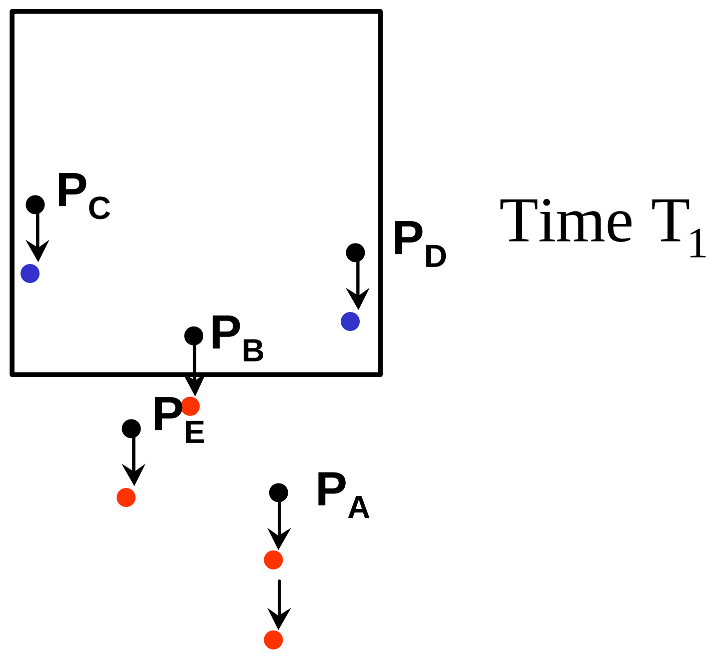
Time T_0

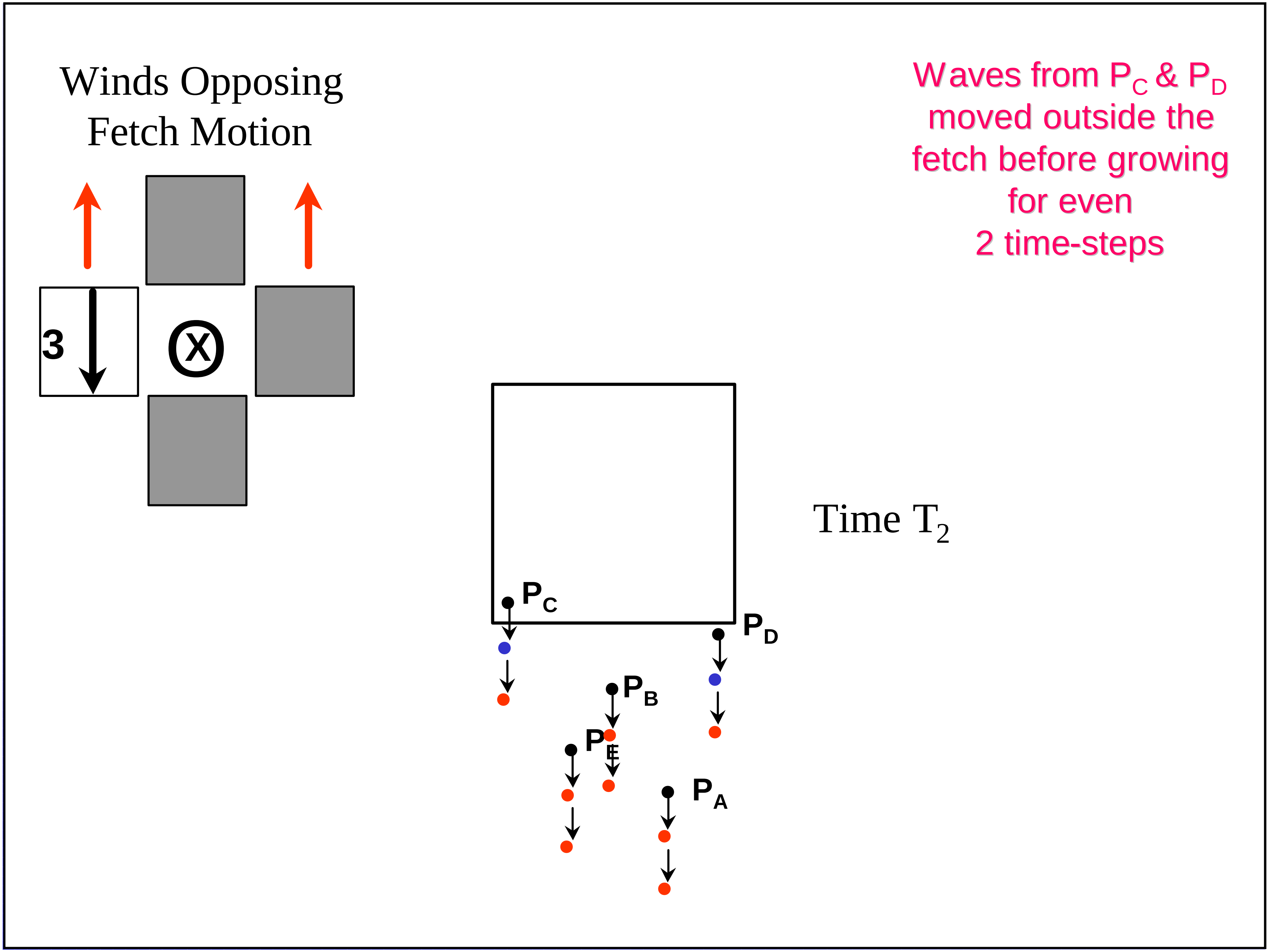
Winds Opposing Fetch Motion



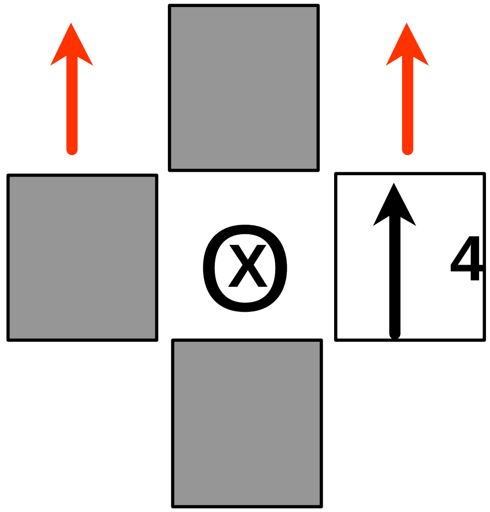
Waves from P_C & P_D grew for 1 time-step

Waves from P_E & P_B & P_A grew for less than 1 time-step before moving outside the fetch

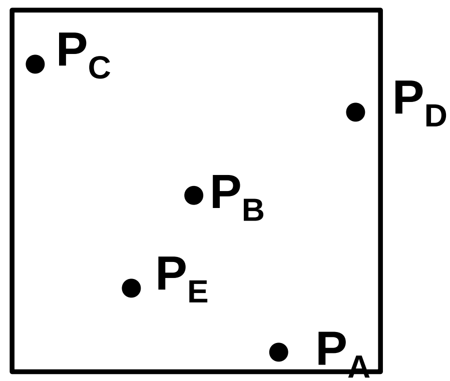



Winds Opposing
Fetch Motion
3
Waves from P_C & P_D
moved outside the
fetch before growing
for even
2 time-steps
Time T_2
P_C
P_D
P_B
P_E
P_A

Winds With
Fetch Motion

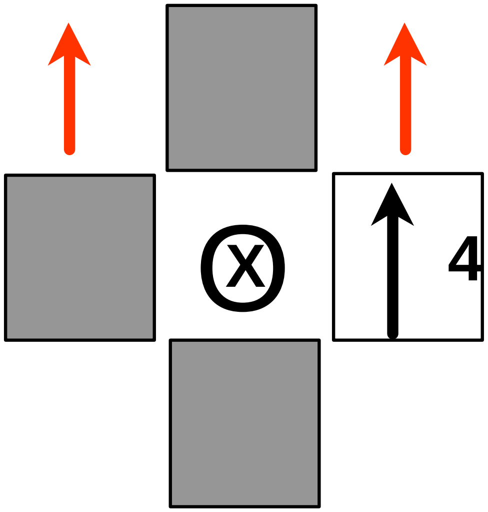


Which waves will remain in the fetch the longest?

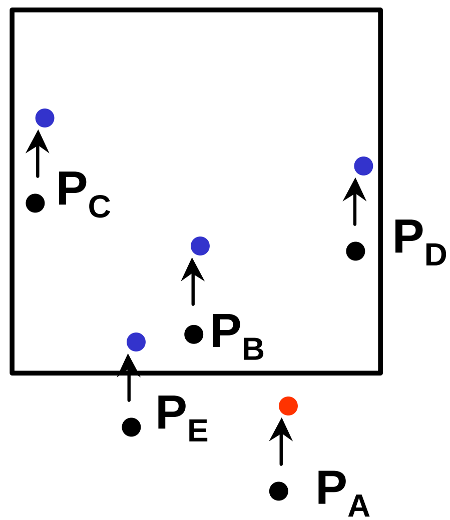


Time T_0

Winds With Fetch Motion

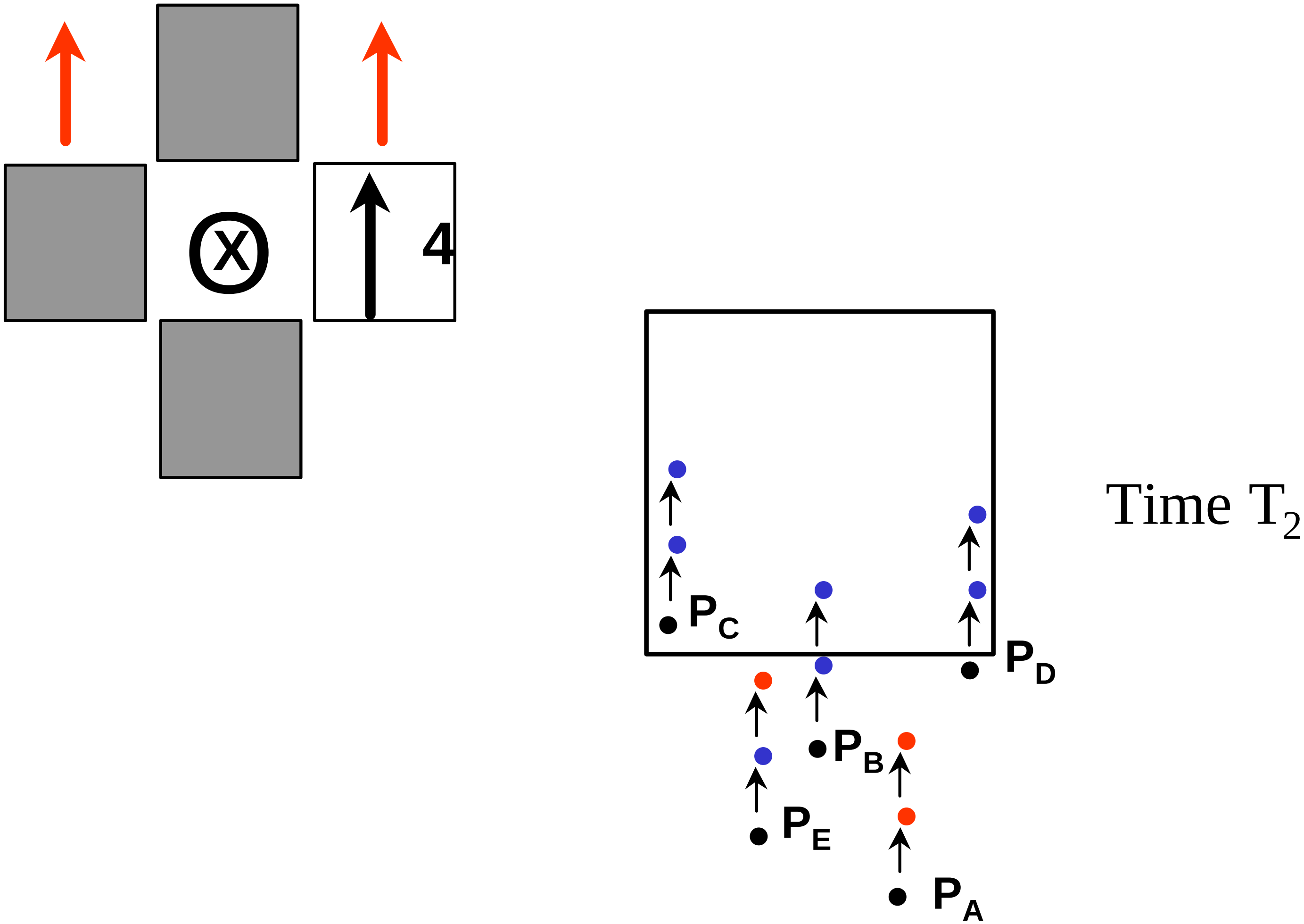


Waves from P_A fell behind the fetch before even 1 time-step



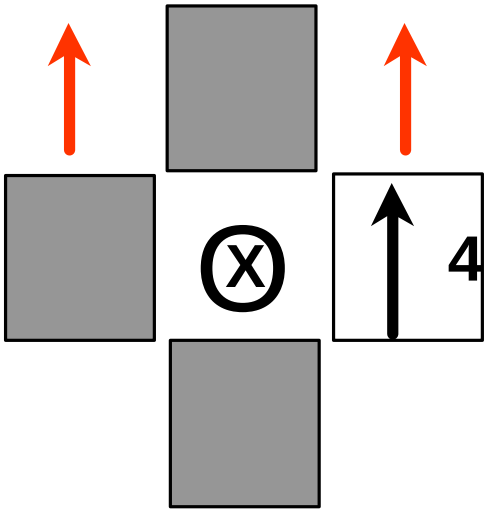
Time T_1

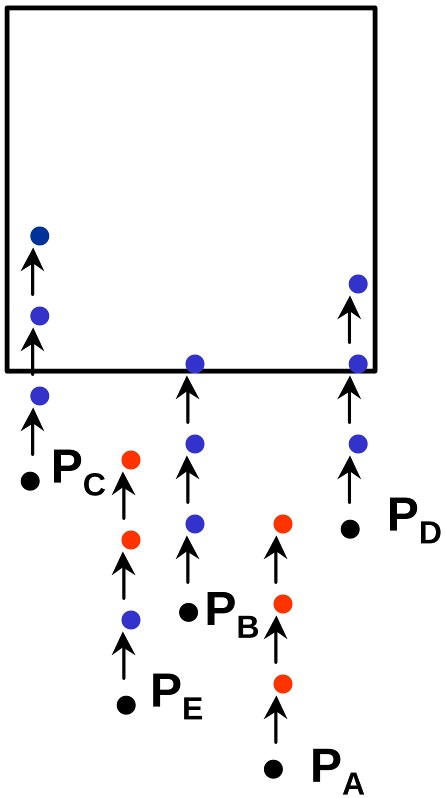
Winds With Fetch Motion



Waves from P_E grew for more than 1 time-step but were then outrun by the fetch

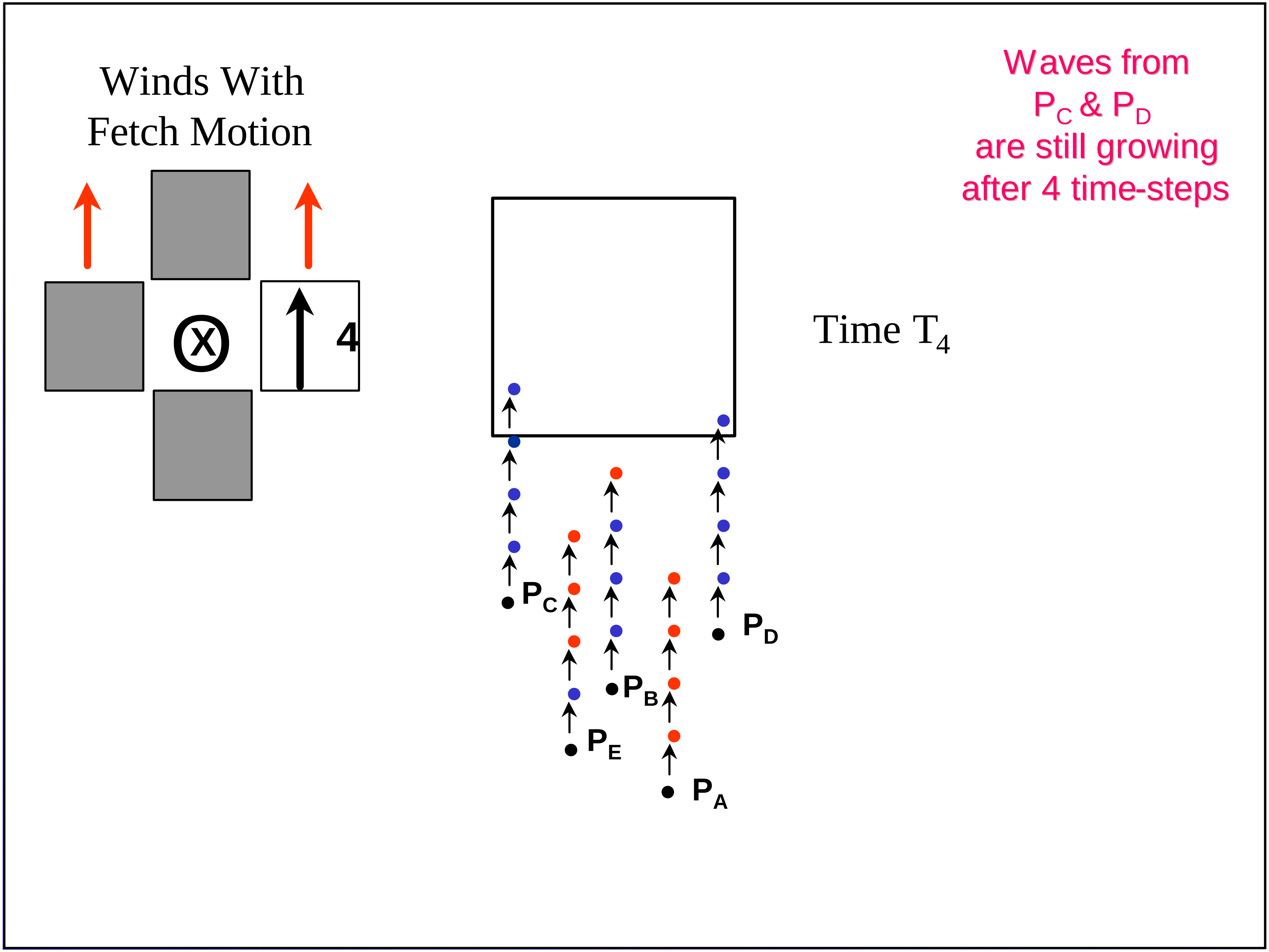
Winds With Fetch Motion





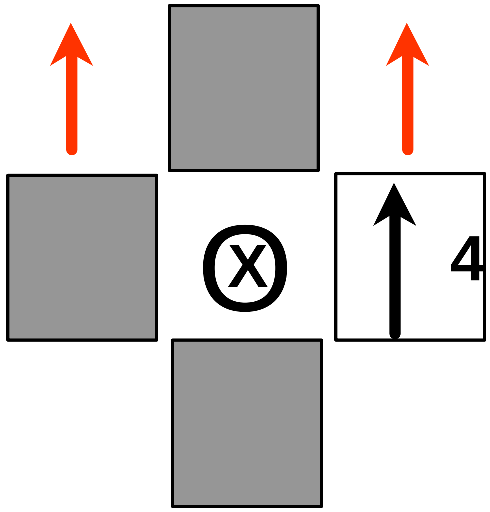
Time T_3

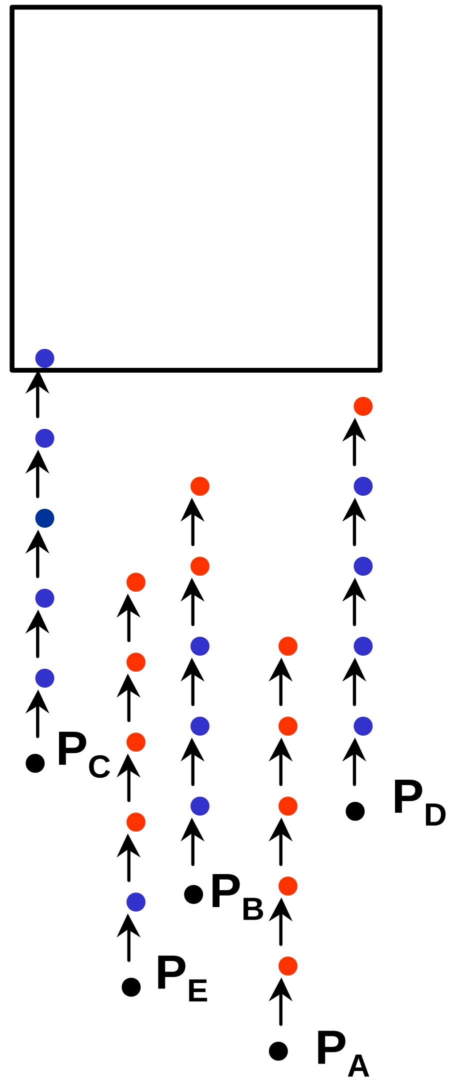
Waves from P_C & P_B & P_D are still growing after 3 time-steps . . . although those from P_B will soon be outrun by the fetch



Winds With
Fetch Motion
4
Time T_4
P_C
P_D
P_B
P_E
P_A
Waves from
P_C & P_D
are still growing
after 4 time-steps

Winds With Fetch Motion



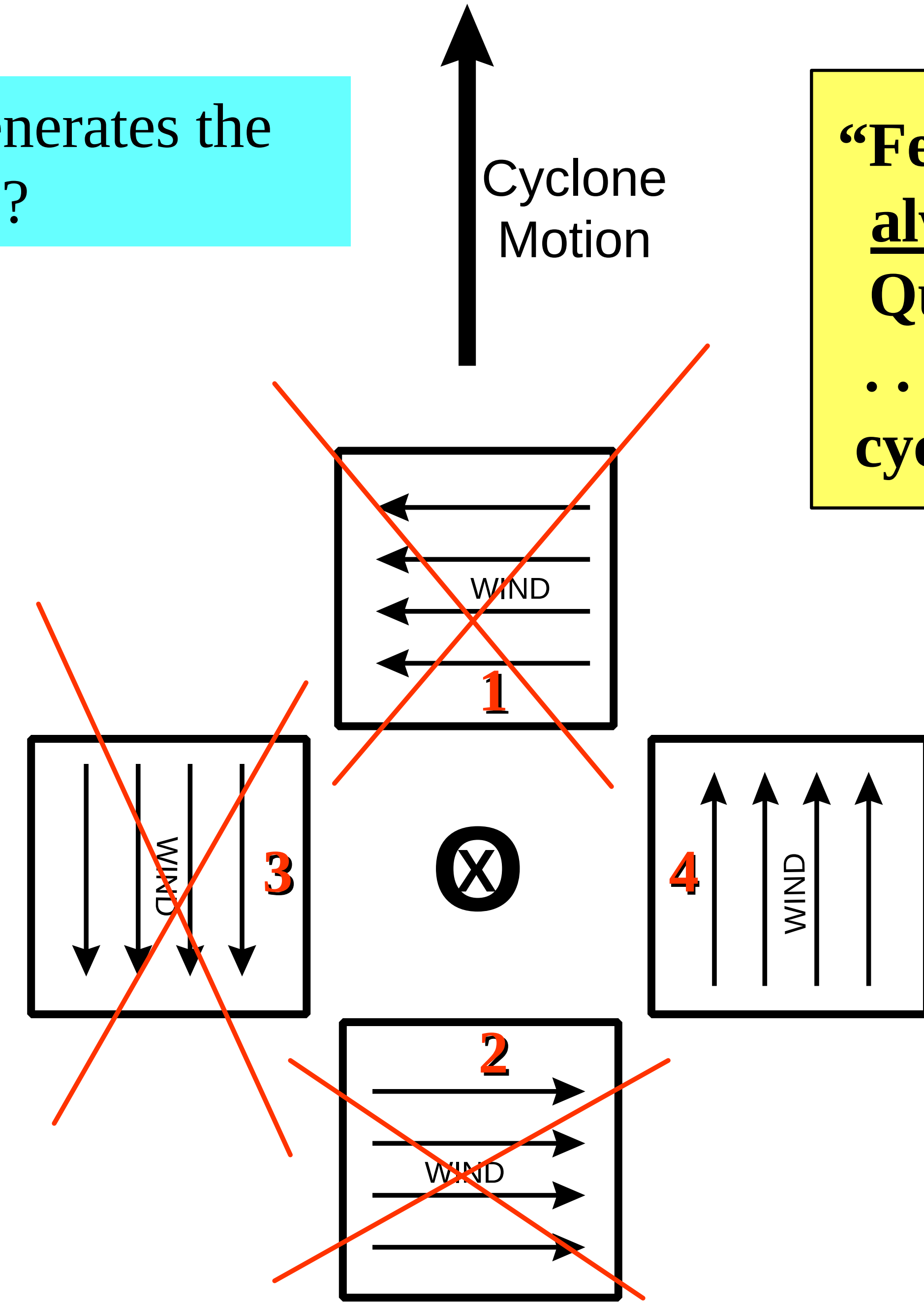


Time T_5

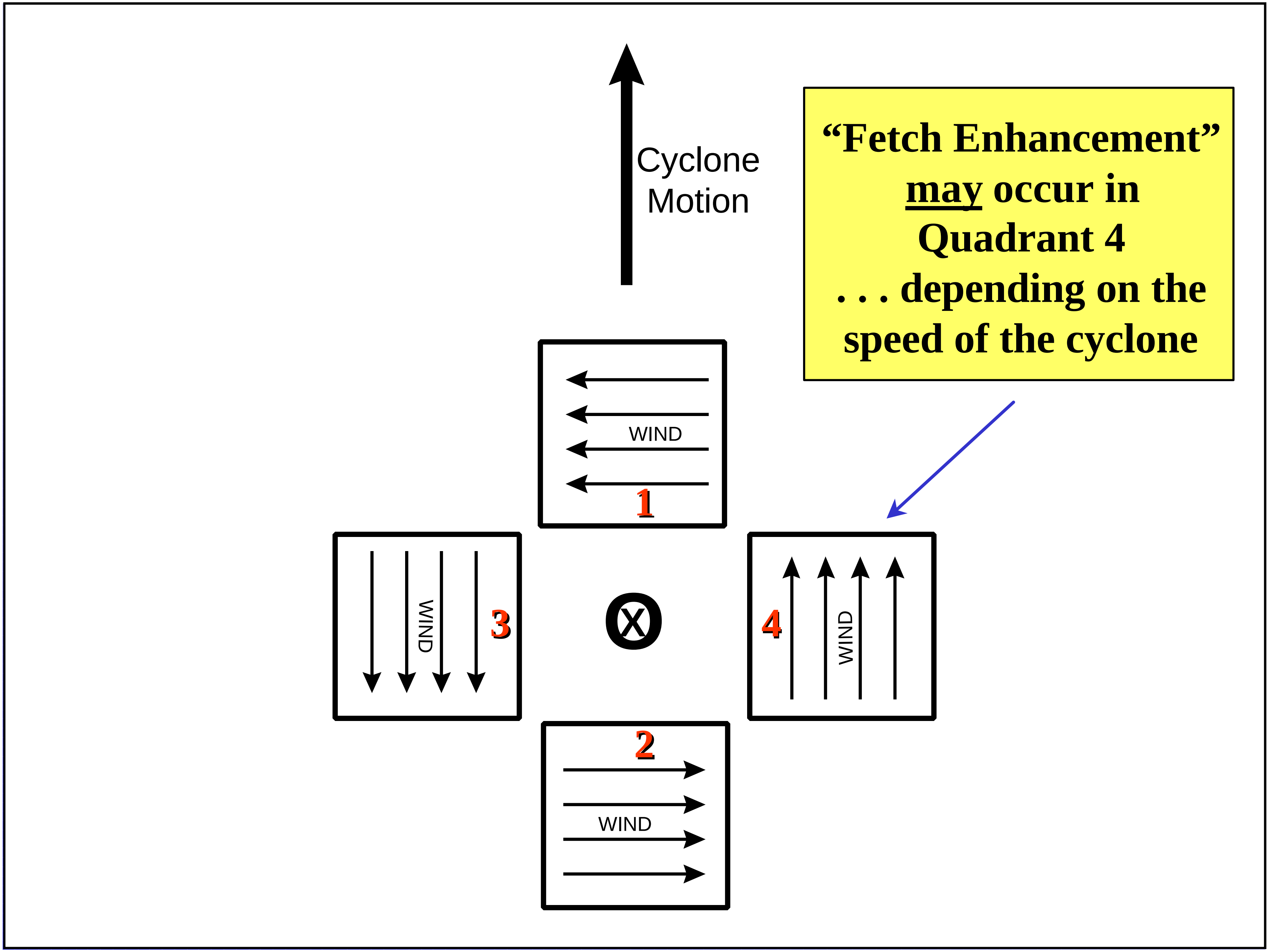
Waves from P_D were finally outrun by the fetch after more than 4 time-steps

Waves from P_C are still growing after 5 time-steps

Which fetch generates the smallest waves?



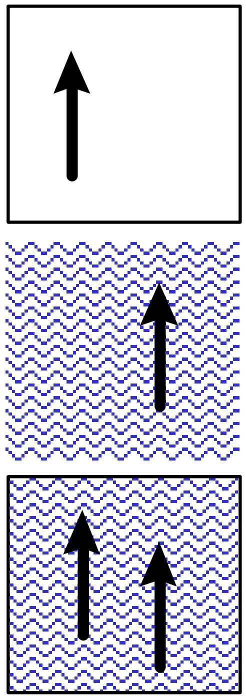
"Fetch Reduction" <u>always</u> occurs in Quadrants 1-2-3 . . . as long as the cyclone is moving


Cyclone Motion
"Fetch Enhancement" may occur in Quadrant 4 . . . depending on the speed of the cyclone
WIND
1
WIND
3
4
WIND
2
WIND

Waves Moving in Same Direction as Their Storm

Potential for Resonance

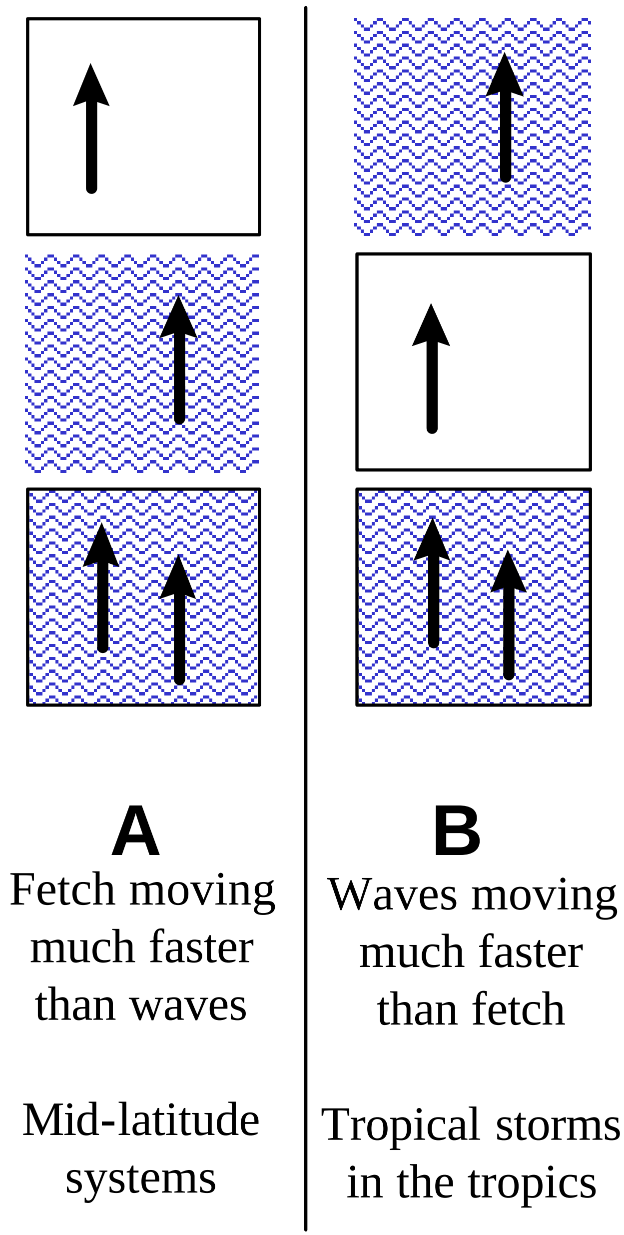
Canadian Hurricane Centre

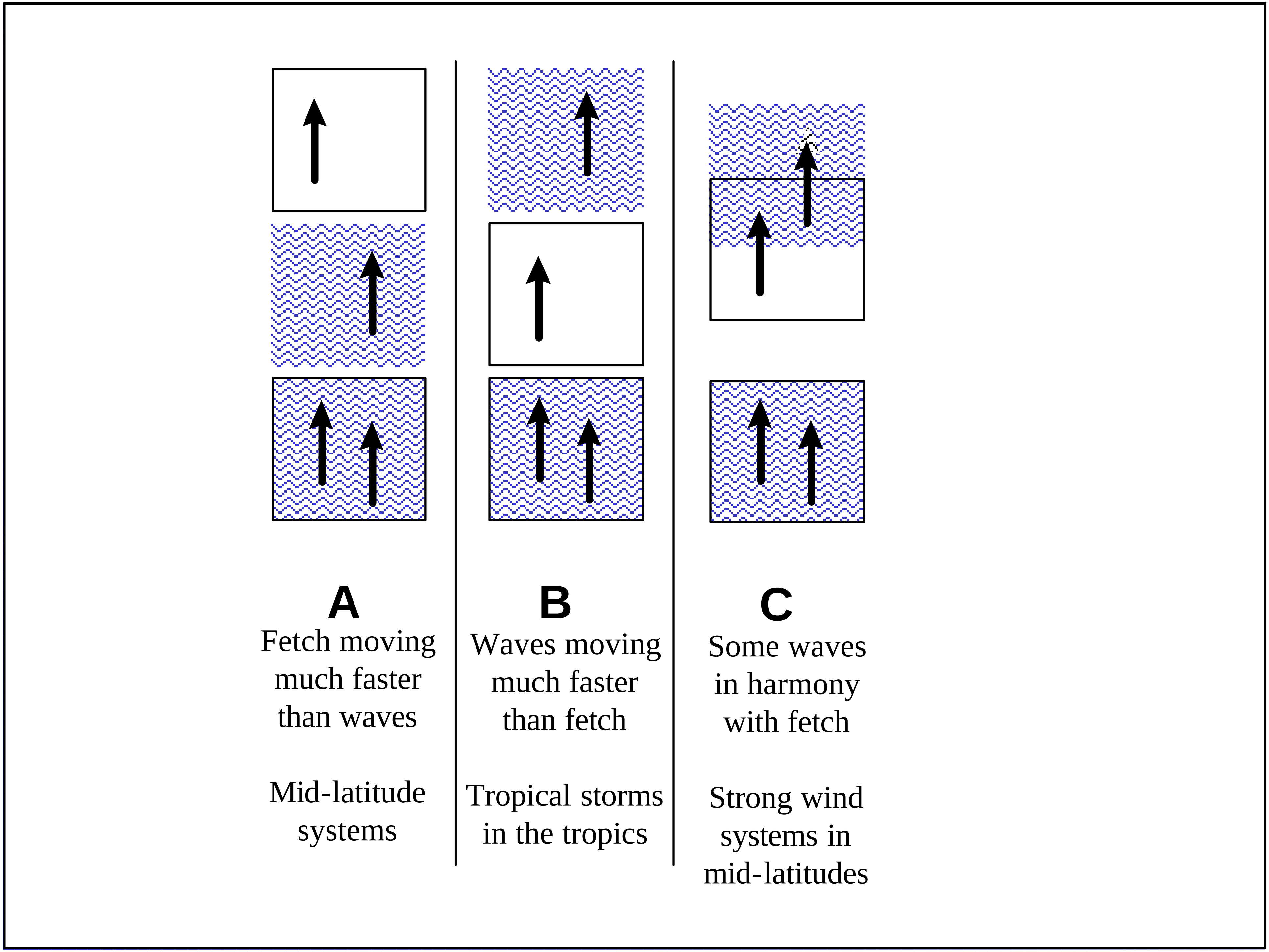


A

Fetch moving much faster than waves

Mid-latitude systems


A
Fetch moving much faster than waves
Mid-latitude systems
B
Waves moving much faster than fetch
Tropical storms in the tropics



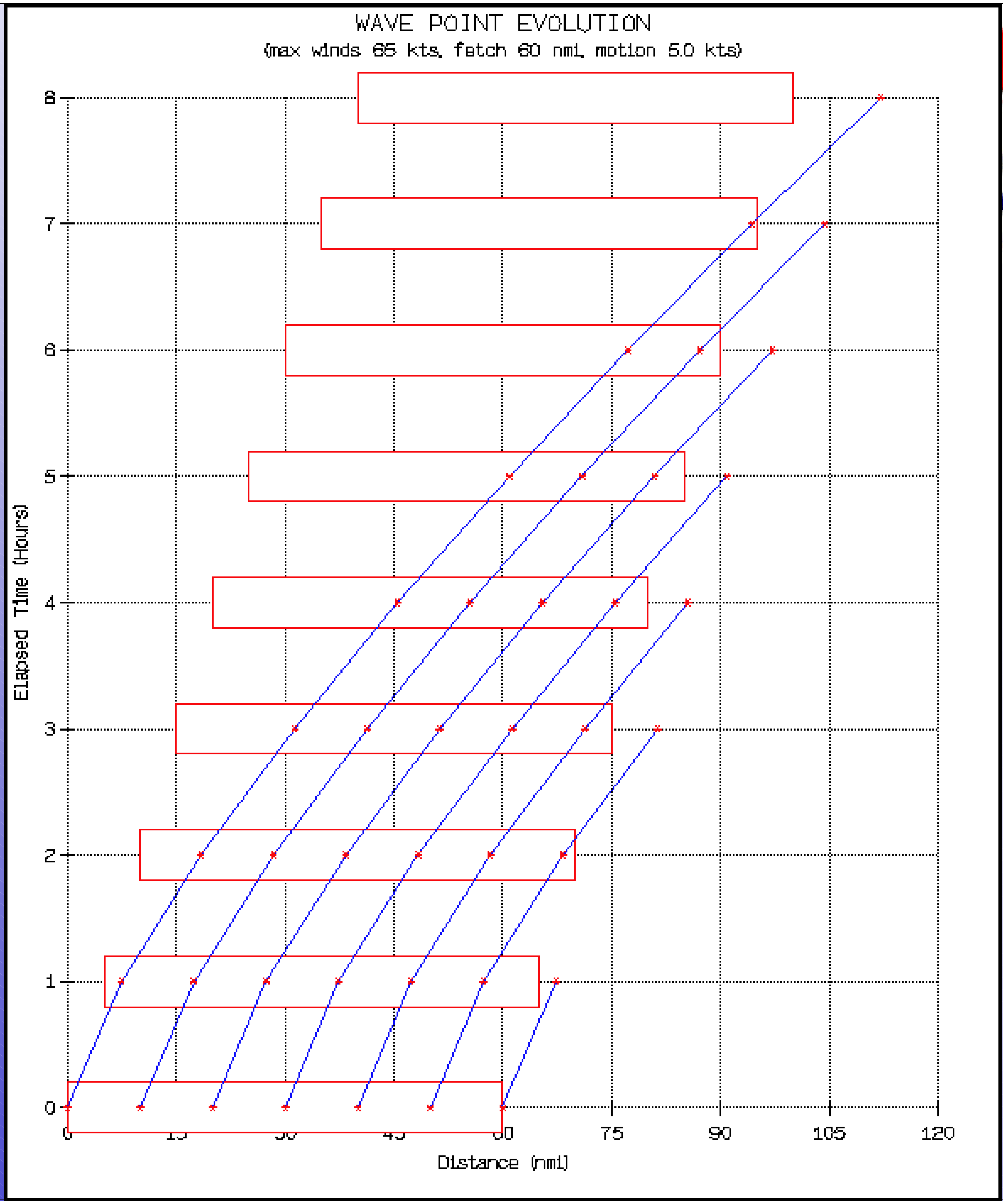
A
Fetch moving much faster than waves
Mid-latitude systems
B
Waves moving much faster than fetch
Tropical storms in the tropics
C
Some waves in harmony with fetch
Strong wind systems in mid-latitudes

Fetches moving with constant speed

Canadian Hurricane Centre

All of the waves quickly outrun the slow-moving storm system

The steady-state solution is reached in 7+ hours.



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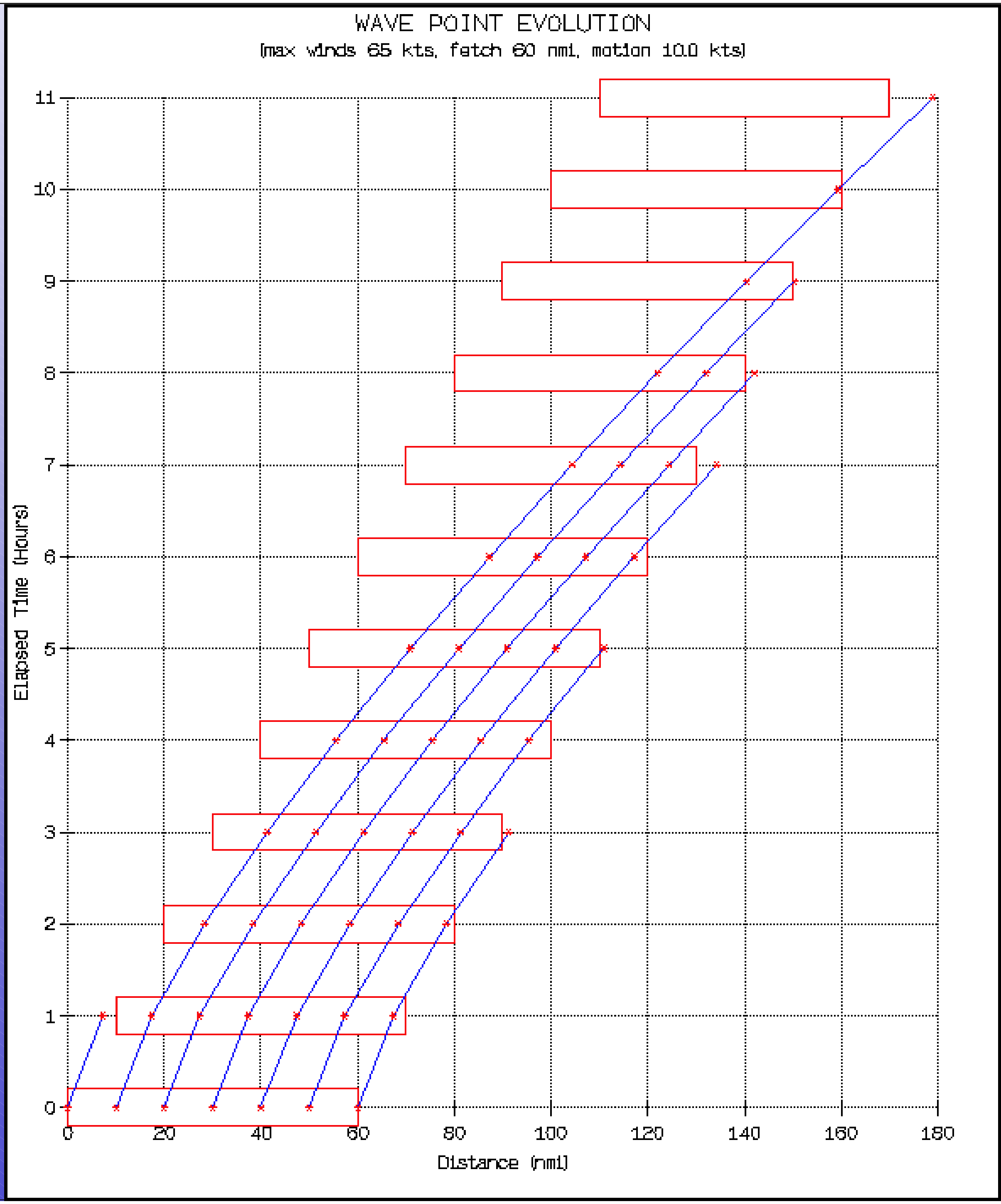
rricane
Centre

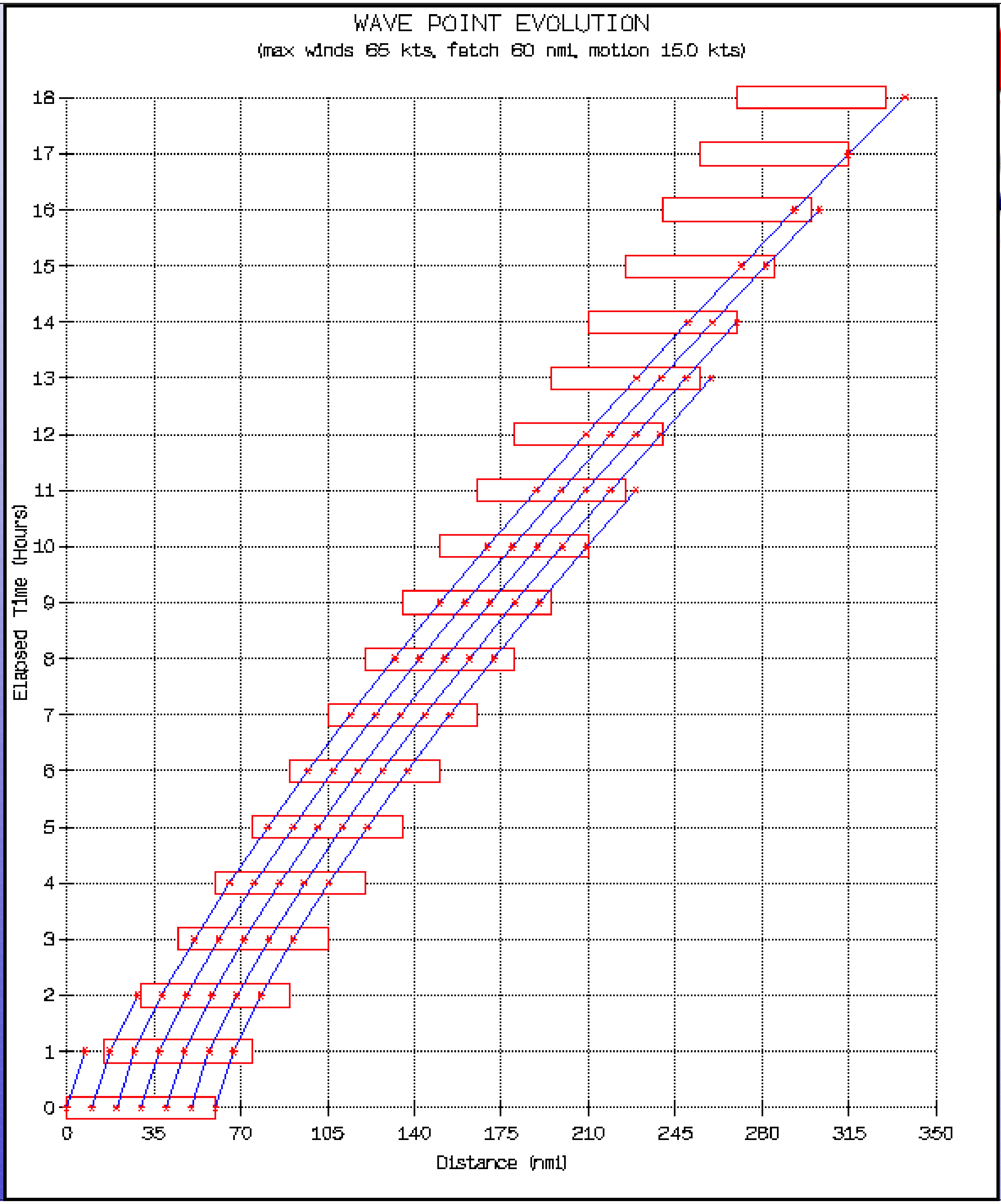
Most of the waves still outrun the slower moving storm system

The steady-state solution is reached in 10+ hours.



Waves leaving the trailing edge of the fetch are outrun by the wind system . . . however, all others move out ahead.

The steady-state solution is reached in 17+ hours.



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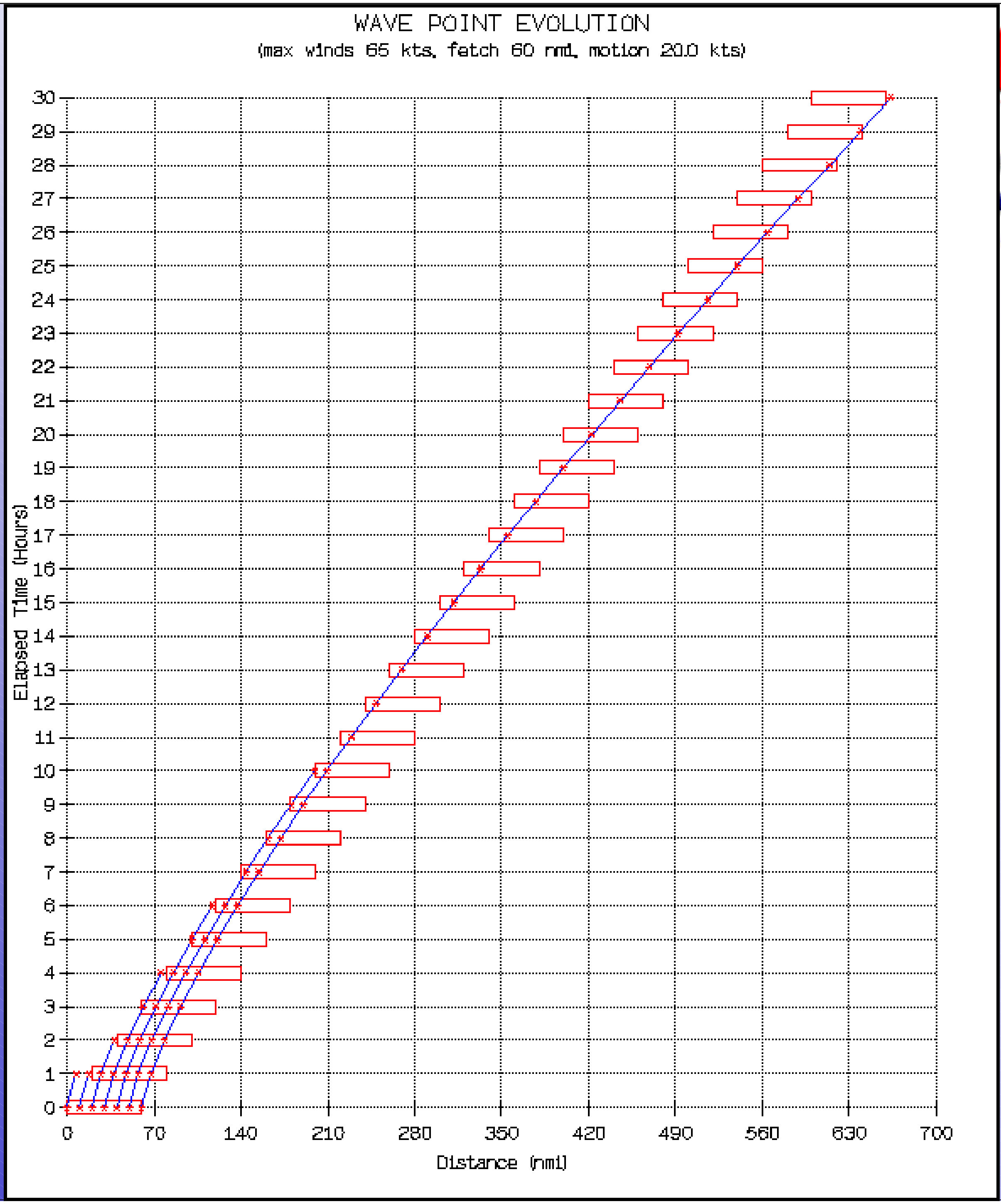
rricane
Centre

Most waves are soon outrun by the initially quicker moving wind system . . . however, waves starting at the leading edge “hold on long enough” until their speed catches up to the system speed . . . and eventually outruns the system.

Steady state is reached in 30 hrs.



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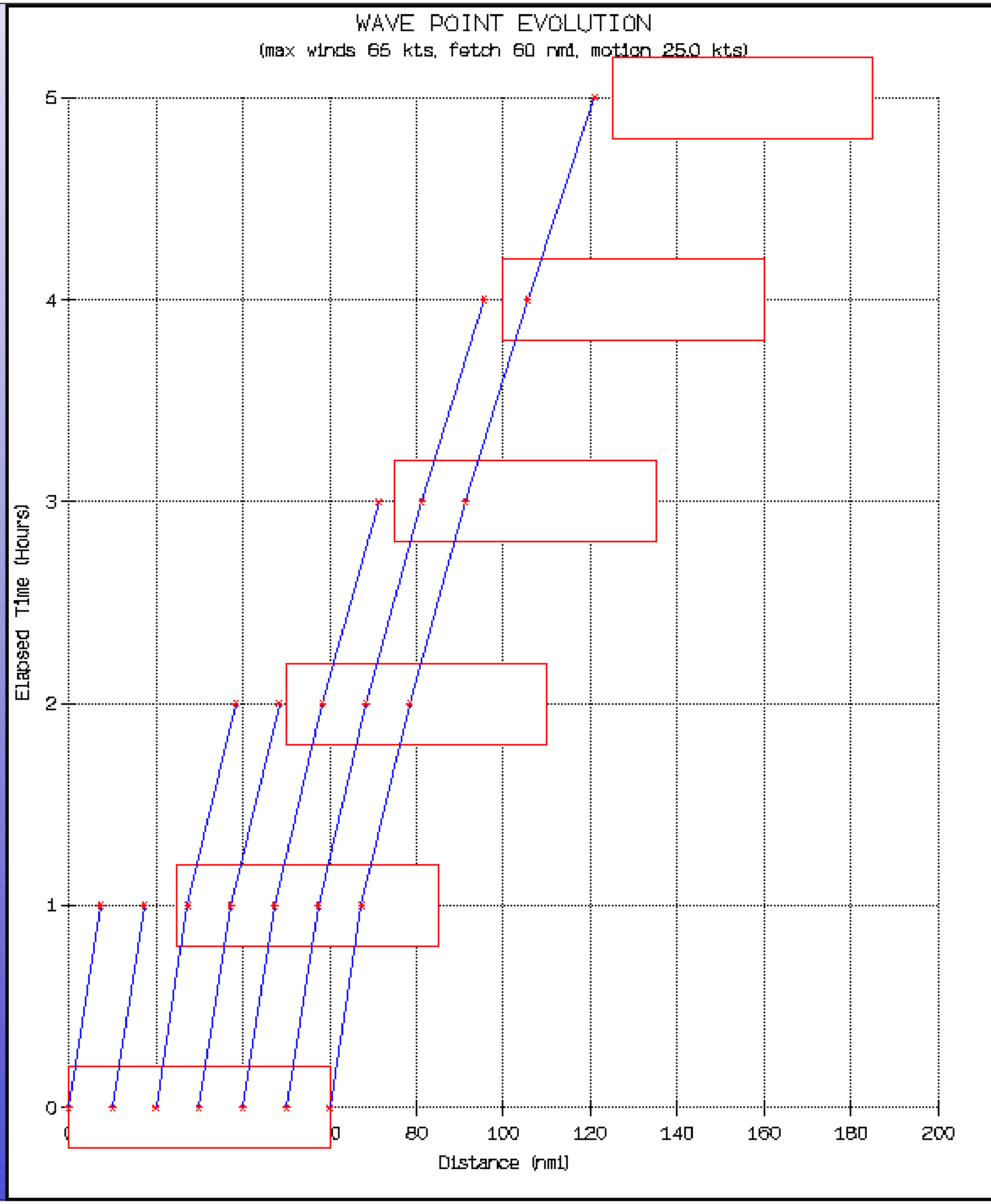
rricane
Centre

All waves are quickly outrun by the much quicker wind system . . . and growth is very limited.

The steady-state solution is reached in under 5 hours.



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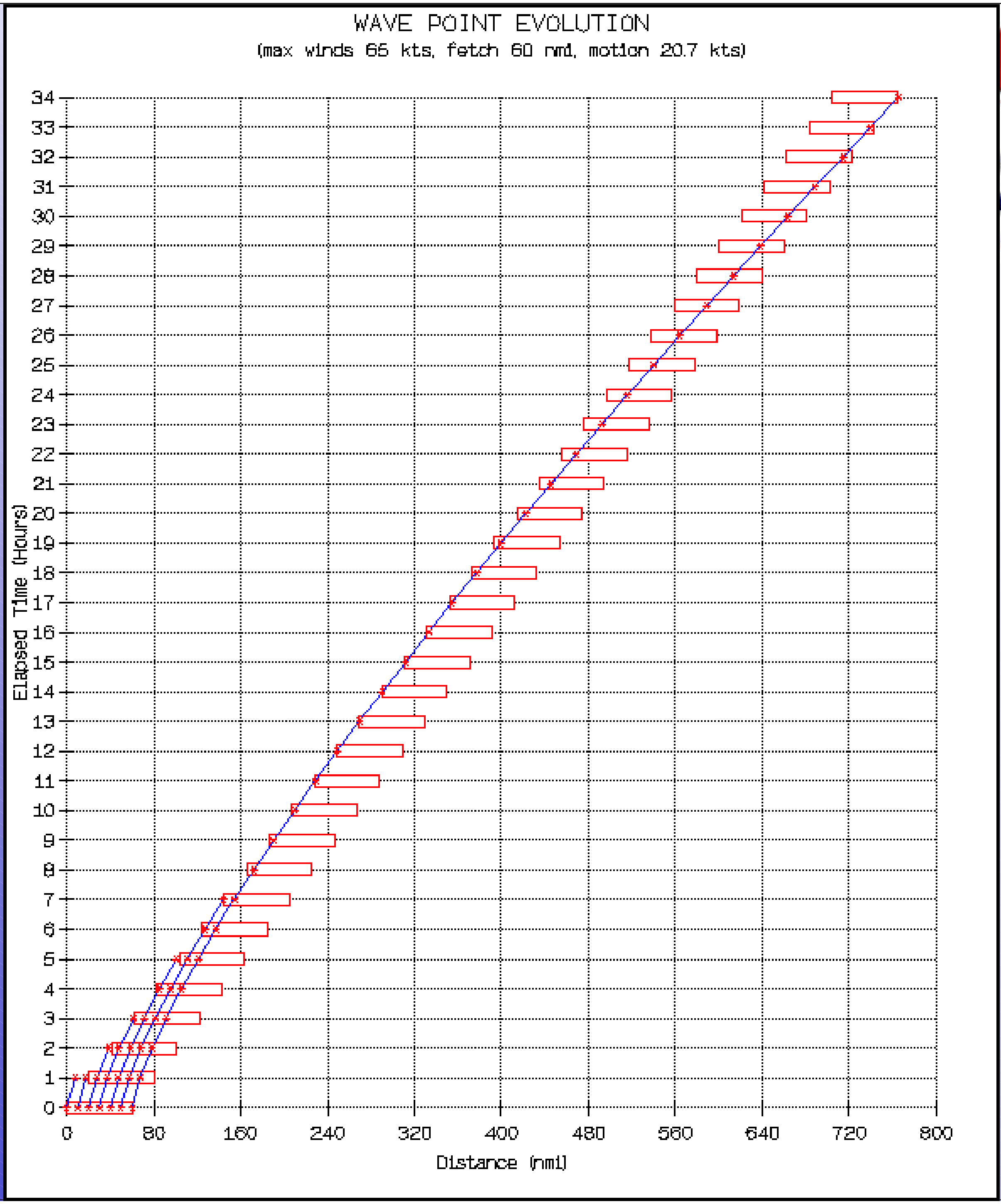
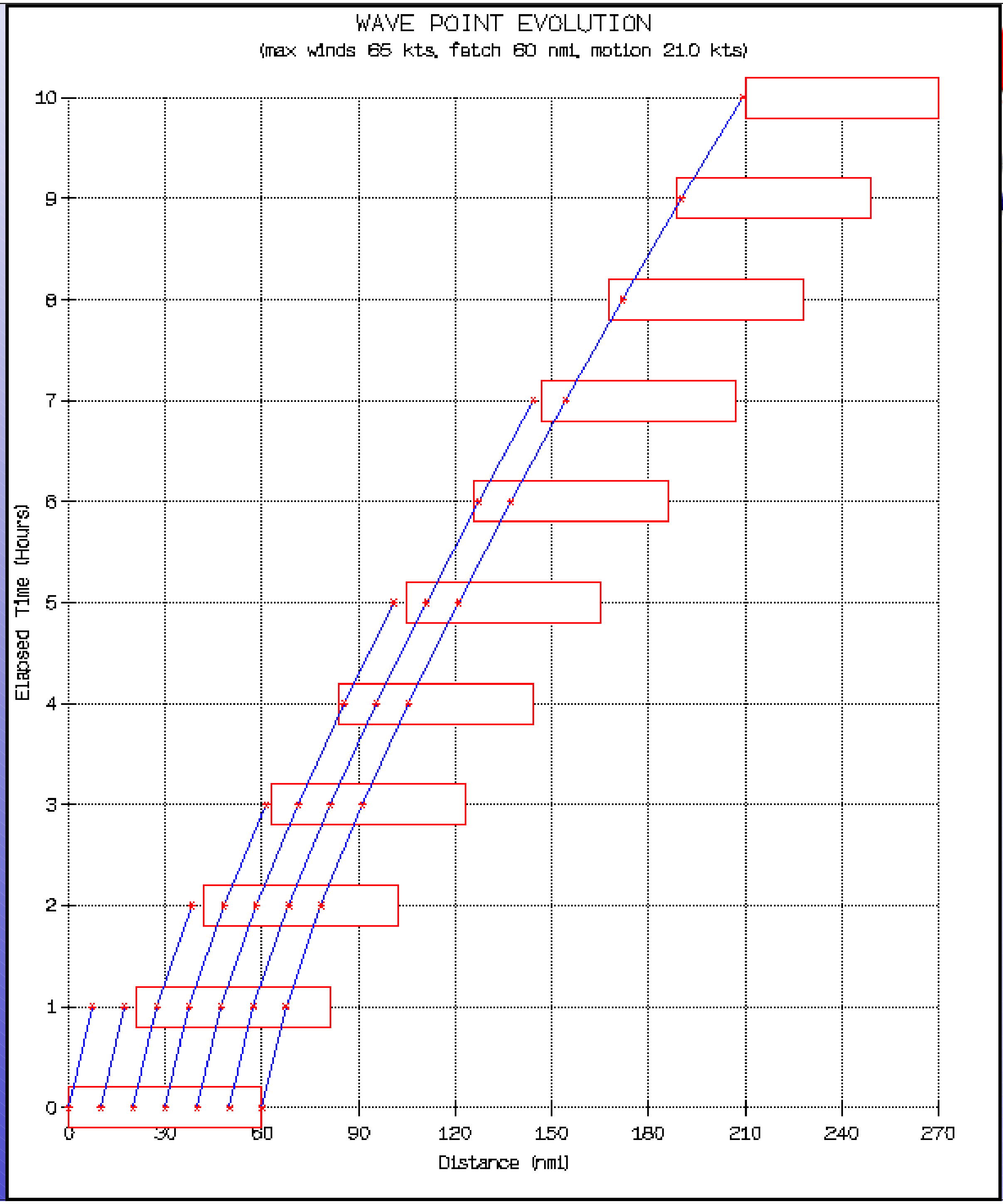
Centre

Maximum wave growth occurs for a constant system speed of 20.7 knots. All speeds greater or less than this will result in lower wave heights.

The steady-state solution is not reached until 34 hours.



Even for speeds only slightly greater, there is a significant difference in the resonance of the storm-waves system.



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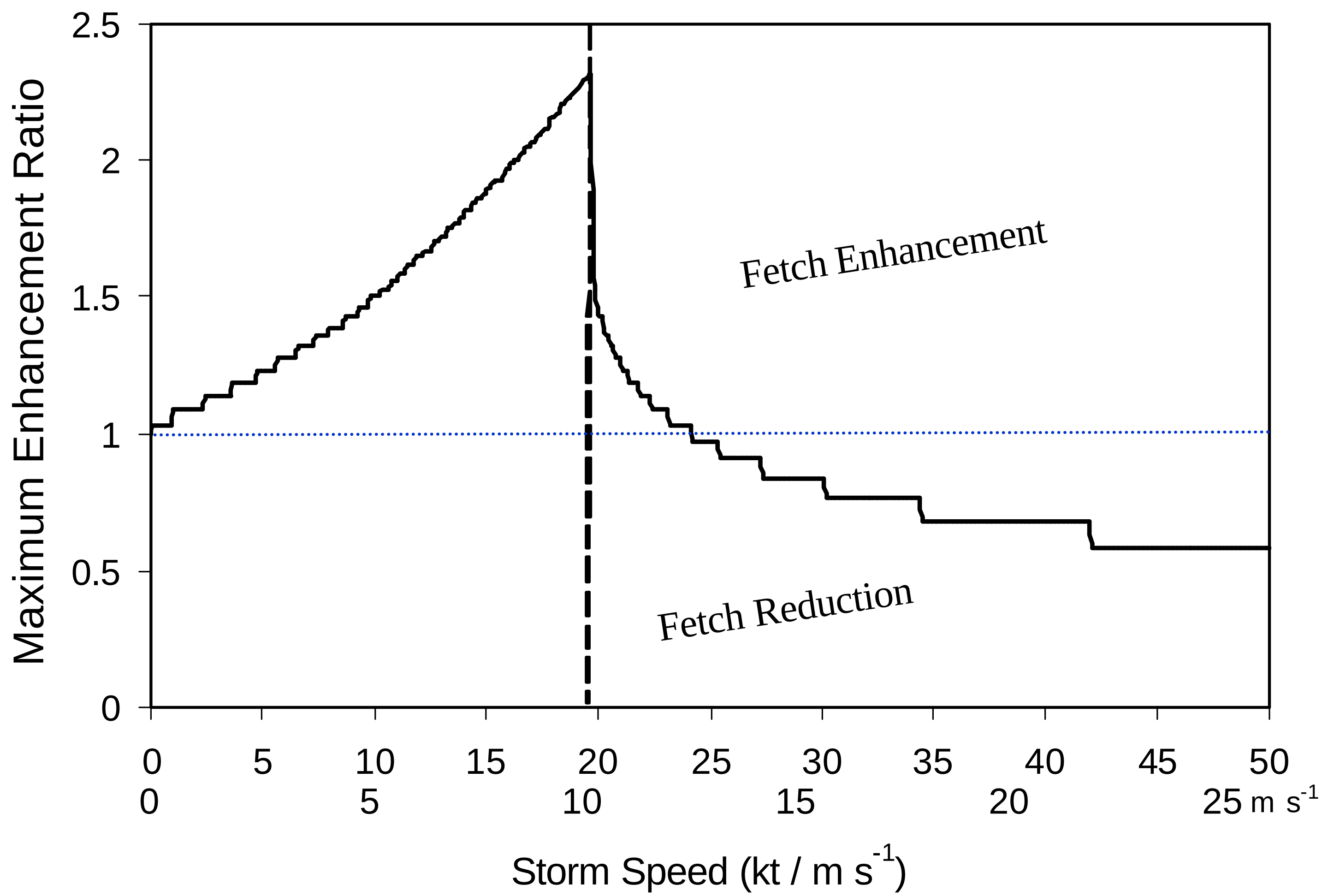
rricane
Centre



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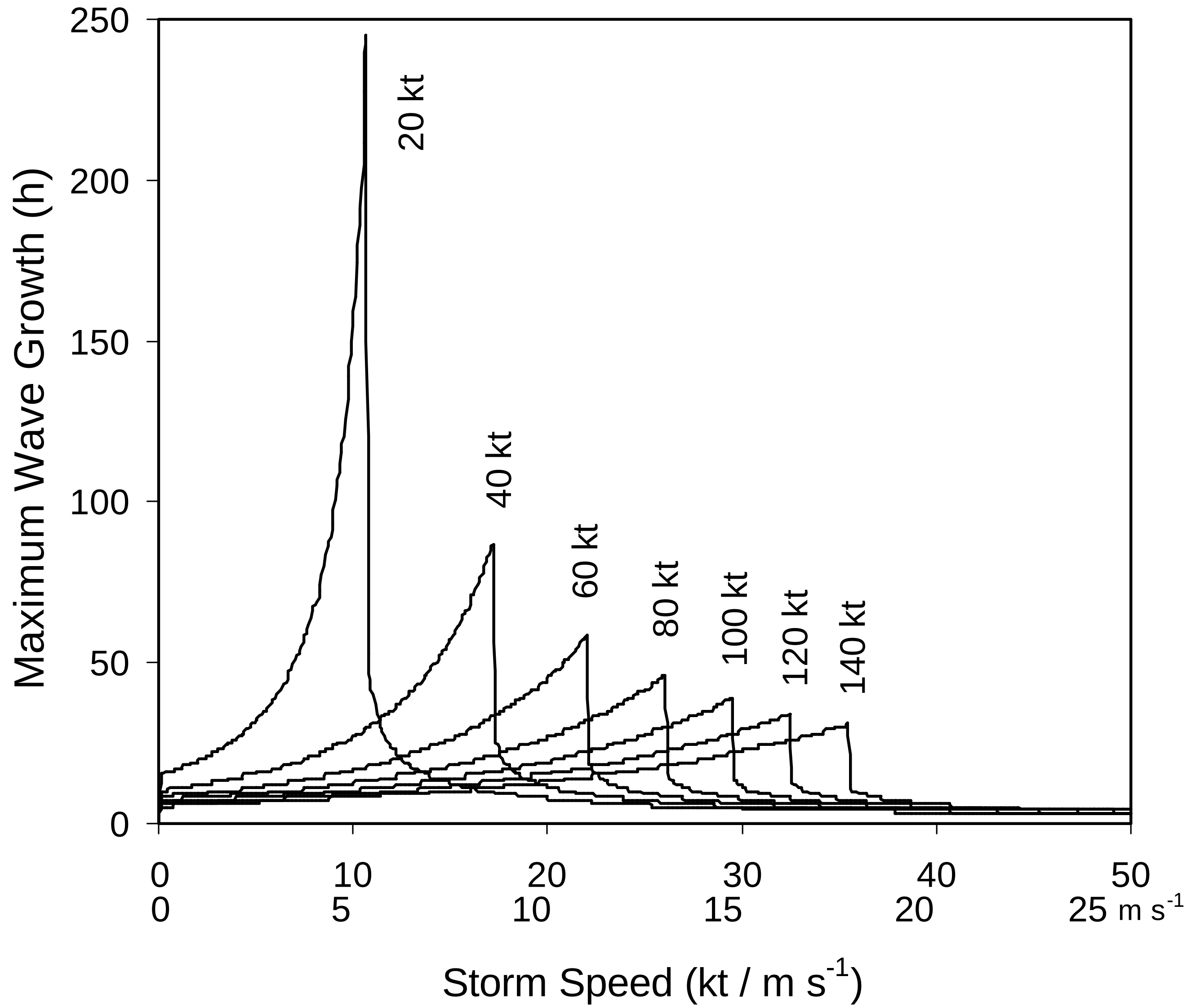

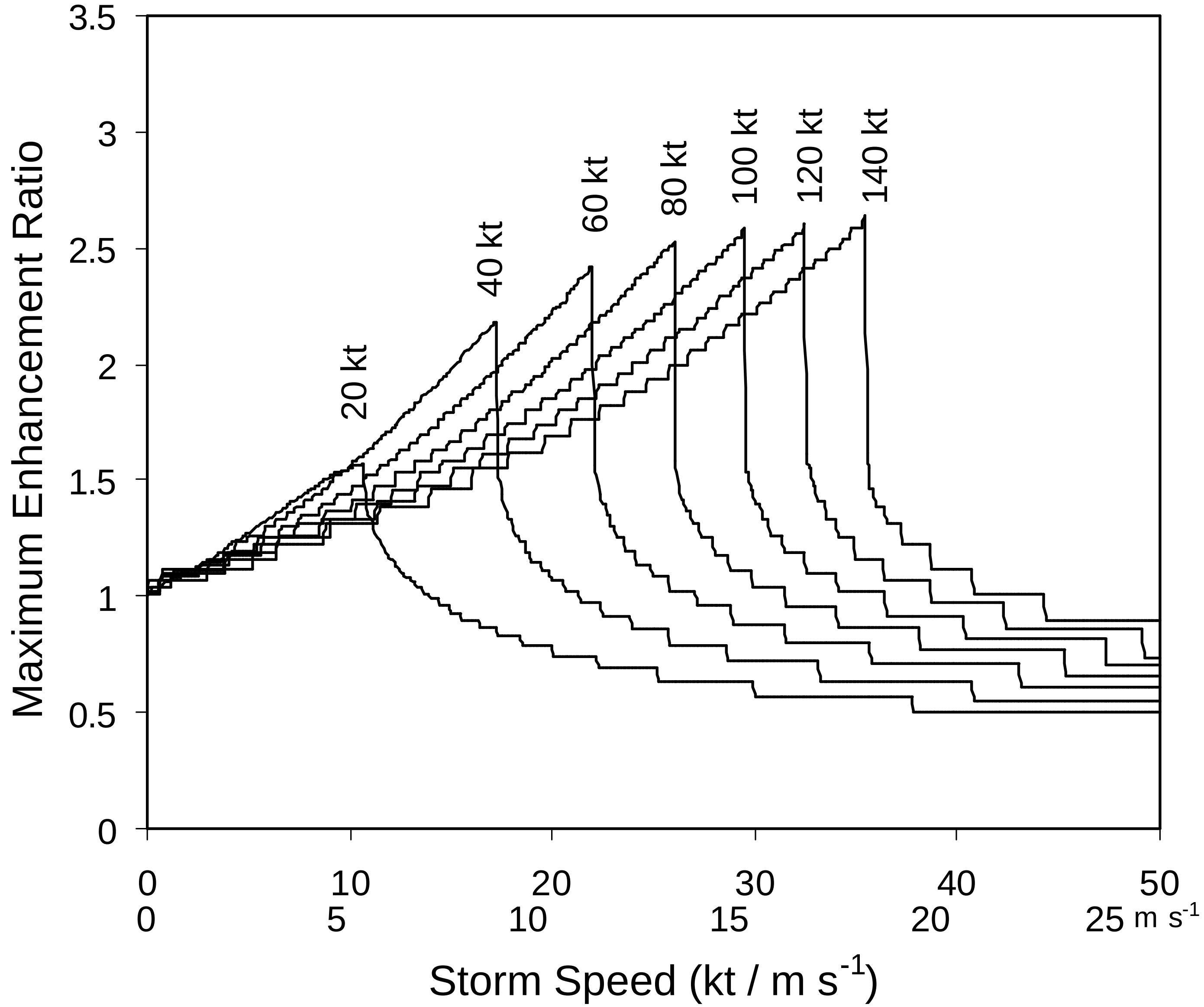

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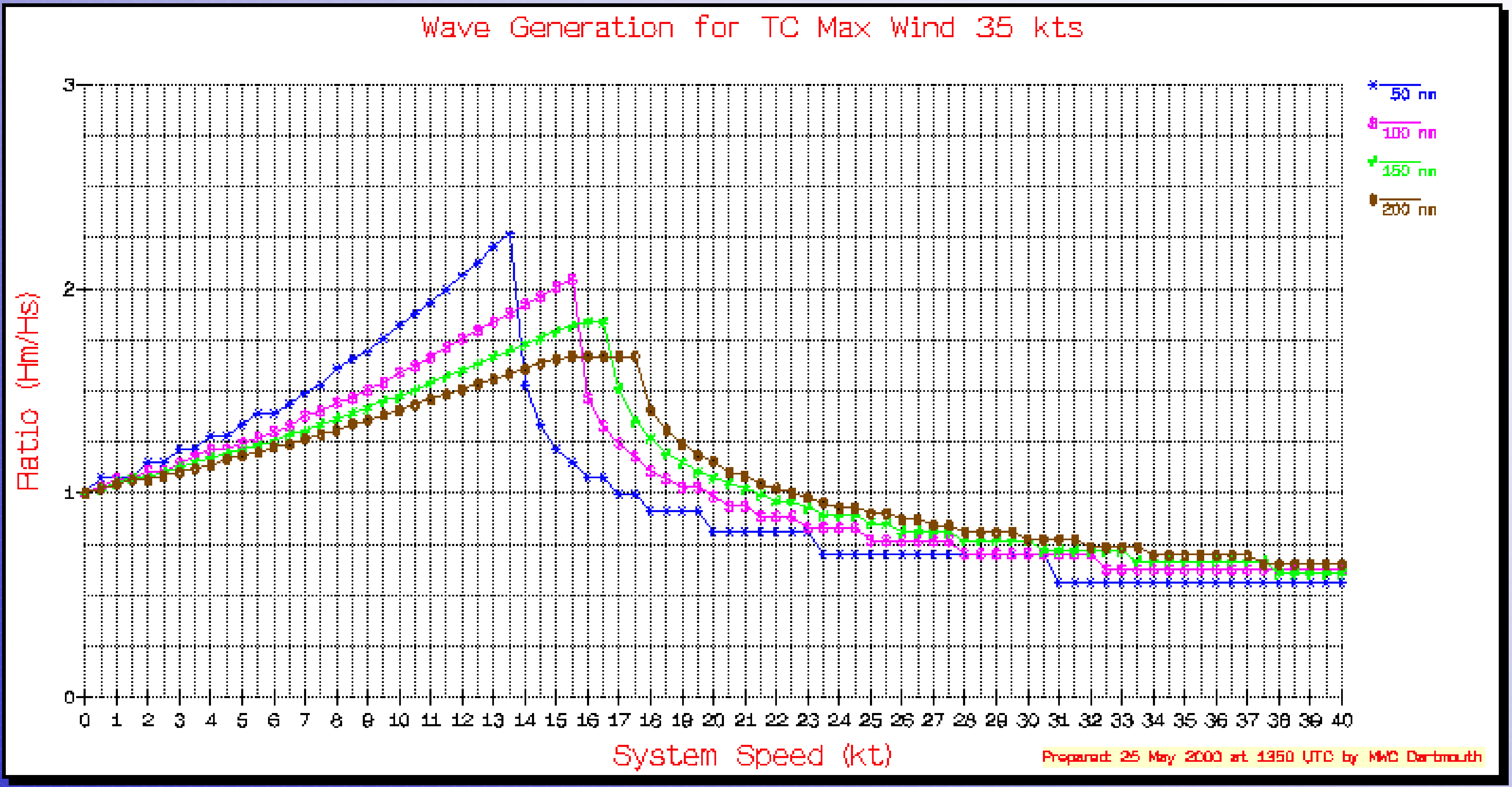
Observation

The greater the wind speed, the greater the enhancement

Maximum Possible Significant Wave Heights

35-knot winds

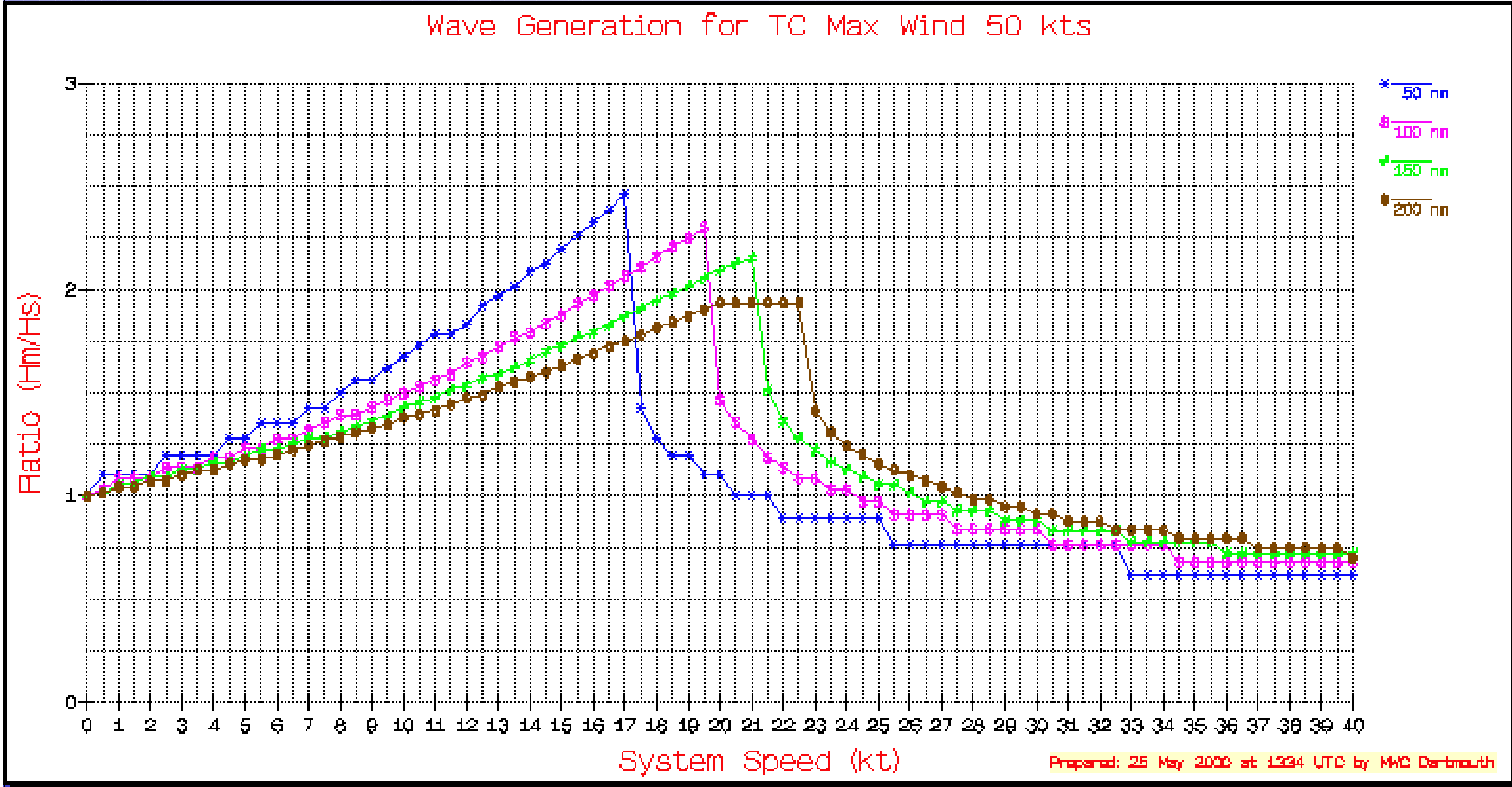
Canadian Hurricane Centre



Maximum Possible Significant Wave Heights

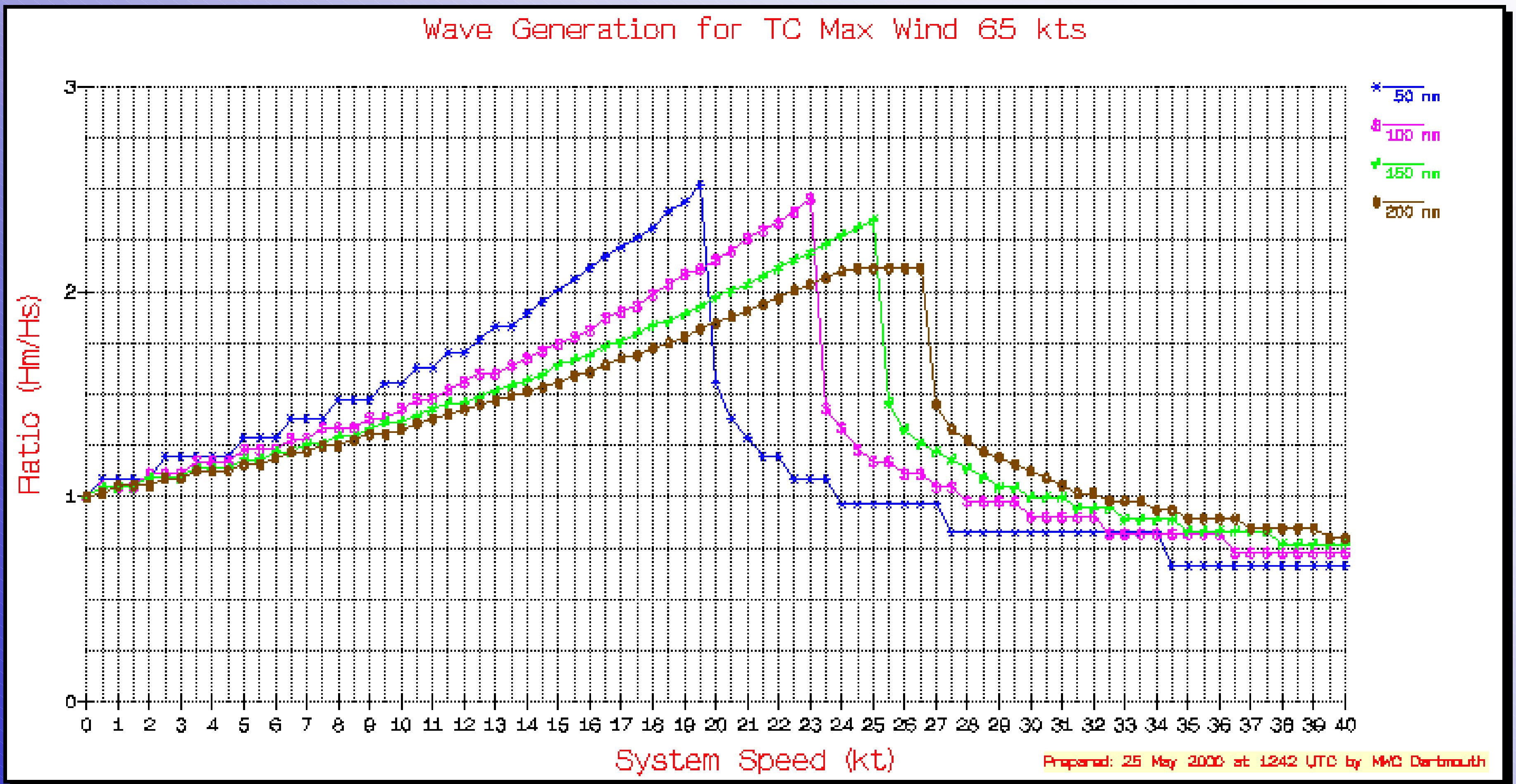
50-knot winds

Canadian Hurricane Centre



Maximum Possible Significant Wave Heights
65-knot winds

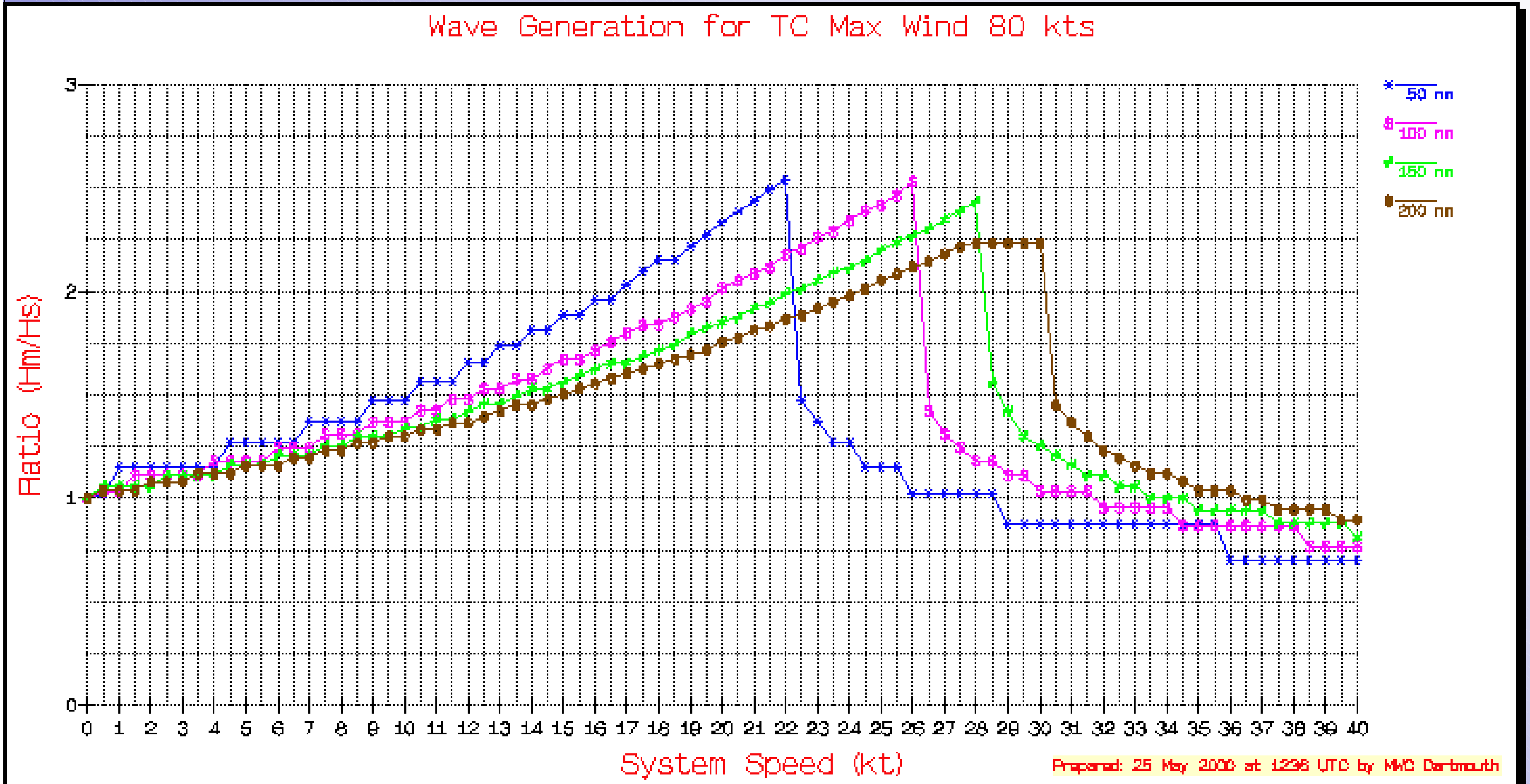
Canadian Hurricane Centre



Maximum Possible Significant Wave Heights

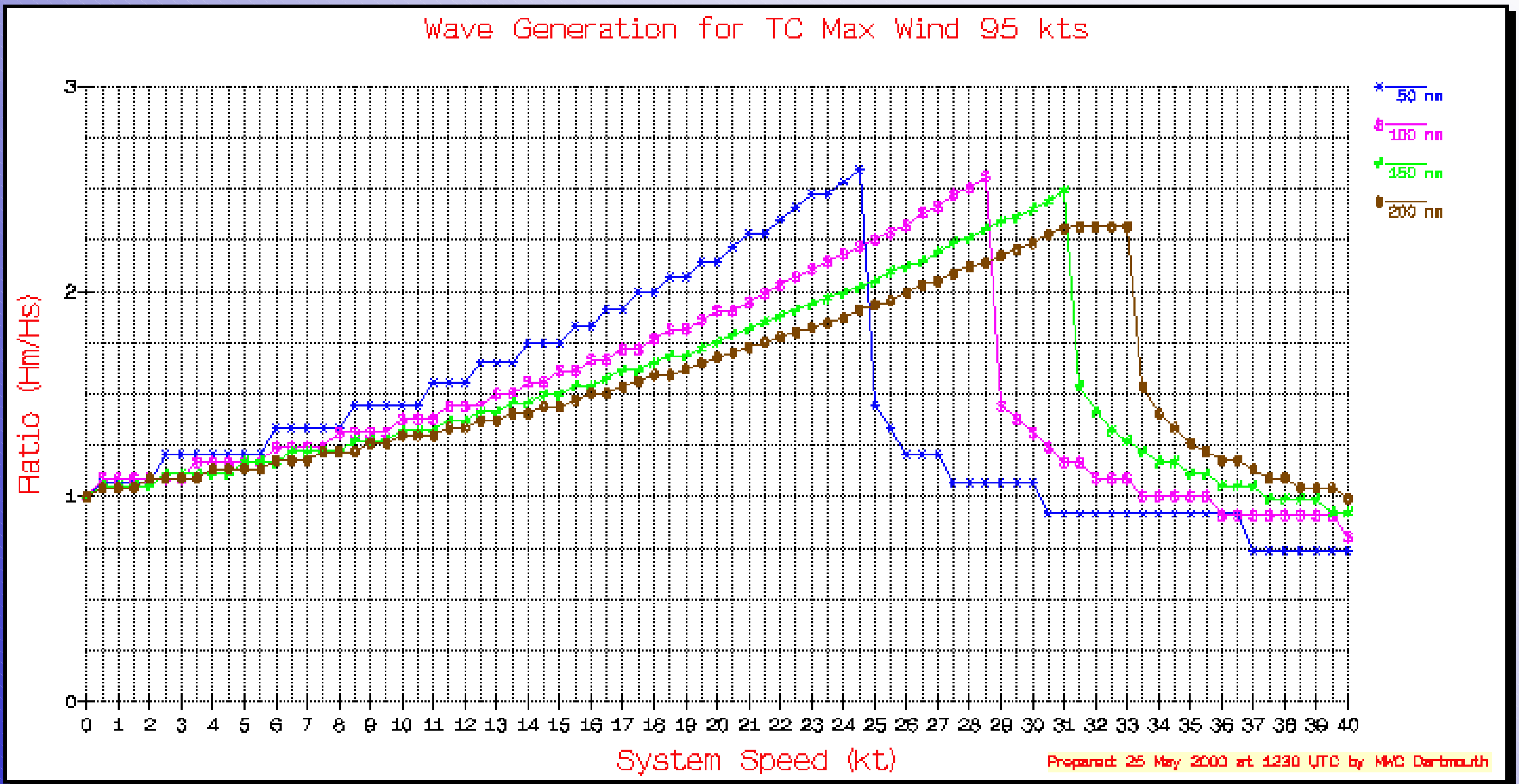
80-knot winds

Canadian Hurricane Centre



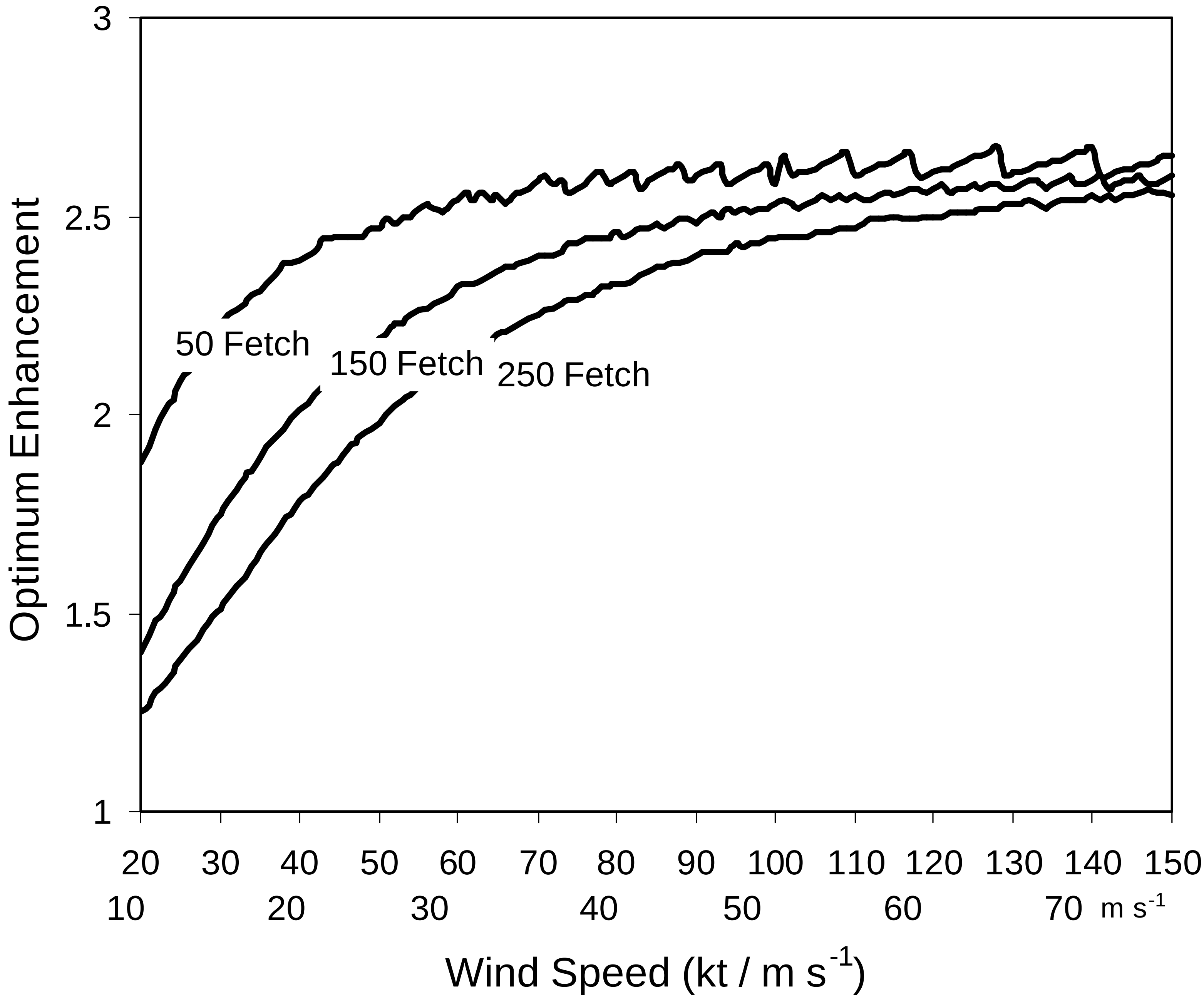
Maximum Possible Significant Wave Heights
95-knot winds

Canadian Hurricane Centre

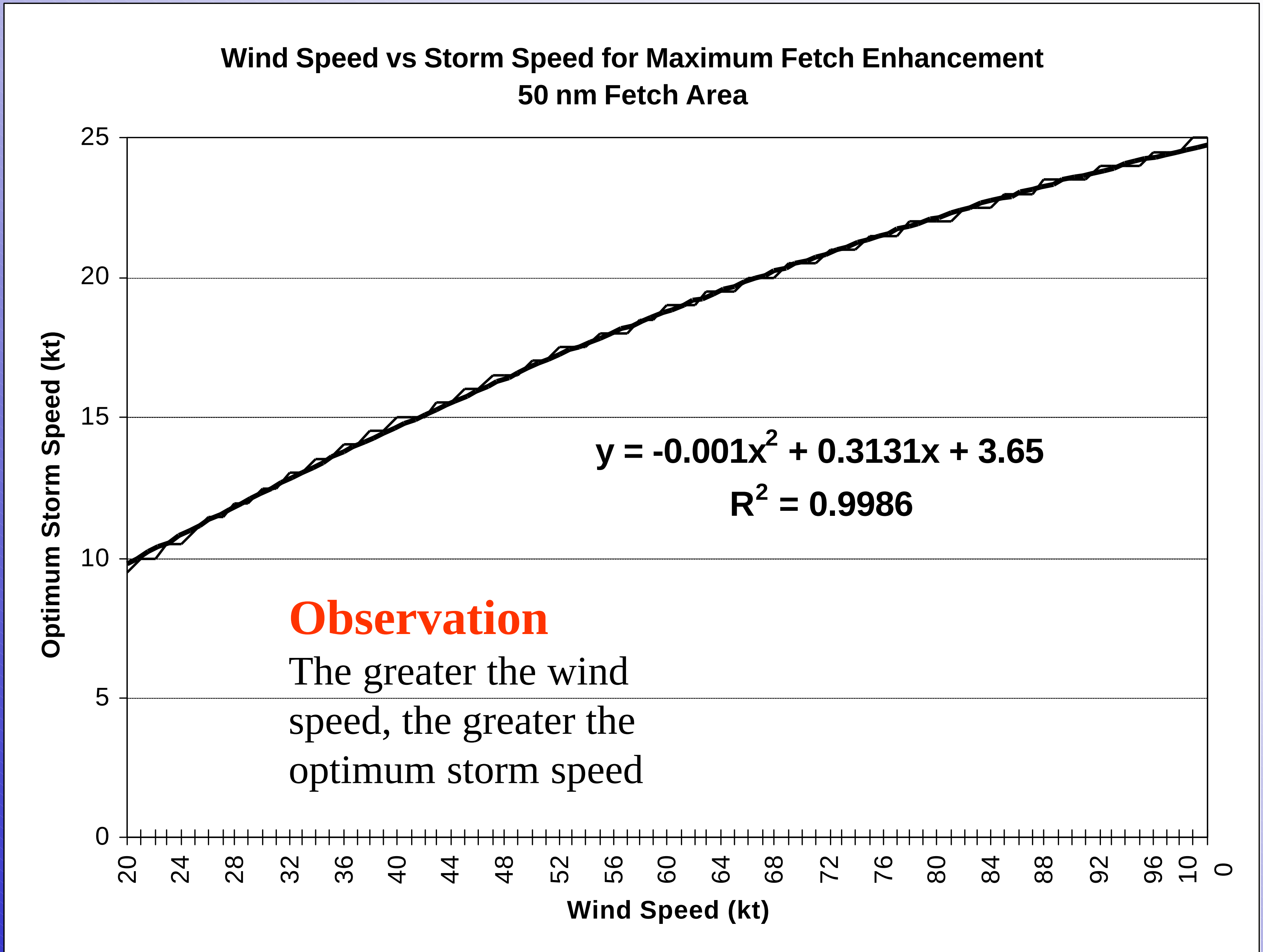


Observation

The smaller the fetch, the greater the enhancement



Optimum Enhancement
3
2.5
2
1.5
1
50 Fetch
150 Fetch
250 Fetch
20 30 40 50 60 70 80 90 100 110 120 130 140 150
10 20 30 40 50 60 70 m s-1
Wind Speed (kt / m s-1)



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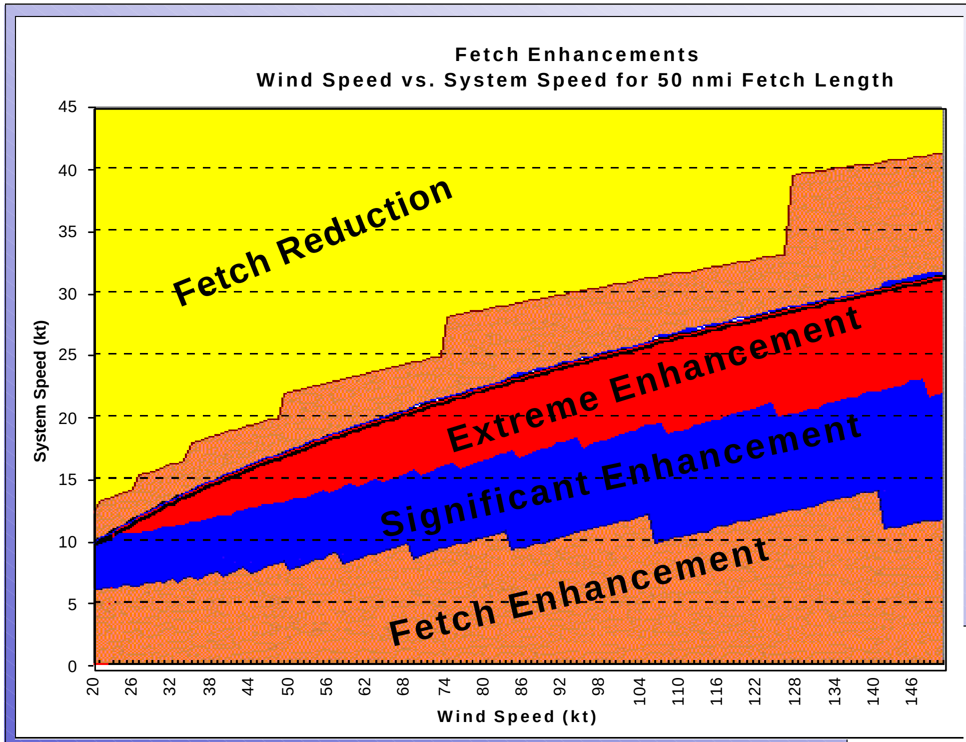
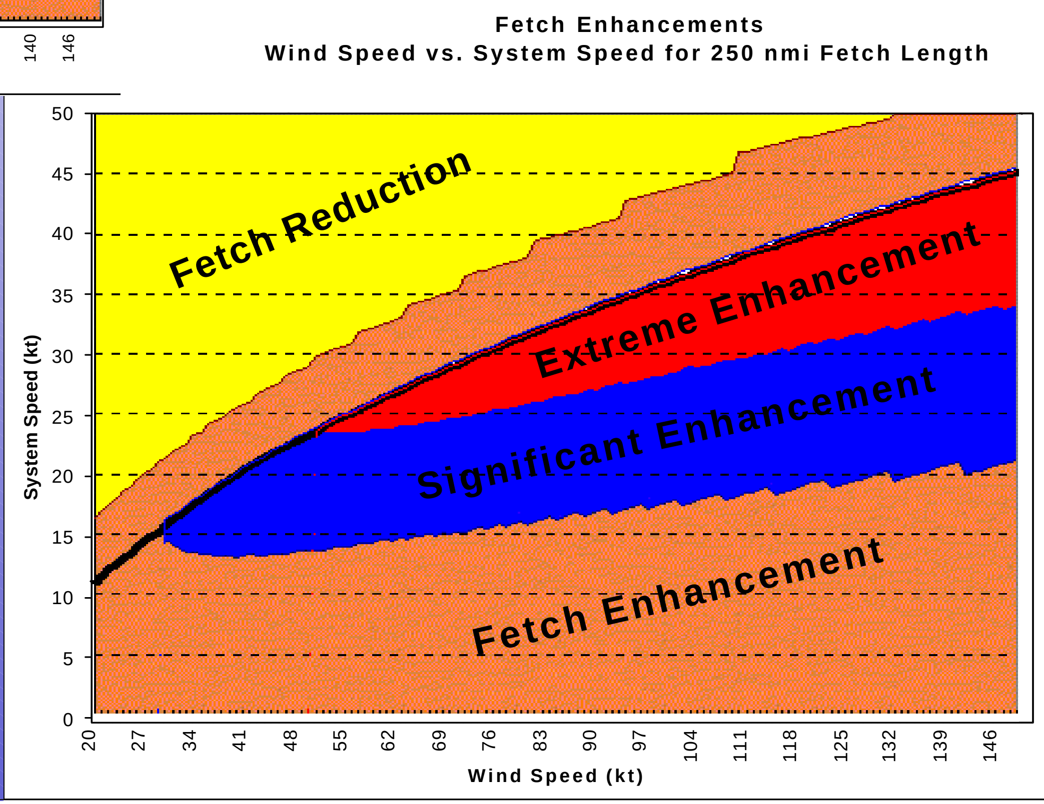
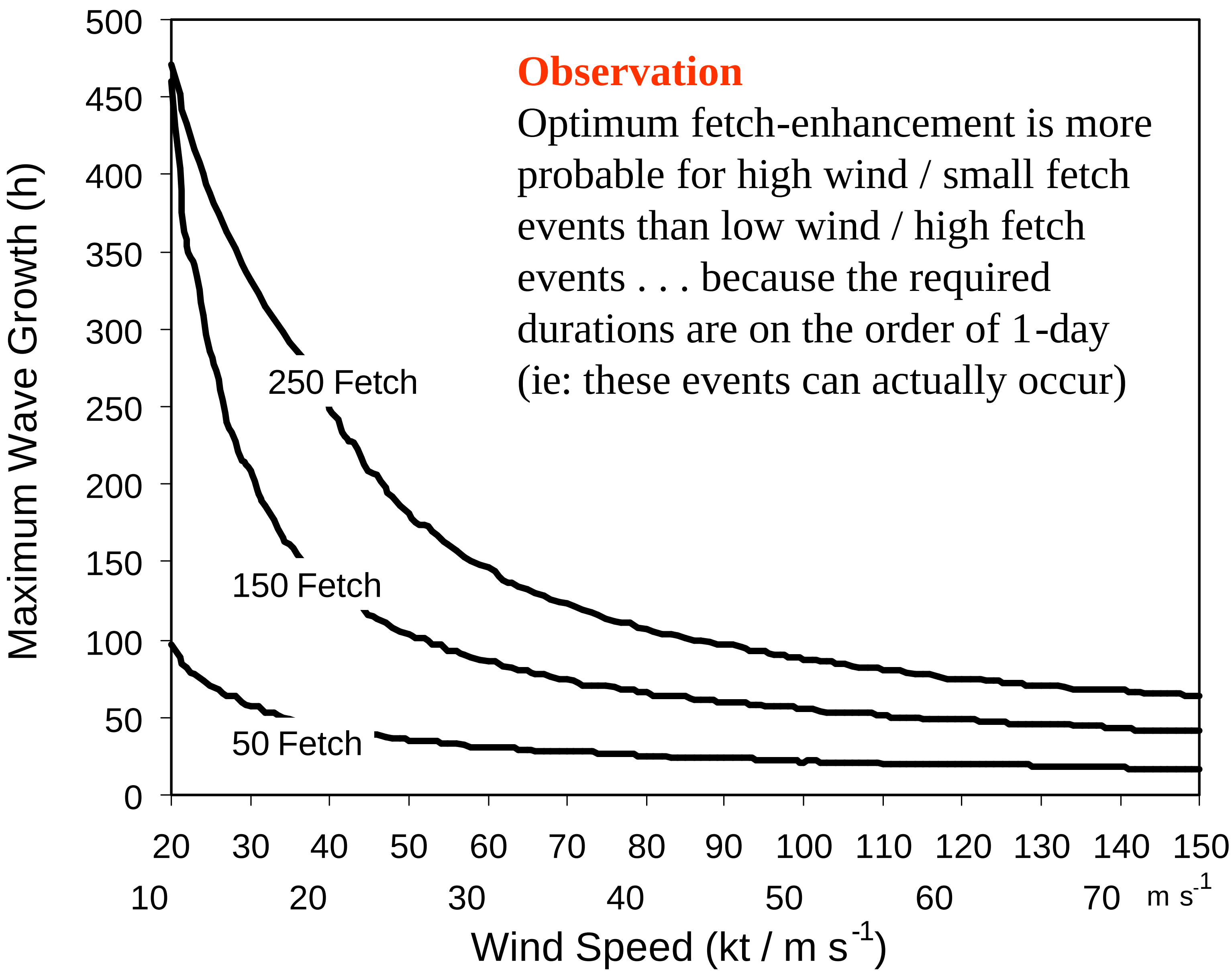


Canadian Hurricane Centre





Observation

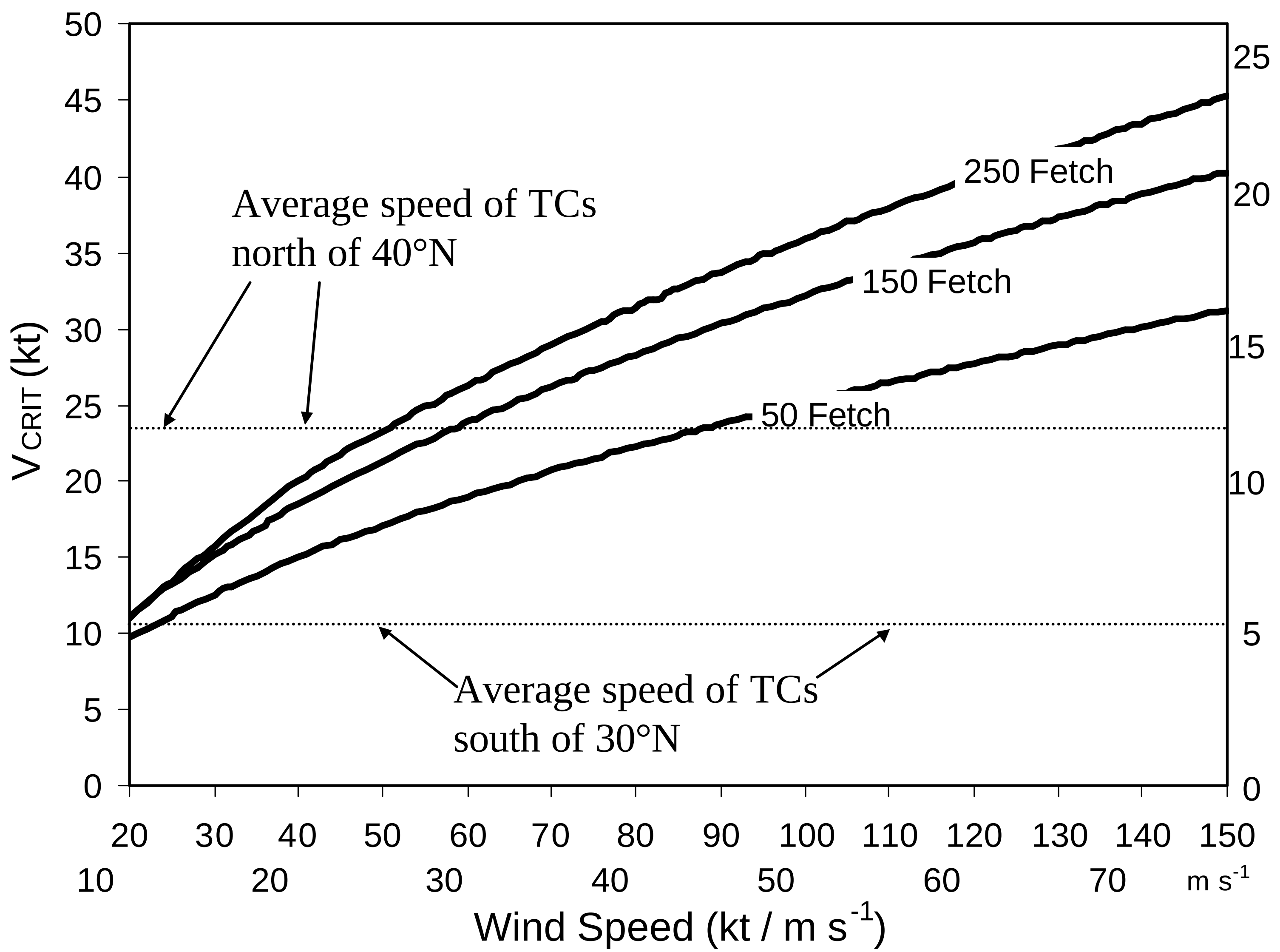
Optimum fetch-enhancement is more probable for high wind / small fetch events than low wind / high fetch events . . . because the required durations are on the order of 1-day (ie: these events can actually occur)

Canadian Hurricane Centre

Canadian Hurricane Centre

Conclusion 1

Sub-synoptic scale storm systems, like tropical cyclones and polar lows, have the greatest potential for optimum resonance



Canadian Hurricane Centre

Observation

Fetch enhancement for TS or Hurricanes is greater in mid latitudes than in the tropics.

Canadian Hurricane Centre

As tropical cyclones undergo extratropical transition (ET), they are typically increasing in speed under the influence of a mid-latitude stream.

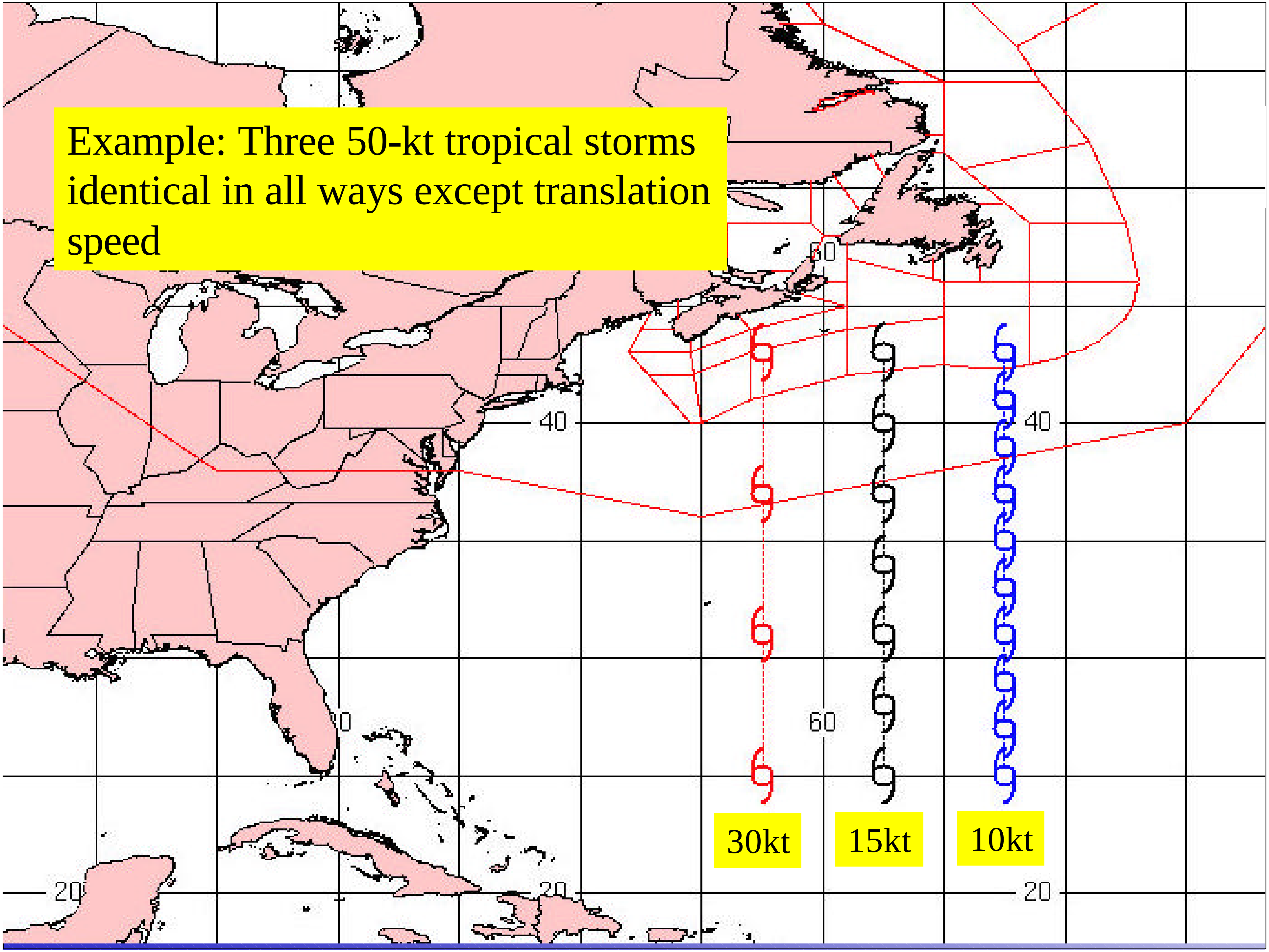
The seas associated with these systems (and even minimal hurricanes that move “quickly”) can be greater than those associated with major hurricanes.

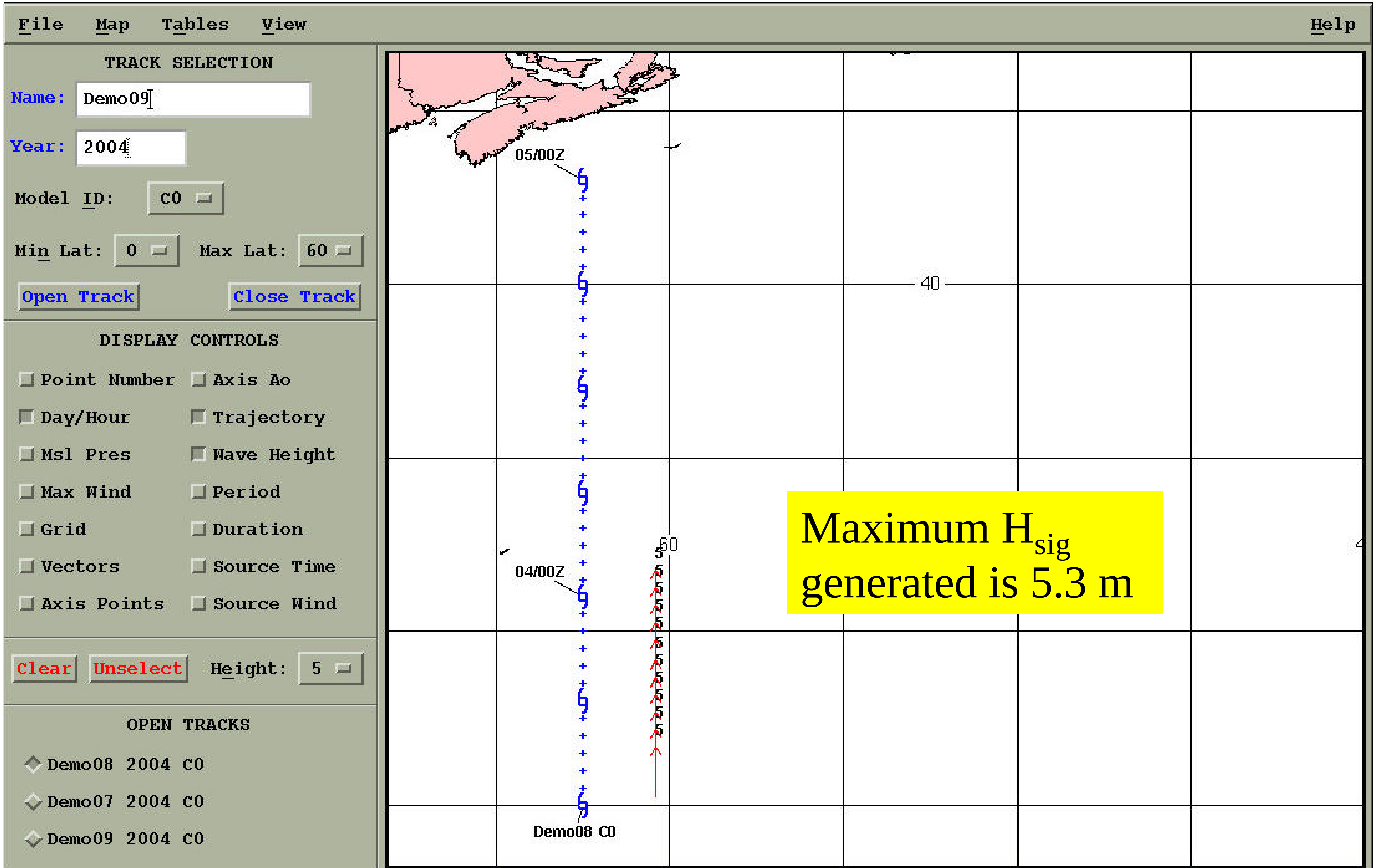
Conclusion 2

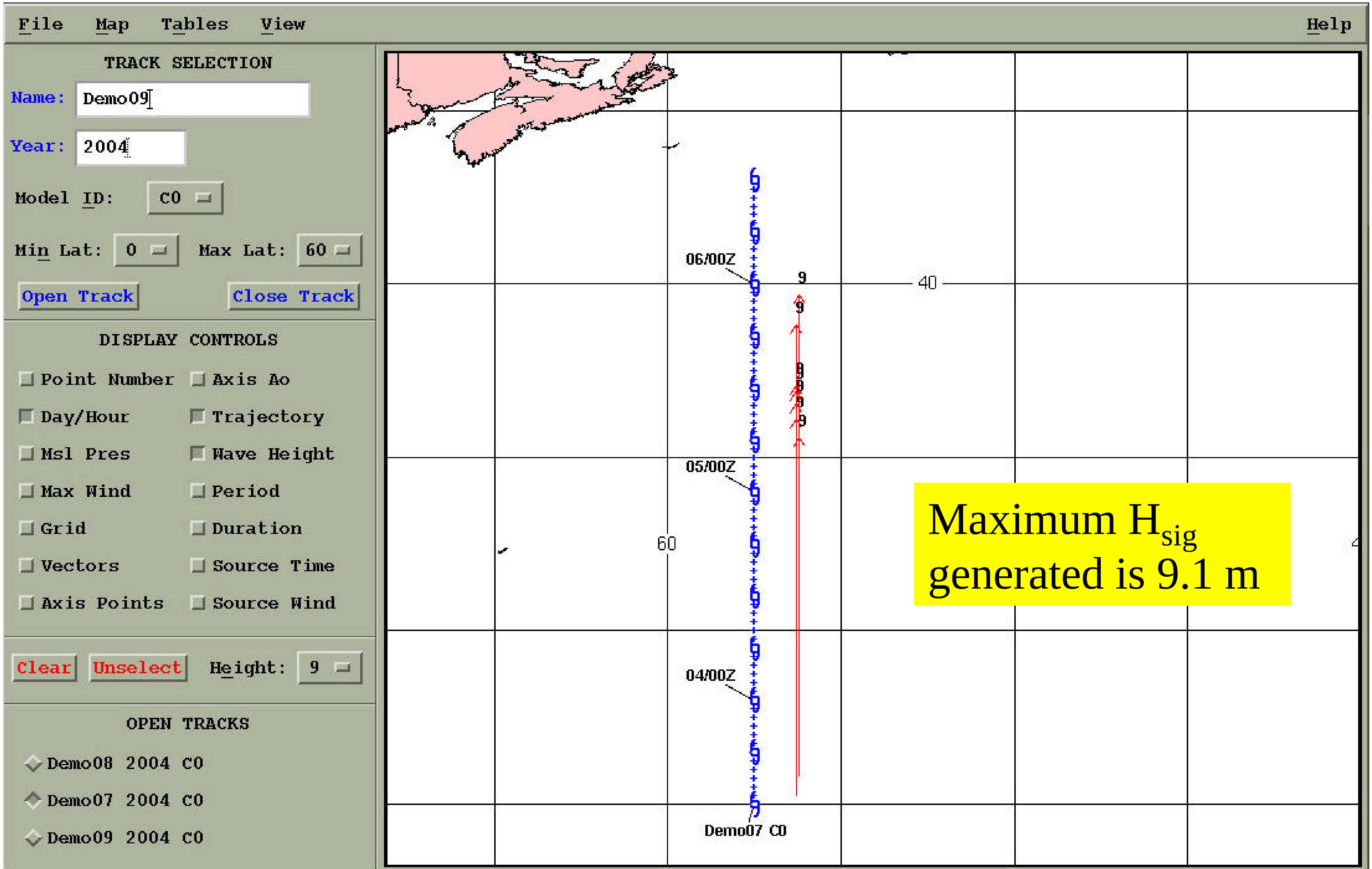
Very high waves with TCs should be expected in mid latitudes as these systems become ET

Canadian Hurricane Centre

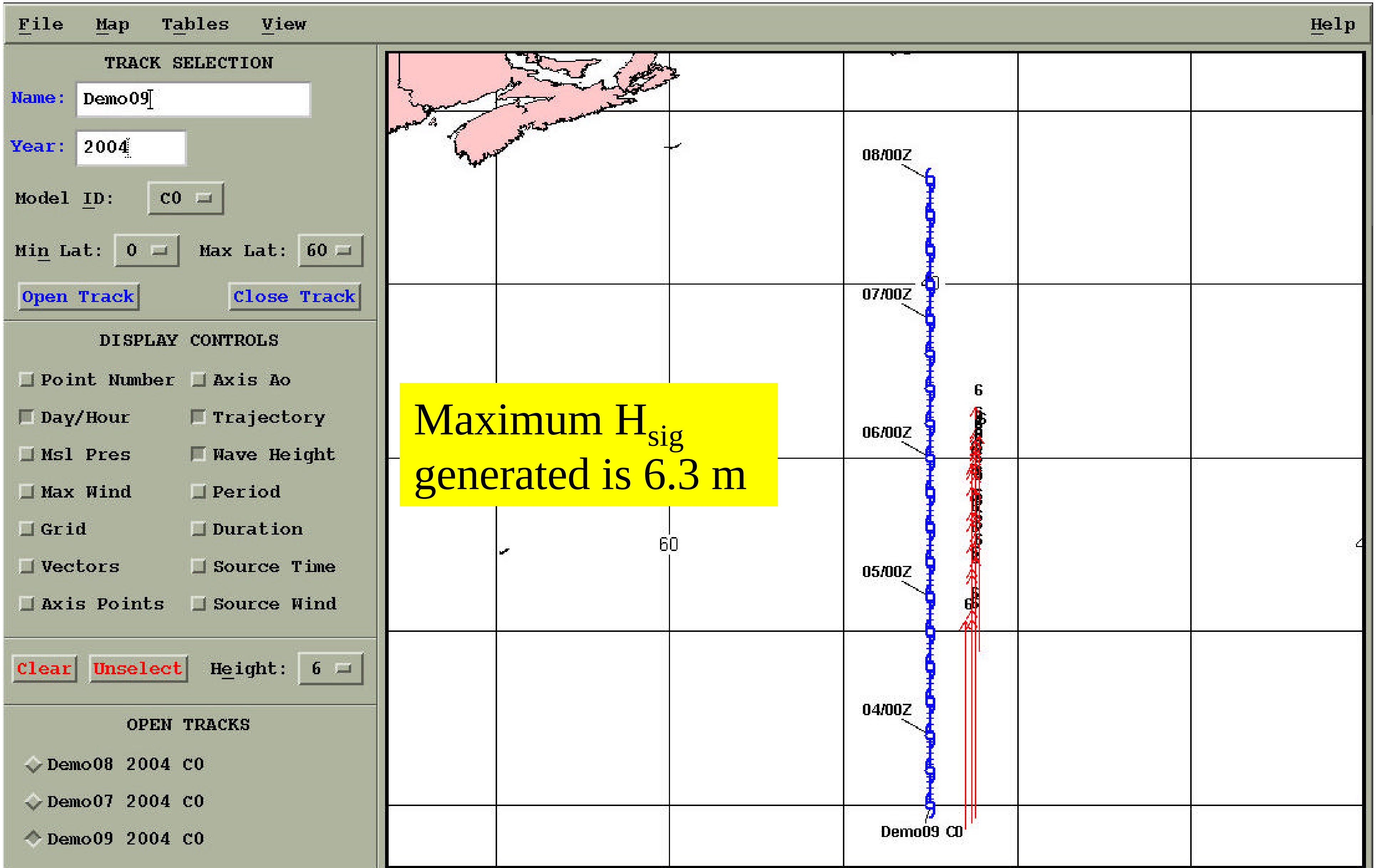
Example: Three 50-kt tropical storms identical in all ways except translation speed



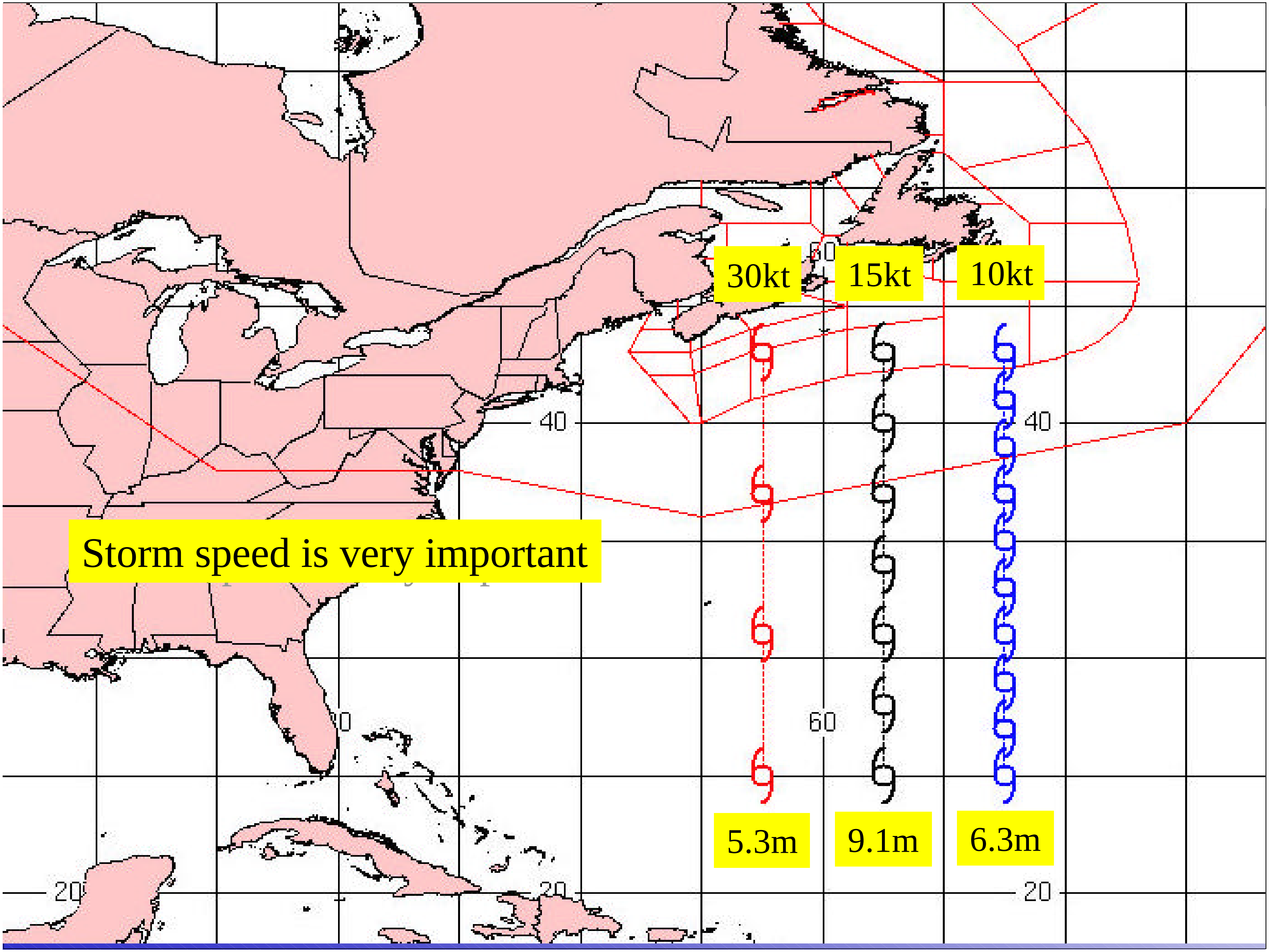

File
Map
Tables
View
Help
TRACK SELECTION
Name: Demo09
Year: 2004
Model ID: C0
Min Lat: 0
Max Lat: 60
Open Track
Close Track
DISPLAY CONTROLS
Point Number
Axis Ao
Day/Hour
Trajectory
Msl Pres
Wave Height
Max Wind
Period
Grid
Duration
Vectors
Source Time
Axis Points
Source Wind
Clear
Unselect
Height: 5
OPEN TRACKS
Demo08 2004 C0
Demo07 2004 C0
Demo09 2004 C0
05/00Z
04/00Z
40
60
Demo08 C0
Maximum H_{sig} generated is 5.3 m



Maximum H_{sig} generated is 9.1 m



Maximum H_{sig} generated is 6.3 m

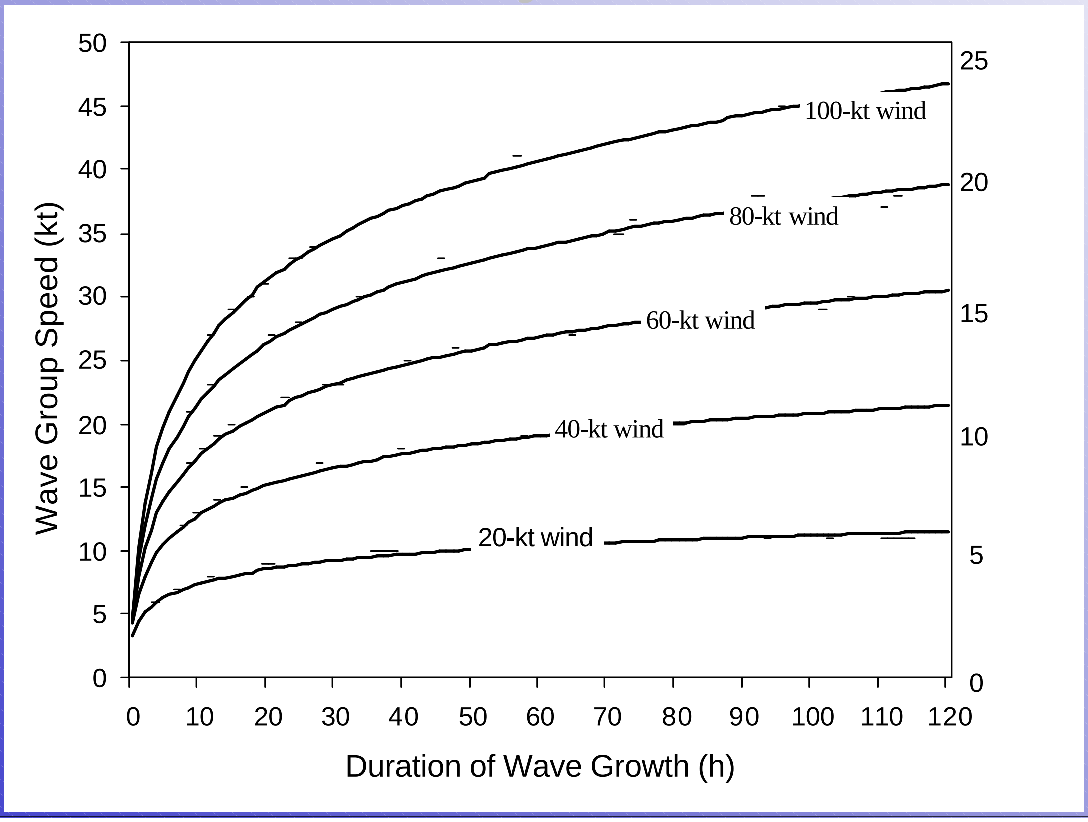


30kt
15kt
10kt
40
40
60
60
20
20
Storm speed is very important
5.3m
9.1m
6.3m

Accelerating Fetches

Canadian Hurricane Centre

If the storm system accelerates with a speed matching that of the waves it generates, the conditions for *perfect* resonance exists and wave growth is more easily maximized.



Storms moving in a straight line,
at the optimum speed,
can result in the potential for
phenomenally large waves to
develop

The Worst-Case Scenario is a storm centre . . .

- moving in a straight line,
- covering a large distance over open ocean,
- increasing in speed, continually matching the speed of the waves that corresponds closely with the peak in the energy spectrum

The Pattern . . .

Canadian Hurricane Centre

- area of maximum waves to the right of track
- very tight gradient in the wave field at the leading edge . . . as the trapped-fetch arrives, it brings with it a “wall of water” (little or no forerunners to warn of storm)
- waves can subside rather quickly in the wake of these storms, however, the trailing gradient is usually much weaker