Air-sea interactions during tropical cyclone in the Indian Ocean

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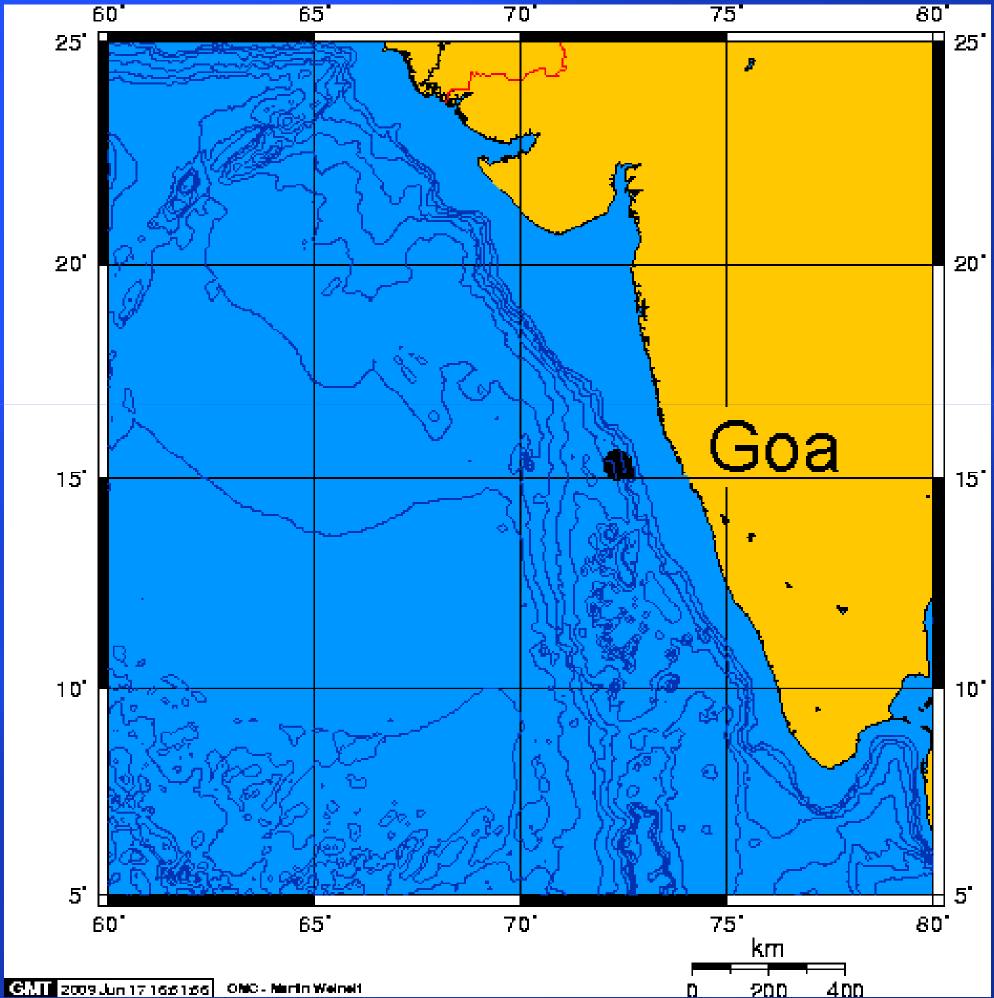
Area of Study



Location	Longitude (E)	Latitude (N)	Water Depth (m)	Duration
Goa	73^0 41.0’	15^0 27.9’	23	15-25 Jun 1996

Wave measurement location and bathymetry along the west coast of India

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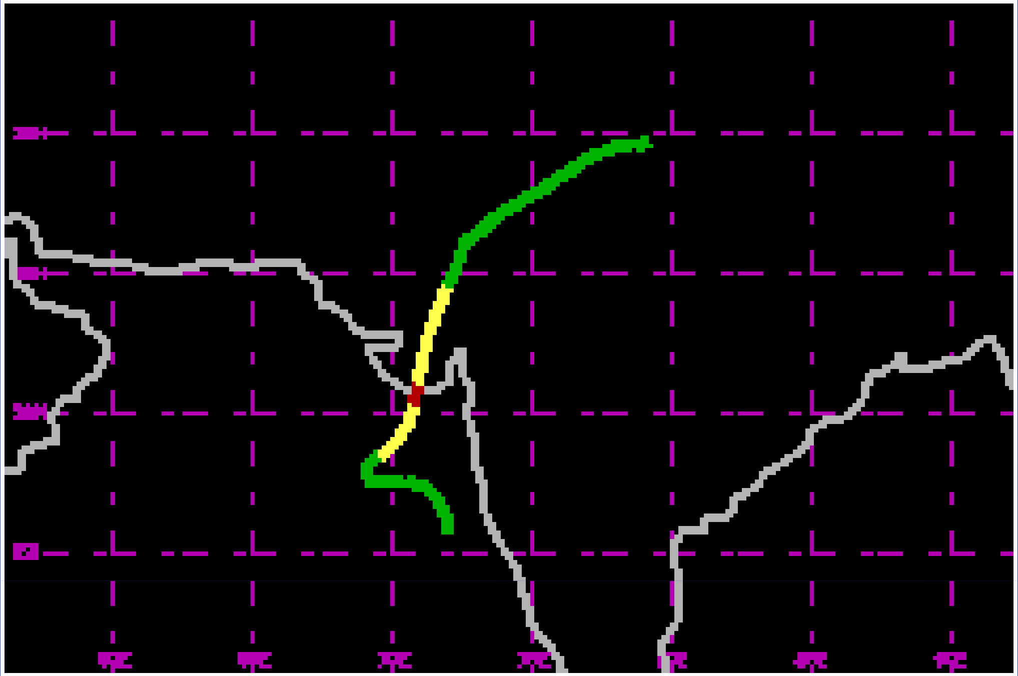

http://weather.unisys.com/hurricane/n_indian/index.html

Type	Duration	Wind speed (knots)	Wind speed off Goa (knots)
Cyclone	15-25 Jun 1996	65	25

Cyclone details along the west coast of India

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Wave Watch III (*Version 3.14*)

- The WAVE WATCH **III** model is a third generation wave model
- WAVE WATCH **III** solves the spectral action density balance equation for wave number-direction spectra
- Source terms include **wave** growth and decay due to the actions of wind, nonlinear resonant interactions, dissipation (`white capping') and bottom friction.
- Wave propagation is considered to be linear.
- The model includes sub-grid representation of unresolved islands

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Basic Equations (WW3 Model)

$$\frac{\partial N}{\partial t} + \nabla_x \cdot \dot{\mathbf{x}} N + \frac{\partial}{\partial k} \dot{k} N + \frac{\partial}{\partial \theta} \dot{\theta} N = \frac{S}{\sigma} \,,$$

$$\dot{\mathbf{x}} = \mathbf{c}_g + \mathbf{U}$$

$$\dot{k} = -\frac{\partial \sigma}{\partial d} \frac{\partial d}{\partial s} - \mathbf{k} \cdot \frac{\partial \mathbf{U}}{\partial s}$$

$$\dot{\theta} = -\frac{1}{k} \left[\frac{\partial \sigma}{\partial d} \frac{\partial d}{\partial m} - \mathbf{k} \cdot \frac{\partial \mathbf{U}}{\partial m} \right]$$

where c_g is group velocity ; **k is** wavenumber vector; *k is* the wavenumber;

θ is the direction;

the relative or intrinsic (radian) frequency σ (= $2\pi f_r$) and the absolute (radian) frequency ω (= $2 \pi f_a$)

s is a coordinate in the direction θ and m is a coordinate perpendicular to s

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Basic Equations (WW3 Model)

$$S = S_{ln} + S_{in} + S_{nl} + S_{ds} + S_{bot} + S_{db} + S_{tr} + S_{sc} + S_{xx}$$

S_{ln} - linear input term

S_{in} - wind-wave interaction term

S_{nl} - nonlinear wave-wave interactions term

S_{ds} - dissipation (`white-capping') term

S_{bot} - wave-bottom interactions term

S_{db} - depth-induced breaking term

S_{tr} - triad wave-wave interactions term

S_{sc} - scattering of waves by bottom features

S_{xx} - additional, user defined source terms

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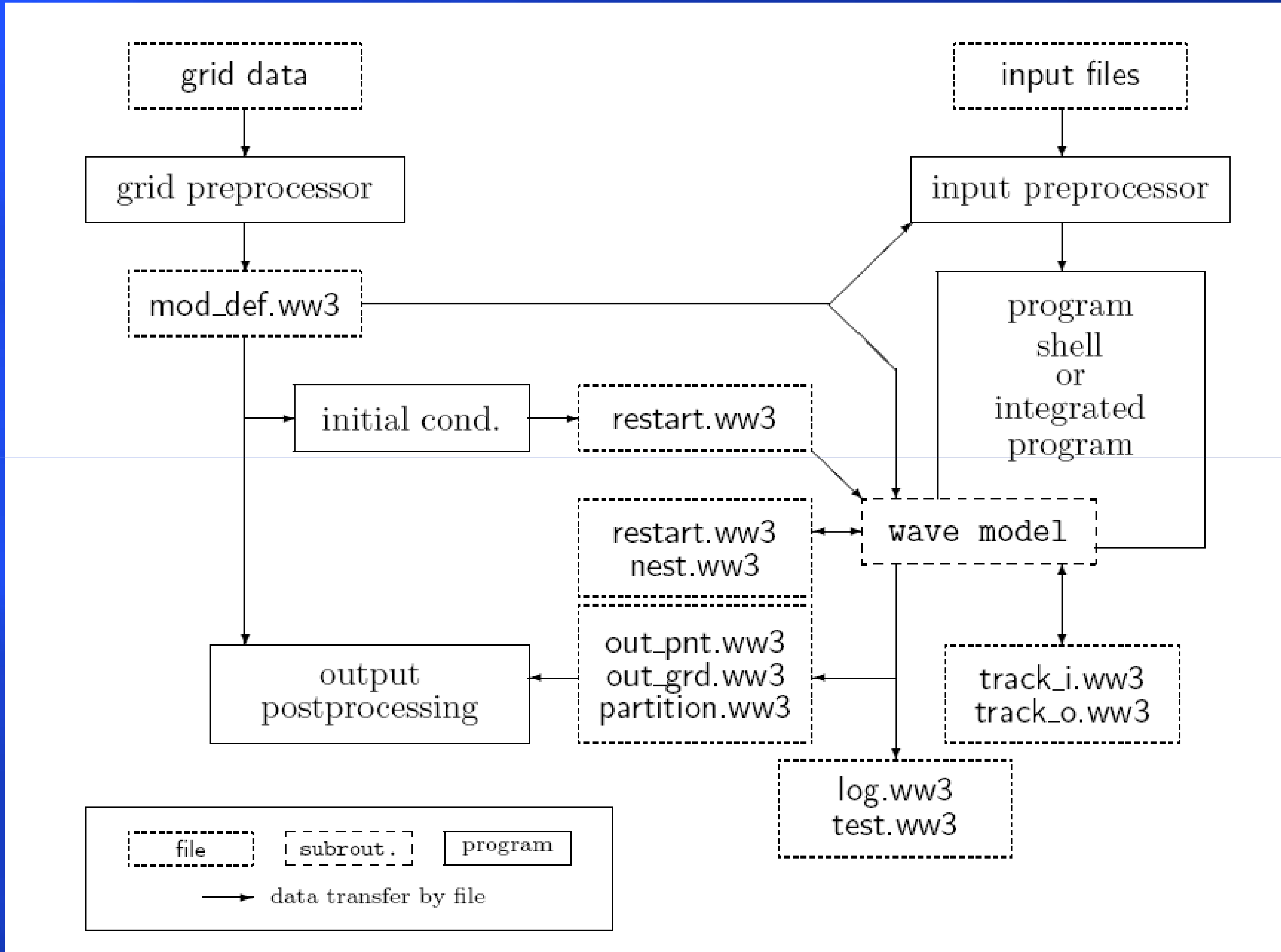
W W 3 - PROGRAM STRUCTURE



Data used

Domain: The Arabian Sea - 0°S to 30°N and 40°E to 80°E

Bathymetry:

Etopo-1 Data set

Data Used:

Measured wave data:

Off Goa (Jun 1996)

Wind data:

ECMWF INTERIM winds

6 hr interval

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✓ The momentum and energy exchange processes between the ocean surface and the marine atmospheric boundary layer (MABL) is different, depending on the wave regime.

The total stress at the sea surface is given by,

$$\tau(z) = \tau_{turb}(z) + \tau_{wave}(z) + \tau_{visc}(z)$$

where,

τ_{turb} – turbulent shear stress
τ_{wave} – wave-induced stress
τ_{visc} – viscous stress

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- If the stress at the surface is facing in the wind direction, the momentum flux is directed downward ($\tau > 0$); otherwise, it is directed upward ($\tau < 0$).
- The turbulent momentum flux is always positive i.e., $\tau_{turb} > 0$.
- For young or developing seas, the wave induced momentum flux is downward i.e., $\tau_{wave} > 0$ (Grachev and Fairall, 2001).
- For old sea, the wave induced momentum flux is upward, i.e., $\tau_{wave} < 0$.

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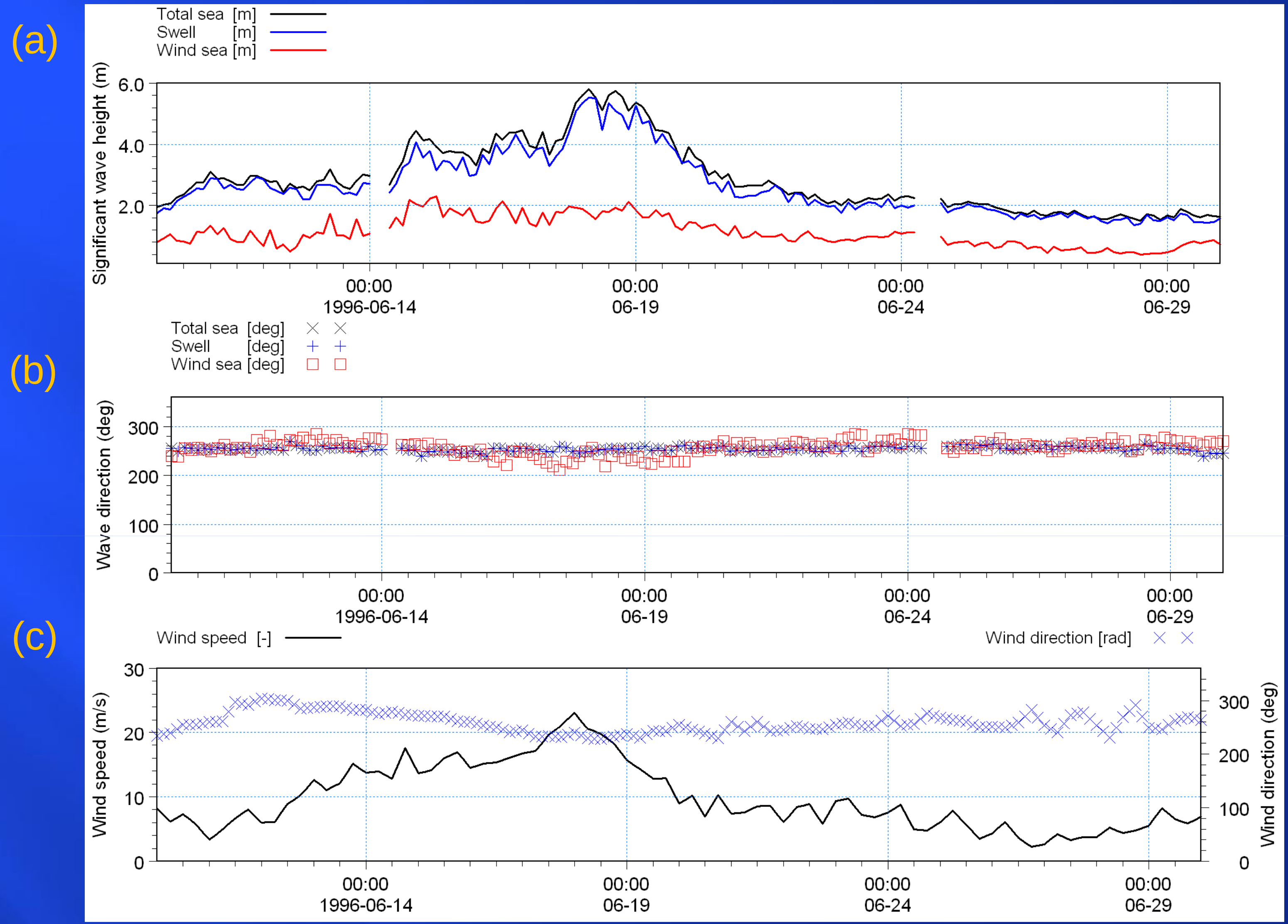
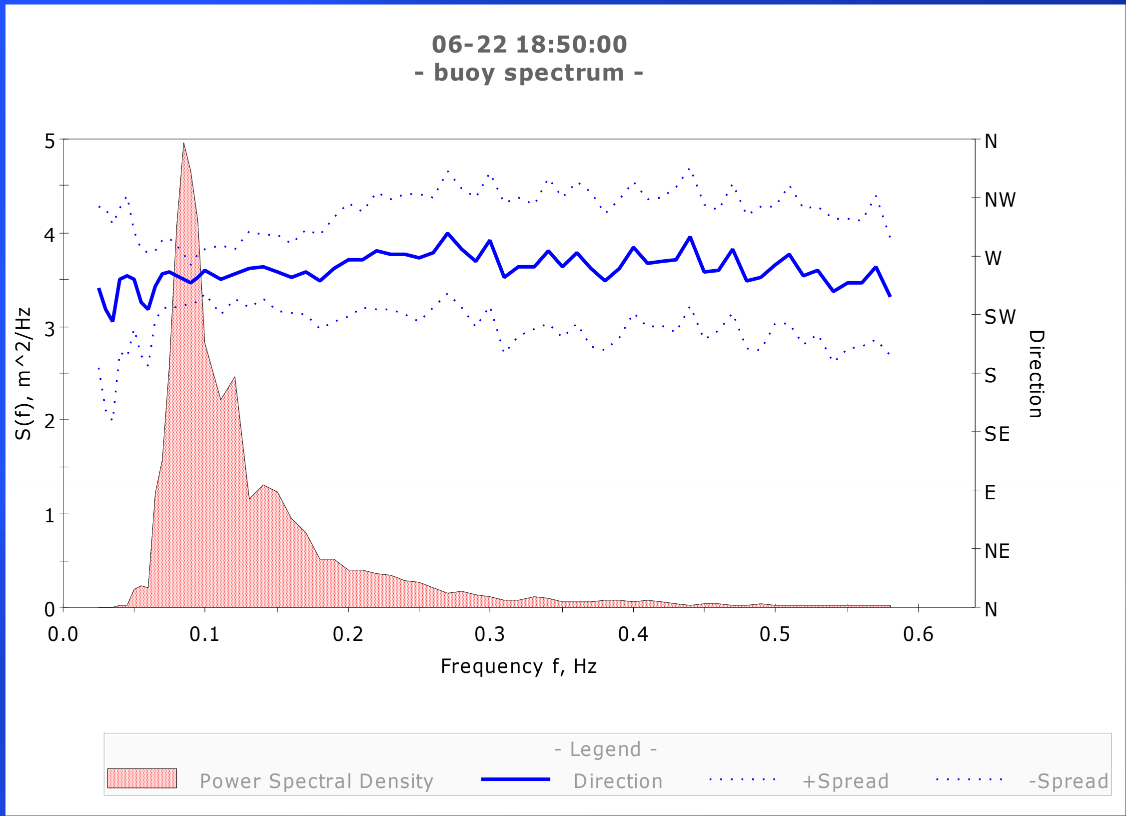
- Wave-induced momentum flux in the marine boundary layer shows strong dependence on wave age (Sullivan et al. 2000).
- Further increase of wave age tends to enhance the negative portion of total momentum flux, and finally leads to sign reversal of τ (i.e., $\tau < 0$).
- Harris (1966) named this phenomenon as “wave-driven wind”.

- Hanley et al. (2010) used 40-yr ECMWF Re-Analysis (ERA-40) data to calculate the global distribution of wave-driven wind regime.
- Hanley et al. (2010) found wave – driven wind regime prevalent in tropics and higher latitudes whereas, the wind – driven wave regime is prevalent in mid latitude.

- ✓ Charnock coefficient (α) is firstly considered as a constant 0.0144 (Charnock, 1955).
- ✓ Toba et al. (1990) suggested that increases with the wave age (β)
- ✓ Donelan (1990), Johnson et al. (1998), Lange et al. (2004), showed that decreases with the wave age (β).
- ✓ Moon et al. (2004) pointed out that under tropical cyclones the Charnock coefficient is mainly determined by two parameters: the wave age and the wind speed.

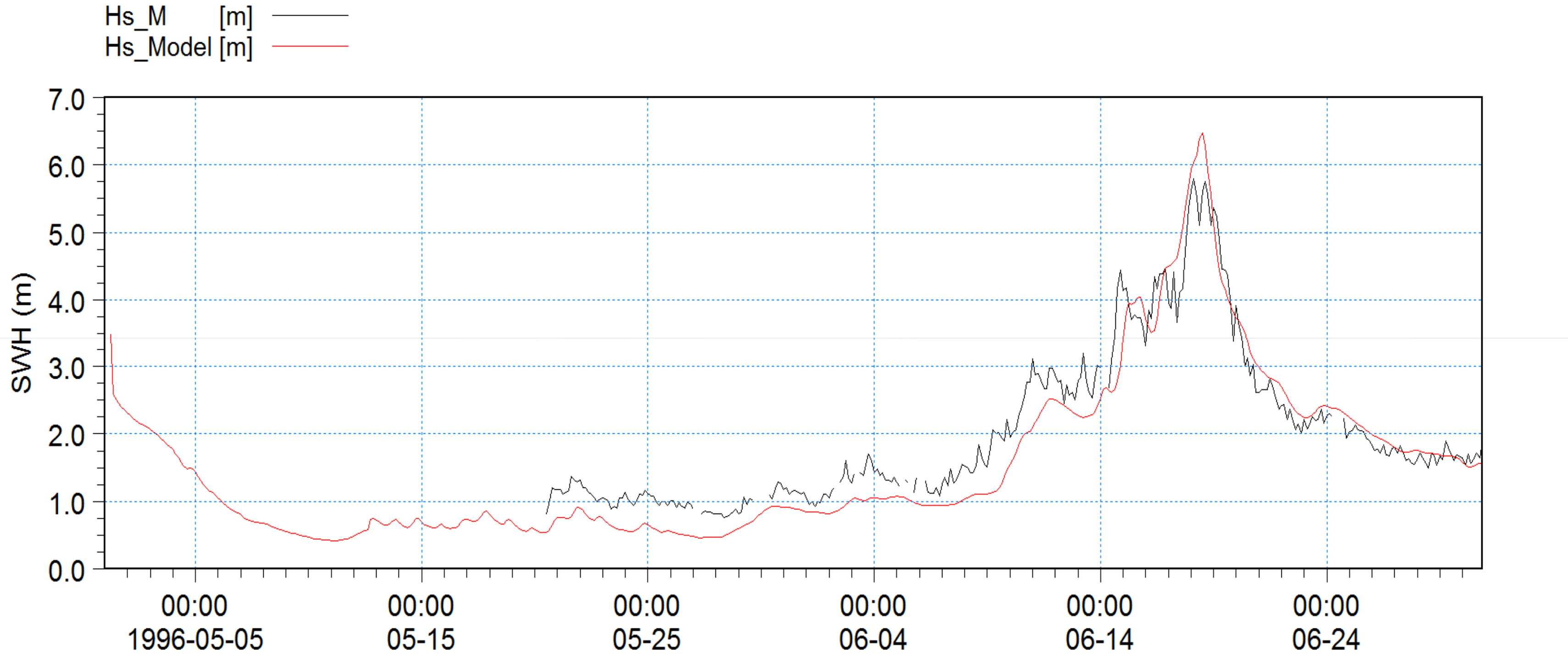


(a) Significant wave height (Hs) (b) Wave direction (c) Wind speed and direction off Goa during 10 - 30 Jun 1996.



Downward momentum takes place in the higher frequency part of the spectra whereas, upward momentum takes place in the low frequency part of the spectra.

Typical spectra during the cyclone period


Hs_M [m]
Hs_Model [m]
SWH (m)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
00:00
1996-05-05
00:00
05-15
00:00
05-25
00:00
06-04
00:00
06-14
00:00
06-24

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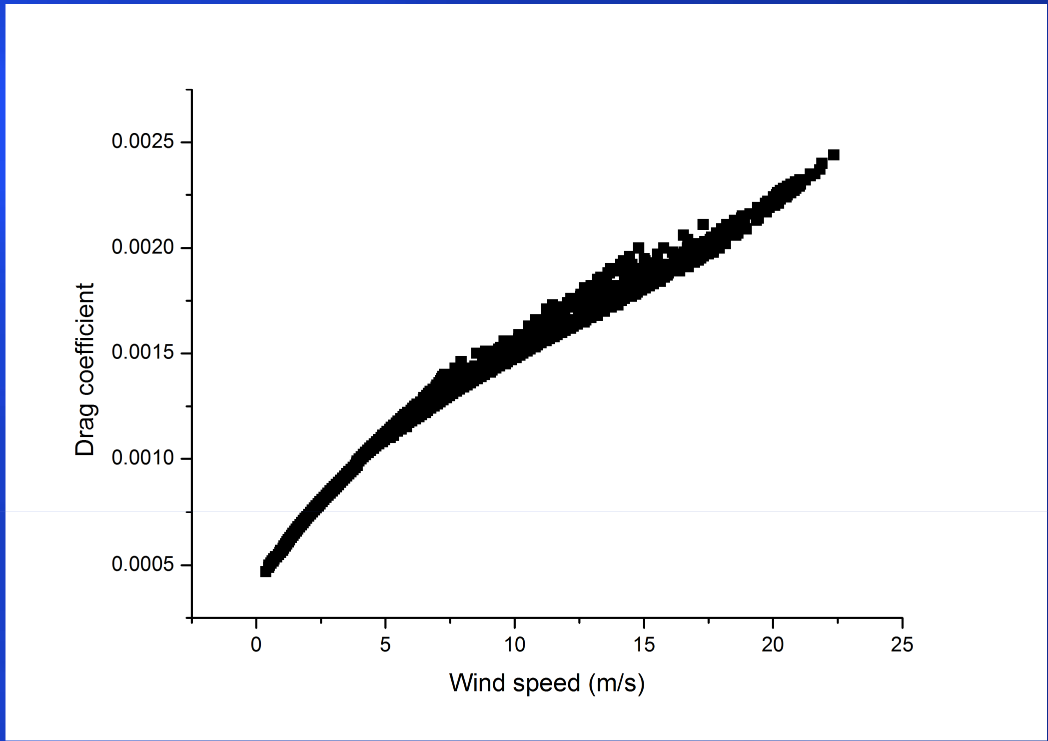
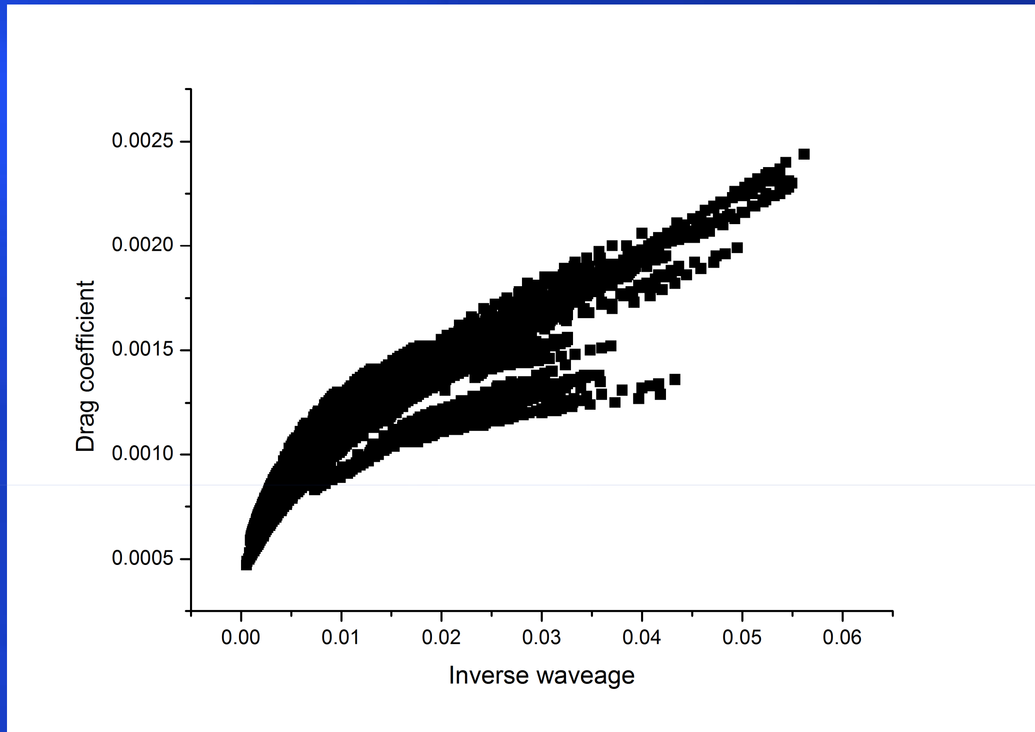


Wind speed v/s Drag coefficient



Inverse waveage v/s Drag coefficient

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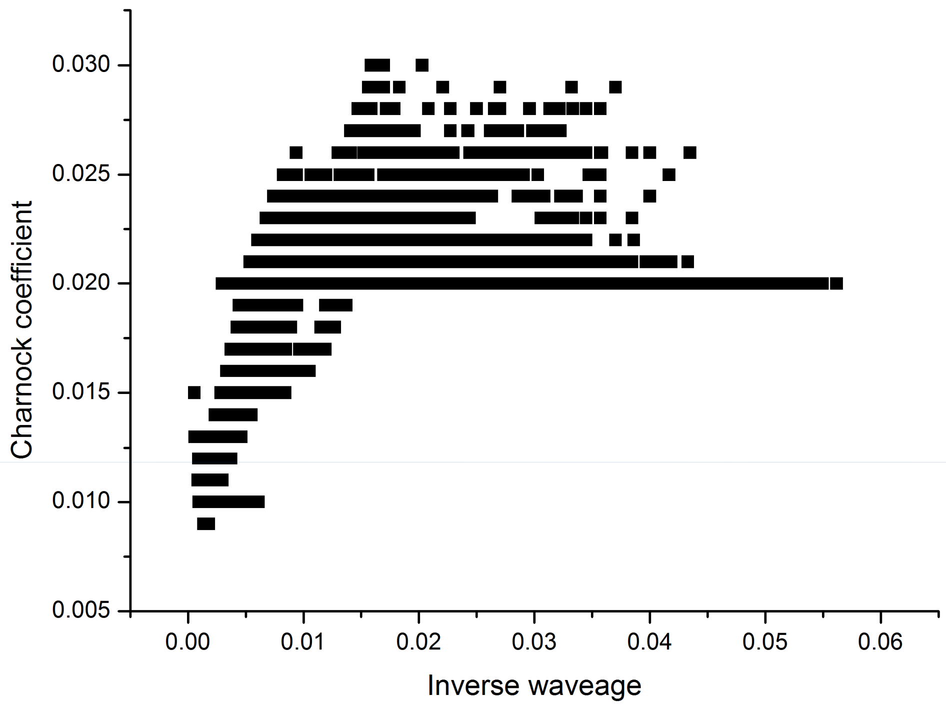

Inverse waveage v/s Charnock coefficient

Conclusion:

- Drag coefficient increases as wind speed increases.
- During cyclone the waves are mostly young waves.
- As wave age increases, drag coefficient decreases.
- Charnock coefficient is exponentially decreasing as the wave age increases.

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- Grachev, A.A., Fairall, C.W., 2001: Upward momentum transfer in the marine boundary layer. *J. Phys. Oceanogr*., 31,1698–1711.

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- Hanley, K. E., S. E. Belcher and Sullivan P. P. 2010: A global climatology of wind-wave interaction. *J. Phys. Oceanogr.* 40 (10), 1263–1282.

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Thank You

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