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Surface mean flow and Drag coefficient behavior during Tropical cyclone GAJA at Tiruchirappalli, an in-land site, Tamil Nadu

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Abstract

Tropical cyclones are one of the deadliest and costliest natural hazards affecting the Indian coast and particularly in the eastern coastal areas of India. Accurate predictions of winds during land falling cyclone events are essential for meteorologists, emergency managers, social scientists, wind engineer and structural designer to reduce the risk of loss of life and of property damage. It is also helpful in risk analysis and model validation studies. This study examines the changes in mean wind, drag coefficient, wind gust and turbulent intensity variations during tropical cyclone GAJA at Tiruchirappalli, an in-land site of Tamil Nadu. Mean wind speed of 20-30 km h^{-1} gusting to 40-50 km h^{-1} was observed over Tiruchirappalli during the passage of tropical storm GAJA on 16th November 2018 and peak wind speeds occurred at approximately the same time during minimum pressure periods. The mean gust factor for inland site is to be 2.36 for the wind range 3-12 m s^{-1}. This study also describes drag coefficient behavior at inland as well as near shore sites during the GAJA cyclone period using NCEPGFS model derived parameters

Keywords:

Tropical Cyclone ;
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1. Introduction

Tropical storms with extreme wind gust conditions have a sizable contribution to damage caused by natural hazards. A large proportion of the world's population lives in the coastal regions. In the eastern coastal state of Tamilnadu, India over 20 million people currently live in cyclone prone coastal regions stretching from Chennai to kanyakumari. Cyclones all develop and mature over the ocean, fed by heat and moisture exchanges. Wind storming cyclone generates hazards that include strong winds, intense rainfall and storm surge. Storming wind results in structural and infrastructure damages and causalities. Extreme winds typically cause damage to trees, plants and power lines resulting in a larger economic impact during cyclone events. Strong gusts are a risk to safety for aviation and gust speeds are used for calculating wind load on structure and designing the structures. Wind gust factor estimation and turbulent wind gust forecast in numerical models are based on parameterization schemes as model lags in representing the local scale wind gust and turbulent behavior because of the spatial resolution of the model. Surface meteorological measurements near coastal and along the cyclone passing region are a critical data asset in prediction, mitigation and risk and wind load assessments.

Lower atmosphere namely atmospheric boundary layer is characterised by turbulence and frictional effects caused by topographical features and thermal gradients. The lowest 100 m of the ABL represents surface layer and stress in the surface layer create logarithmic wind profile as the shear stress slows the momentum transfer. The transfer coefficient of momentum (surface Drag coefficient) is playing important role in exchange of momentum fluxes between land-atmosphere and air-sea interface. Quantifying of momentum transport in the mixing layer requires turbulent eddies to be resolved through explicit method by means of parameterization (momentum flux derived in terms of wind speed). Drag coefficient is derived from different experimental and empirical equations. Common techniques are profile, bulk aerodynamic, eddy correlation, inertial dissipation, turbulence intensity, and gust factor methods. In this analysis drag coefficient was calculated from turbulence intensity and gust factor methods. Drag coefficient parameterizations for Open Ocean are commonly used for shore line and near coastal areas. Additional and improved field measurements are essential to gaining a better understanding of drag coefficient (C_D) behaviour under high wind conditions over near coastal and inland areas. The dependence of the C_D on wind speed under tropical cyclone conditions is critically important for understanding and modelling storm intensity [Rogers et al., 2013; Soloviev et al., 2014] and design load studies. This paper investigates the variation of mean wind speed, friction velocity, roughness length, 10 m drag coefficient, and wind gust factor from two sites (one over the coastal regions and the other on an inland site) during the GAJA cyclone

2. Study area

Mean wind variation, drag coefficient and other surface layer scaling parameters are studied over an inland and coastal site during the GAJA cyclonic storm period. The coastal site of Vedaranyam and an inland site of Tiruchirappalli were taken for this study. Meteorological data obtained from the weather service organization and GFS model data from NCEP have been used for this analysis. Surface layer scaling parameters of friction velocity, drag coefficient, roughness parameter, turbulent intensity in neutral condition and wind gust factors are derived from surface layer aerodynamic and log-law empirical methods.

3. Tropical Cyclone GAJA

Cyclone 'GAJA' originated from an area of low pressure over the Bay of Bengal near Andaman region and it moved south west and adjoining south east and west central Bay of Bengal and finally moved west and south west direction and intensified in to a cyclonic storm (CS) on 15th November, 2018 and made landfall near Vedaranyam and Adirapattinam site, Tamilnadu on 16th November 2018 with a wind speed of 80-100 kmph gusting to 120-140kmph and further crossed Tamilnadu and enter west coast into the Arabian sea.

4. Methodology

At high wind speeds, overcast conditions the atmospheric boundary layer approaches neutral stability, and the wind profile in the surface layer follows the log-law [Stull, 1988], as described in the following equation

$$U_z = u^*/k \ln (z_{10}/z_0) \qquad (1)$$

The equation (1) is the usual form of logarithmic law. K is known as von karma's constant and has been found experimentally to have a value of 0.4, Z_0 is the roughness length is a measure of roughness at ground surface.

Another measure of the terrain roughness is the surface drag coefficients C_D which is a non dimensional surface shear stress defined as;

$$C_{D10} = u_*^2/U_{10}^2 \qquad (2)$$

Where U_{10} is the wind speed at 10m height

By applying equations (1) and (2) for height Z equal to 10 m, a relationship between the drag coefficient and roughness length can be determined

$$C_{D10} = K\,[\ln (z_{10}/z_o)]^{-2} \qquad (3)$$

Drag coefficient is derived from different experimental and empirical equations. Common techniques are profile method, bulk aerodynamic eddy correlation, inertial dissipation, turbulence intensity, and gust factor methods. In this analysis drag coefficient has been calculated from turbulence intensity and gust factor methods. Turbulence intensity is a measure of the fluctuating component of the wind and it characterizes the intensity of gust in the flow. TI method is based on logarithmic wind profile and the ratio of the standard deviation of the wind record to the frictional velocity. For single level data, the turbulence intensity method was utilized to estimate the roughness length and the drag coefficient as follows:

$$Z_0 = Z_a \exp(-1/TI) \qquad (4)$$

$$CD_{10} = K\,[\ln (z_a/z_0)]^{-2} \qquad (5)$$

Another method to determine z_0 using the GF method is described by Wieringa (1993, 1996), where the gust factor (GF) is defined as the ratio between the peak and mean wind speeds. In this case it is important to understand the frequency response characteristics of the anemometers used in surface micrometeorological observations. In many design code and standard for wind load studies peak factor and gust factor are used for design purpose. In the random process of wind, the peak gust within the average period (10 minutes) may be estimated based on the assumption of longitudinal wind velocity as a Gaussian probability distribution; it can show the estimated peak gust wind. Generally the wind gust forecasts in NWP models are based on parameterizations. These parameterizations can be divided into two groups, surface-based methodologies and profile methods. In surface-based methods, the wind gust speed (U_{max}) is typically divided into the parts of a mean wind speed (U) and a positive fluctuation, which is taken proportional to the standard deviation of the wind speed (σ_U)

$$U_{max} = U + gx + u \quad (6)$$

Where the coefficient of proportionality is called the peak factor

$$gx = U_{max} - U/\sigma_u \quad (7)$$

The gust factor equation then becomes

$$G_U = 1 + gx\,(\sigma_u/U) = 1 + gx + I_u \quad (8)$$

$I_u = \sigma_u/U$ is the turbulence intensity. In a typical gust parameterization, the peak factor (gx) is derived from statistical considerations and I_u is based on surface-layer similarities.

5. Discussions and conclusions

The data from 15 to 17 November 2018, for tropical cyclone GAJA at an inland site, Tiruchirappalli situated in the central Tamil Nadu region was analyzed. Cyclone landfall and its wind magnitude along the movement track is presented in the Figure 1.

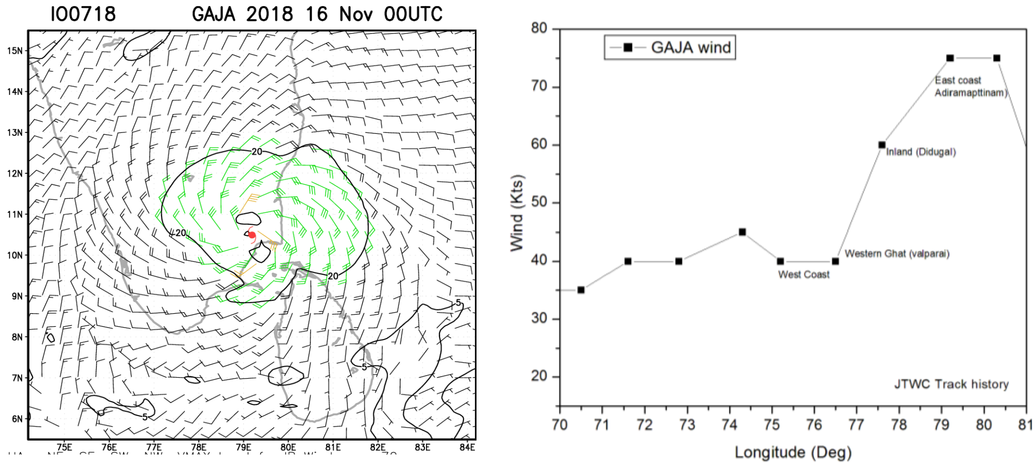

Figure 1: GAJA -CfieldLeft panel) and wind magnitude along the track (Right Panel)

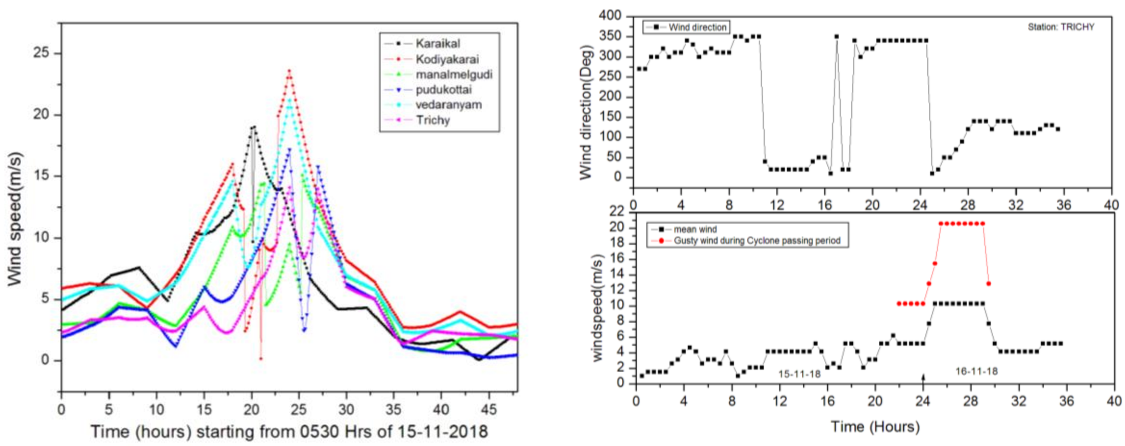

Figure 2: GFS model derived urfacewind variation at different stations during GAJA (Left panel) and Observed wind, wind-gust and wind direction variations at a inland site -Trichy (Right Panel)

It shows wind speed magnitude of about 120-135 km h^{-1} during landfall location (Vedaryam-Adirapattinam, East coast); and further reduced 90-100 km h^{-1} at Dindigul and Pudukkottai; and further reduced to 40-60 Kmph at Tiruchirappalli and Thanjavur, the inland stations. Then it crossed the western coast and moved in to the Arabian sea. The wind speed strength between coastal and inland sites during the cyclone are presented (Figure 2 left panel).

This shows the magnitude of wind in the range of 18-20 m s^{-1} (64 – 72 km h^{-1}) near coastal region and 11-14 m s^{-1} (39 – 50 km h^{-1}) in the inland region. Wind speed of 20-30 km h^{-1} and gusting to 40-50 km h^{-1} observed over Tiruchirappalli (Figure 2 right panel) during the passage of tropical storm GAJA on 16th November 2018 and peak wind speeds occurred at approximately the same time as the minimum pressure duration (Figure 3). Abrupt changes in wind speed of the order of 12-14 m s^{-1} was observed during the passage of storm and strongest gusty winds of 18-20 m s^{-1} was observed in the SSE/SE directional sectors

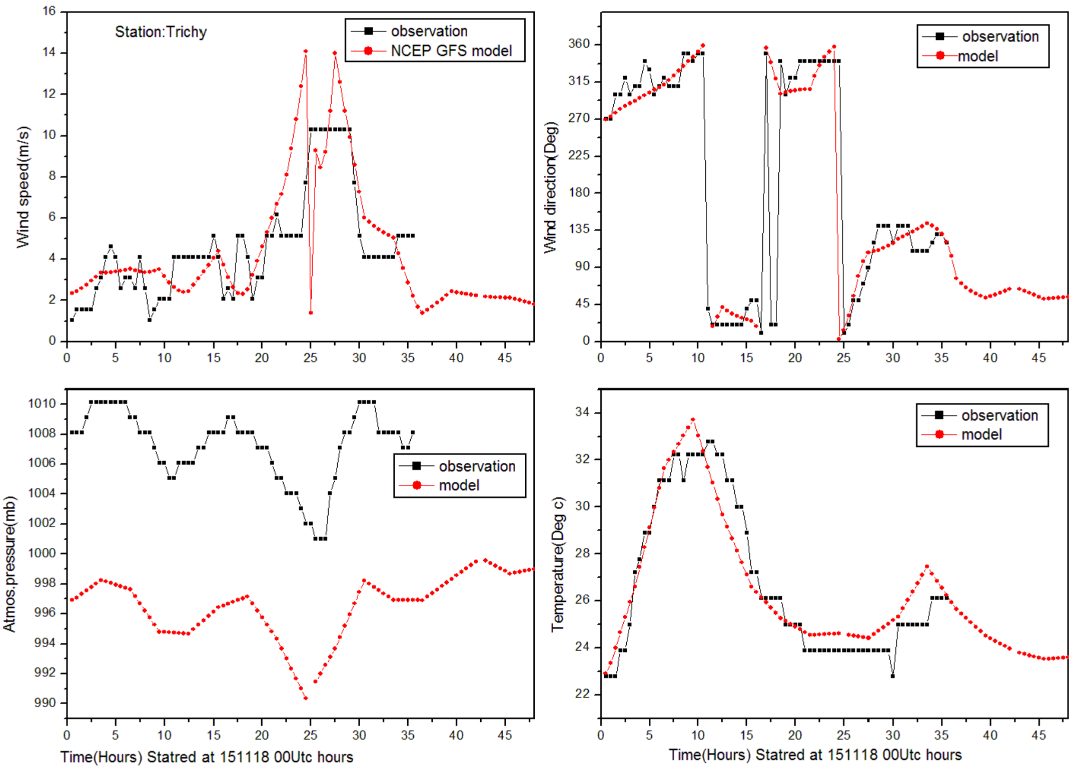

Figure 3 : Observed and model (NCEP GFS) derived meteorological parameters Over an inland site –Trichy during GAJA cyclone period

Computations of roughness length drag coefficient, and frictional velocity, gust factor were tabulated for the coastal and inland site during the high wind speed regimes (Table 1) and during normal period (Table 2). Roughness decreases with increasing wind speed due to the effects of high wind speed smoothing rough obstacles and decreasing role of viscous effect. Roughness considered independent of friction velocity in some cases. Observation based C_{D10} shows decreasing trend with increasing wind speed. Model predicted C_{D10} is higher in both low and high wind regimes. Over an inland site C_{D10} shows more values during low wind cases than in higher wind speed. In the inland site model values showed more C_D than the observational values. For low and moderate wind speed drag coefficient was higher inland site than over coastal site.

Turbulent intensity showed higher value in lower wind speed may be due to wind meandering and for the weak wind the drag coefficient can be sensitive due to meandering motion. In general friction velocity shows increasing trend with increasing wind speed. Model derived roughness parameters shows higher in inland site during high wind speed which is not significant in low wind conditions. Mean gust factor was found to increase with increasing upstream surface roughness. Mean gust factor from coastal site was found to be higher than inland site. The mean gust factor for inland site is to be 2.36 for the wind range 3-12 m s^{-1}. Current design speed code may be modified for different wind speed ranges through more micrometeorological observations during extreme wind events. In this work, just the surface scaling parameters and momentum fluxes were analysed. The relations with heat and moisture fluxes are to be addressed in further studies.

Table 1 : Surface layer quantities during cyclone Landfall high wind speed (5-20m/s)duration for coastal and inland site

Site	Mean wind	Wind Std.Dev	Peak wind	TI	Z_O	U_*	C_D	G_U
Inland (Obs)	8.86	2.42	10.3	0.3001	0.3570	0.6863	0.01441	2.276
Inland (Model)	5.82	3.54	14.1	0.6088	1.9348	1.3566	0.05930	3.424
Coastal site	12.12	3.72	21.4	0.305	0.3767	1.478	0.01487	2.753

TI-Turbulent Intensity, Z_O –Roughness length, U_*-Friction velocity, C_D- Drag coefficient, G_U-wind gust factor

Table 2: Surface layer quantities during cyclone Landfall during stationary Normal (Low wind speed duration < 5m/s) period for coastal and inland site

Site	Mean wind	Wind Std.Dev	Peak wind	TI	Z_O	U_*	C_D	G_U
Inland (Obs)	3.2	1.234	5.2	0.3918	0.7790	0.4496	0.02456	2.462
Inland Model derived	4.02	2.19	8.11	0.544	0.0182	0.723	0.04735	2.251
Coastal site	3.44	1.55	6.96	0.451	1.0890	0.6216	0.03254	3.0243

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