

Surface Layer Conditions of the Atmosphere over Western Bay of Bengal during MONEX

A F ANTO, L V GANGADHARA RAO & Y K SOMAYAJULU

National Institute of Oceanography, Dona Paula, Goa 403 004

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Based on surface meteorological data and wave data collected from 2 stations in the western Bay of Bengal in July 1979, surface layer (SL) conditions of the atmosphere for different situations of surface circulations and the associated sea surface roughness and height of surface roughness were studied. Ri_{bulk} values for SL indicated neutral and near-neutral conditions. The convective activity affected sea-air temperature difference. Wind and convective activity appeared to cause variations in the characteristic height of SL. Larger variations of SL were encountered during the rough regimes of sea surface roughness. The wind hodographs of diurnal variations showed anticyclonic, precursor and cyclonic circulations.

Studies on the structure of the marine atmosphere during summer monsoon assume special significance because during this season troposphere is subjected to intermittent variations due to active, weak and break monsoon conditions. Moist convective motion, a typical characteristic of tropical atmosphere, is an important process to affect the structure of the marine atmosphere. The layered structure of the atmosphere under the large scale monsoonal flow is mainly due to the dynamic and thermodynamic processes. The vertical structure of atmosphere can be divided into different layers, viz. surface (SL), mixed, transition, cloud, inversion, etc¹⁻³. The varying characteristics of these layers can be identified in terms of the energy exchanges at SL and the convective motion which couples SL processes with the higher layers of atmosphere. Thus, the studies on SL conditions are essential for a better understanding of the structure of atmosphere. The paper presents a study of the SL conditions of atmosphere for different situations of surface atmospheric circulations and the associated sea surface roughness and characteristic height of surface roughness over the western Bay of Bengal during MONEX.

Materials and Methods

During the sixth MONEX cruise of *RV Gaveshani*, meteorological and oceanographic observations were carried out at 2 stations: 13°N, 85°E (st A) and 16°N, 87°E (st B), shown in Fig. 1. At st A, the observations were carried out from 0700 hrs (IST) of 19.7.79 to 1000 hrs of 23.7.79 and at st B from 0700 hrs of 24.7.79 to 2000 hrs of 31.7.79. At st A, the present weather (ww) conditions were 02, with rare occurrences of 01, 03 and 95. There was a slight rainfall on 22.7.79. The ww at st B were not persistent and hence the data from this station were divided into 2 groups, GI and GII,

characterized by 2 different types of surface air circulations. For GI, ww were 02, 03 and 13; while those for GII were of mixed type: 02, 13, 21, 50 and 60. Corresponding to these ww of st A, GI and GII, the atmospheric pressure in the SL comprised 3 distinct types of diurnal variations, resulting into 3 different types of circulations in SL. Hence, the surface meteorological data (collected at hourly intervals) were grouped into 3 periods, viz. 20-22 July at st A, 25-27

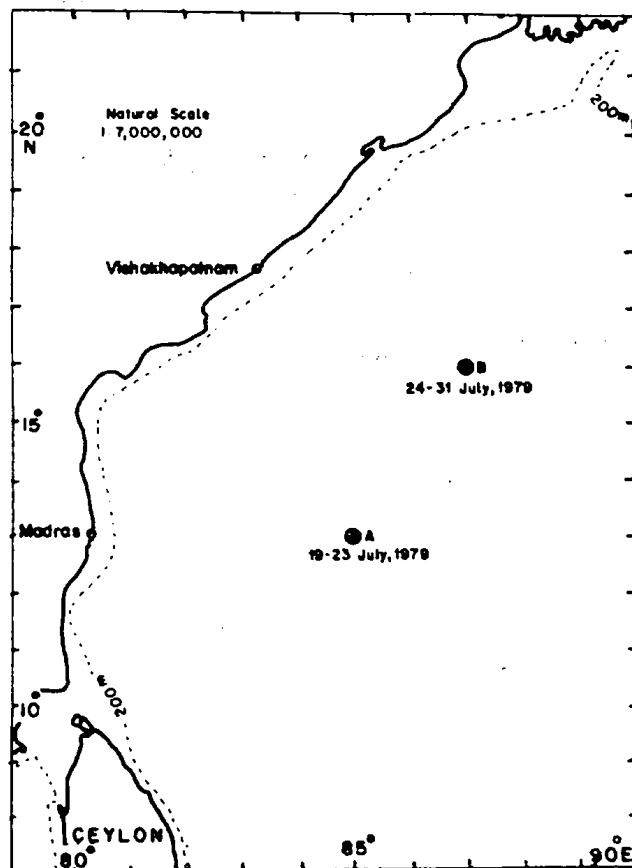


Fig. 1—Location of stations

July at st B (GI) and 28-30 July 1979 at st B (GII), to account for 3 different conditions of ww, atmospheric pressure and circulations. Based on the average values for each hour of the grouped 3 periods (st A, GI and GII), diurnal variations of wind, characteristic height of SL, roughness parameter (Z_0) and characteristic height of surface roughness (h_s) were analysed and studied to elucidate different characteristics of SL associated with the diurnal thermal stratifications and the weather that prevailed during the observation period. For the studies on Z_0 , the waves were recorded for 15 min at 3 hourly intervals, using a shipborne wave recorder. The analysis of oceanographic observations as a function of the meteorological forcings in SL will be explained elsewhere.

Surface wind—Diurnal variations of surface wind (at a height of about 10m) are shown in Fig. 2a. To examine the hourly steadiness in the mean diurnal variation (Fig. 2b), the standard vector deviation method⁴ was adopted. Because of a large scatter in the standard deviations of wind vectors, probable error circles⁵ were fitted (Fig. 2b). The wind data were harmonically analysed to study the type of diurnal circulation and the occurrences of maxima and minima (Fig. 3a) in relation to the atmospheric pressure variations (Fig. 3b).

Surface layer—Structural characteristics of SL could be studied by means of a characteristic height (L) i.e., Monin-Obukhov length which represented the height where the shear production equalled the buoyant energy production. L was computed from a constant and the fluxes which were approximately constant in the SL (constant flux layer).

For the computations of fluxes of momentum, water vapour and sensible heat (τ , E and S) the following bulk aerodynamic relationships⁶ were used:

$$\begin{aligned} \tau &= \rho C_D U_{10}^2 \\ E &= \rho C_E (q_s - q_{10}) U_{10} \text{ and} \\ S &= \rho C_H C_P (T_s - T_{10}) U_{10} \end{aligned}$$

wherein the values of C_D , C_E and C_H were taken from the Tables 2 and 4 of Bunker⁷. From these fluxes, the buoyancy flux (WB) and the Monin-Obukhov length (L) were determined using the following formulae⁸:

$$WB = \frac{geI}{\rho C_P \theta_V} (b + 0.75) \text{ and}$$

$$L = - \frac{U_*^3}{k(WB)}$$

where e is evaporation (g/cal/day), I the latent heat of vaporization of water, θ_V the virtual potential temperature, b the Bowen's ratio, U_* friction velocity

and k von-Karman constant. The negative sign indicates unstable conditions when the buoyancy flux is upward. L could be considered as the characteristic height of SL⁹ only during neutral and near-neutral conditions. Under unstable conditions of atmosphere, L might not be considered as the exact SL height, but L would be higher than the actual SL.

Sea surface roughness—For the determination of sea surface roughness (Z_0), a method using routine surface meteorological data were considered. Hsu¹⁰ related Z_0 to the significant wave height (H), phase velocity of wave (C) in deep water and friction velocity (U_*), as given below:

$$Z_0 = \frac{1}{2\pi} \frac{H}{(C/U_*)^2}$$

where U_* was determined by the parameterization method⁶. With the availability of wave data and parameterized momentum flux, the above formula which accounts for the wind-wave interaction was considered more appropriate for the estimation of sea surface roughness parameter.

Characteristic height of surface roughness—The characteristic height of surface roughness (h_s) was calculated from the following relationship, after Sethu Raman¹¹:

$$h_s = 0.764 \frac{U_*^2}{g}$$

Results and Discussion

Since the Monin-Obukhov length (L) could be taken as the characteristic height of SL only in neutral and near-neutral conditions, let us first examine the diurnal thermal stratifications of SL. The air temperature and sea surface temperature (SST) data from sts A and B showed sea-air temperature difference (SATD) to be mostly positive (Figs 4-a, b&c), indicating higher SST as compared to air temperature. According to Roll¹², the surface winds tend to be more intense with cold air over warm water than with warm air over cold water. During the prevalence of strong surface winds over the Arabian Sea in the monsoon period neutral stability in SL was inferred¹³. Similarly, it is quite probable that the strong surface winds associated with the Bay of Bengal branch of monsoon current cause neutral or near-neutral stability in SL. The computed Bulk Richardson (Ri_{Bulk}) values showed near-neutral conditions with indications of slight instability (Table 1) which might be due to shear convective effects¹⁴ under moderately strong winds.

The mean values of maximum and minimum wind speeds are given in Table 1. During the diurnal variations, the standard deviations of surface wind

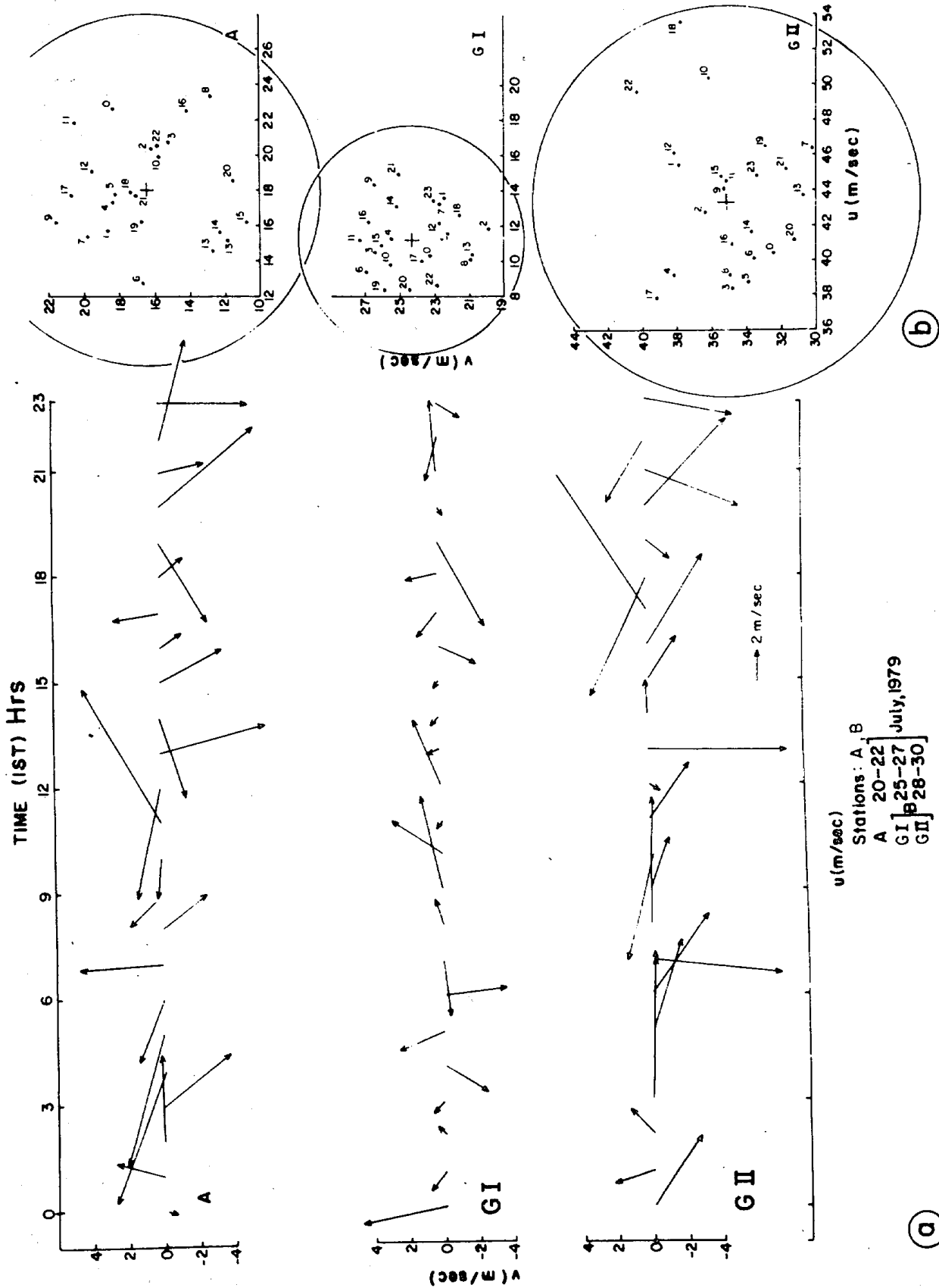


Fig. 2—(a) Diurnal variation of mean surface wind, (b) Steadiness of mean surface wind (small numbers indicate the hours of occurrences)

vectors showed large scatter (Fig 2b), except during GI of st B. Large and small scatter in the diurnal standard deviation of wind vectors were observed for both high and low wind speeds, suggesting that scatter was independent of the wind speeds. The standard deviations of certain wind vectors clustered around the centre of probable error circle (Fig 2b), inferring the degree of steadiness—about 60% at st A and GII and 90% during GI. Hodographs (Fig. 3a) projected the mean diurnal variation of surface wind with veering and backing. It could be seen from the hodographs that the zonal component was predominant during st A and GII, whereas the meridional component was prominent during GI.

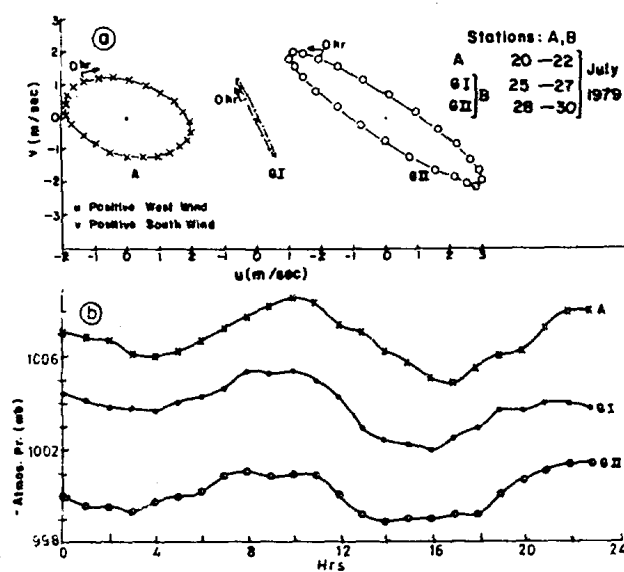


Fig. 3—(a) Wind hodographs, (b) Diurnal Variation of mean atmospheric pressure

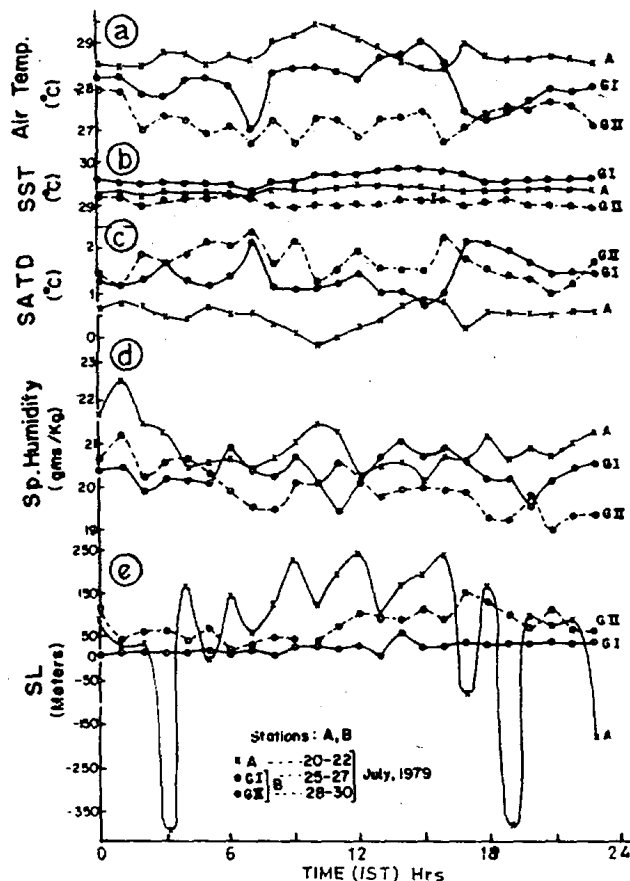


Fig. 4—Diurnal variation of (a) mean air temperature, (b) mean sea surface temperature, (c) mean sea-air temperature difference, (d) mean specific humidity and (e) mean characteristic height of surface layer

Table 1—Mean Values during Diurnal variation

	A(13°N, 85°E) 20-22 July, '79		GI(16°N, 87°E) 25-27 July, '79		GII(16°N, 87°E) 28-30 July, '79	
Sea surface temp. (SST-°C)	29.29		29.57		29.04	
Air temp. (°C)	28.81		28.12		27.3	
Sea-air temp. difference (SATD °C)	0.49		1.42		1.7	
Specific humidity (gm/Kg)	20.82		20.23		19.84	
Bulk Richardson number (Ri_{bulk})	-0.0047		-0.0225		-0.0079	
Roughness parameter (Z_0 cm)	0.0213		0.0044		0.0573	
Characteristic roughness height (h_s cm)	0.8785		0.3724		1.6974	
Characteristic surface layer height (SL m)	50.65		10.5		62.11	
Wind	Speed (m/sec)	Time (IST)*	Speed (m/sec)	Time (IST)*	Speed (m/sec)	Time (IST)*
Maximum	9.0	1100	5.6	1800	9.4	1600
Minimum	0.6	0000	0.4	1100	0.8	1200
Max. U component	5.4	2200	3.99	2100	8.05	0300
Max V component	4.6	0700	4.80	0000	5.05	1700
Min. U component	0.4	2100	0.36	0600	2.47	1500
Min. V component	0.01	0200	0.32	2100	0.05	1400

* In hrs

Surface wind and convective activity were found to control the variations in the thickness of SL. At st A, the maximum variation in the characteristic height of SL is encountered at 0300 hrs when the wind speed was minimum (Figs. 3a and 4e). A similar variation in the height of SL occurred at 1900 hrs, i.e., with a time lag of 2 hr from the occurrence of maximum wind speed at 2100 hrs. Between 0900 hrs (maximum wind) and 1500 hrs (minimum wind), SL changes were of oscillatory type and no spikes were observed. SL variations were less during GI when weak surface winds were observed. During GII, SL had the maximum height at 1700 hrs and the minimum height at 0600 hrs, exhibiting a lag of 2 hr from the occurrence of maximum wind speed (at 1500 hrs) and a lead of 2 hr from the occurrence of minimum wind speed (at 0800 hrs). It is interesting to note a time lag of 2 hr between the occurrences of maximum SL height and maximum wind speed, at both st A and GII.

The second parameter which affects SL conditions is convective activity that could be determined through the variations of specific humidity rather than that of air temperature¹⁵. The fall in specific humidity indicates increase of convective activity and vice versa. The latter situation meant the positive feedback and the former the negative feedback². During GI, the increase in SL height around 1400 hrs coincided with the weak convective activity (Figs 4-d and e). Similarly the slight fall in SL height around 1300 hrs might be the consequence of deep convective activity, around 1100 hrs. In this case of weak surface winds, the observed SL variations appeared to depend on convective activity. Further, the higher value of SL at 0000 hr during GII corresponded to strong convective activity. The oscillatory nature and the peaks in SL at st A, confirmed that the characteristic height of SL was not only dependent on wind speed but also on convective activity. Apart from the specific humidity variations, SATD also reflects the effects of variations in convective activity.

For studying the effects of wind-wave interaction on SL, the parameters to be considered are Z_0 and h_s . Z_0 could be used to classify the 3 different stages—smooth, slightly rough and rough surface of sea surface roughness^{16, 17}. At st A, sea surface was smooth during 2100-0300 hrs (Fig. 5a). Rough seas prevailed during 0900-1500 hrs. The periods of transition from smooth to rough and vice versa were observed during 0300-0900 hrs and 1500-2100 hrs respectively. Similarly, various stages of roughness could be seen during GI and GII. SL had larger variations when the sea surface was rough. But, when the convective activity was intense, SL variations were large, even during smooth and transition stages of sea surface roughness. Variations of Z_0 (Fig. 5a), in general, agreed with those

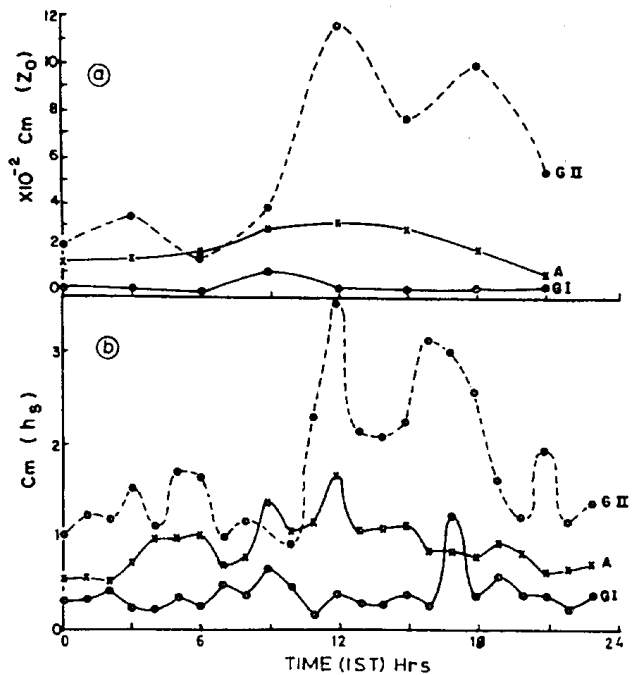


Fig. 5—Diurnal Variation of (a) mean roughness parameter and (b) mean characteristic height of surface roughness

of h_s (Fig. 5b). For an aerodynamically rough surface, h_s/Z_0 satisfied a unique value of 30 (ref. 11), so that by knowing one parameter, the second could be estimated. In the present study, which includes the three different stages of sea surface roughness, h_s/Z_0 values varied between 30 and 100.

Comparative features at sts A and B (GI and GII)—SL conditions appear to be different at sts A and B, probably due to difference in their location and ww. With the available limited data, the variations in properties with latitude were not considered in the present study. This comparison is to highlight the SL conditions under 3 different synoptic weather situations. Table 1 brings out the mean values of SL conditions in the diurnal cycle.

Air temperature and pressure were higher at st A than that during GI and GII. The relatively warmer sea surface during GI reflects the precursor situation for the formation of cyclonic circulation. During GII, both air temperature and SST were lower and this resulted into higher SATD, compared to the other 2 cases (Fig. 4c). It is interesting to note that the SATD values were comparatively low at st A, where larger variations in SL were encountered. Similarly, the convective activity was more during GII. This might have caused the mixing up of the colder air from higher levels with the warmer surface air and thereby relatively low surface air temperature. The low SST observed during GII appears to be the result of evaporational cooling by strong surface winds. These changes in surface air temperature and SST might have caused the observed

diurnal irregular variations of surface wind (Fig. 2), as a part of large scale circulation change¹⁸.

The mean diurnal variation of wind during GI depicted the precursor anticyclonic circulation (Fig. 3a), reflecting the transition stage between anticyclonic and cyclonic circulations at st A and GII respectively. In the case of cyclonic circulation during GII, the maximum zonal wind component occurred earlier than that in the case of strong anticyclonic circulation at st A. The zonal wind component occurred about the same time with low amplitude during GI and high amplitude during GII, while the meridional wind component occurred with low amplitude at st A and high amplitude during GII, around the same time.

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