

A satellite study of cloud clusters over southeast Asia during SMONEX-79

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सार - इस शोध पत्र में (0-30° उ., 70-120° पू.) दक्षिण पूर्वी एशिया के "स्मोनेक्स" गुच्छों के वितरण, आकार, तीव्रता, जीवनकाल और प्रक्षेप पथों को प्रस्तुत किया गया है। इसमें रक्षा मौसम विज्ञान उपग्रह कार्यक्रम (डी.एम.एस.पी.) अवरक्त (दिन और रात) और जून, जुलाई एवं अगस्त 1979 के दृश्य (दिन) चित्रों को प्रयुक्त किया गया था। इसमें देखा गया है कि मेघ गुच्छों का औसत जीवन काल एक दिन से भी अधिक (31 घंटे) है और यह आकार और तीव्रता के साथ बढ़ता है। "तीव्र" और बहुत बड़े गुच्छे मानसून अवदावों से संबंधित पाये जाते हैं। महासागरीय गुच्छे स्थली गुच्छों से अधिक सक्रिय थे। स्मोनेक्स के दौरान गुच्छों की सक्रियता दिन की अपेक्षा रात में सांध्यता से अधिक थी। तुलनात्मक अध्ययनों से पता चलता है कि स्मोनेक्स गुच्छों की गति धीमी होती है किन्तु गेट गुच्छों की अपेक्षा इनका जीवनकाल बड़ा था।

ABSTRACT. This paper presents the distribution, size, intensity, lifetime and trajectories of the 'SMONEX' clusters of southeast Asia (0-30° N, 70-120° E). Defence Meteorological Satellite Program (DMSP) infrared (day and night) and visible (day) pictures for June, July & August 1979 were used. It was found that lifetime of cloud clusters averaged more than a day (31 hours) and it increased with size and intensity. The intense and very large clusters were found to be related with monsoon depressions. The oceanic clusters were more active than those over the land. The cluster activity was significantly greater at night than at day during SMONEX. Comparative studies showed that SMONEX clusters were slower in movement but of longer lifetime than GATE clusters.

1. Introduction

It has been possible to delineate salient features of the monsoon circulation due to the advent of weather satellites and the mounting of the various international monsoon experiments, like Monsoon Experiments (MONEX) in 1979.

A good number of publications is available in the literature on the characteristics of cloud clusters over the Atlantic (say, Sikdar *et al.* 1980); Pacific and tropics (Knox and Gray 1973, Martin and Sikdar 1975, 1979).

Sikka and Gadgil (1980) examined the daily variation of maximum cloud zones (MCZs) and the intertropical convergence zone (ITCZ) over Indian longitudes during the southwest monsoon. They found that MCZ mainly occurs in monsoon region north of Lat. 15°N with a secondary MCZ in the equatorial region (0°-10°N).

The objectives of this study include: first, to describe the distribution, size, intensity, trajectory and lifetime characteristics of cloud clusters of SMONEX region (*i.e.*, 0°-30°N, 70°-120° E) during June, July and August 1979; second, to examine the association of cluster activity to the synoptic-scale weather disturbances and third, to study the kinematic behaviour of a few long lasting intense clusters.

2. Data

To answer these questions the detailed study of cloud cluster characteristics has been made using the high resolution (600 m), Defence Meteorological

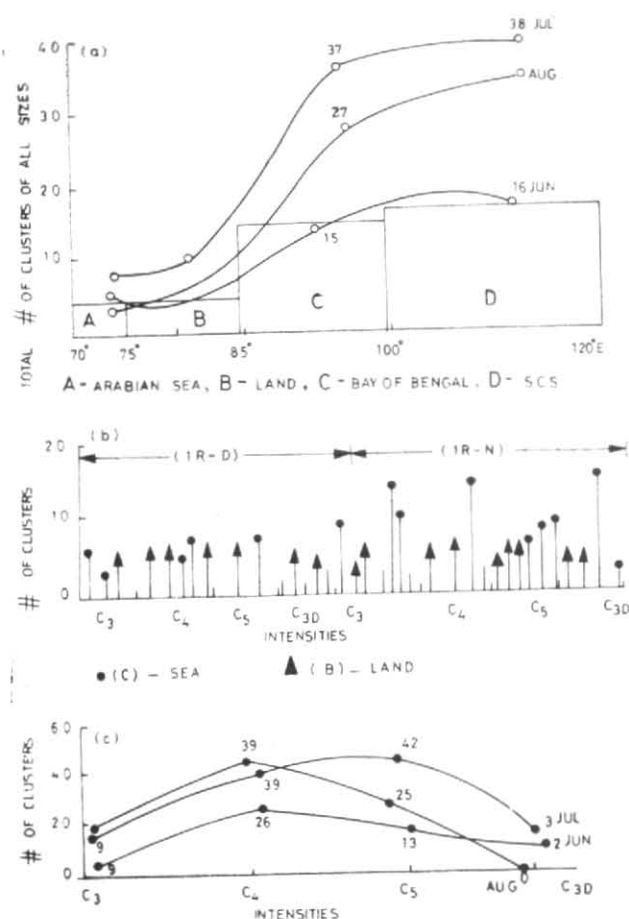
Satellite Program (DMSP) imagery. We examined 210 satellite imageries consisting of IR-day (0830 IST), IR-night (2030 IST) and visible data for the significant monsoon months, *viz.*, June, July & August of SMONEX 1979. DMSP is a system of near-polar orbiting satellites providing information in two spectral bands (visual: 0.4-1.1µm and infrared: 8-13µm, changed to 10.4-12.0 µm after June 1979). The imagery collection consists of positive transparency products (18"×12") at a resolution of 0.6 km by the two satellites in near polar (inclination of 98.7°), sun-synchronous orbits at 825 km altitude.

3. Analysis procedure

3.1. Satellite nephanalysis of cloud clusters

3.1(a). *Identification of cloud clusters* - In the present study, the 'cloud cluster' has been identified as a bright persisting cloudmass containing significant convection. The shape of a cluster is preferably a circular or quasi-circular, oval, with well defined cloud boundaries of highly covered (80-100%) cloud coverage. Sometimes, this definition was stretched on to accommodate E-W or N-S elongated clusters. Cloud masses remaining smaller than the 1° were ignored due to their short lifetime and indistinguishable features. The cloud band which has a longitudinal extent of at least 10° were categorised as MCZ; as defined by Sikka and Gadgil (1980). Cloud type was recognised from brightness and texture characteristics as per guidelines of Tech. Note No. 124 of WMO (1973).

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Figs. 1(a-c). (a) Zonal frequency of all sizes clusters during Jun-Aug 1979 (IR-D) (b) Frequency of clusters intensities over land (B-zone) and sea (C-zone during Jun-Aug 1979) and (c) Frequency of all type cluster's intensities over 'SMONEX' domain during Jun-Aug 1979

3.1 (b). *Intensity* — The categories pertinent to the present investigations are C_3 , C_4 , C_5 and C_3D . Category C_3 represents slightly enhanced convection consisting of large cumulus and cumulus congestus. C_4 represents moderately enhanced convection consisting of cumulonimbus clouds. C_5 represents intense convection consisting mainly of cumulonimbus clouds. Category C_3D accounts for the decay stage of clusters are mainly cirrostratus and altostratus.

3.1 (c). *Size* — Size was estimated by means of "unit" comprising of $2.5^\circ \times 2.5^\circ$ squared grid on a transparent overlay. By means of the overlay, the number of "units" covered by each satellite observed cluster were counted. "very small" (1° squared) clusters were excluded. The clusters covering up to 2, 4, 8 and greater than 8 units were categorised as SC_1 , SC_2 , SB & SA sized clusters respectively.

3.1 (d). *Lifetime* — It was estimated by computing the time interval between the appearance (the first sighting) and the disappearance of an individual cluster. Each cluster location was determined by its mass weighted

centre, *i.e.*, the highest spot in the centre of the cluster; and was labelled by a number. It was followed until it merges with another cluster, moved outside the area of interest (*i.e.*, $30^\circ \times 50^\circ$ grid), or dissipated. Both IR-day and IR-night imagery were used to maintain the observational interval of 12 hours. New clusters were labelled and counted by superimposing the first day picture on the next day's satellite picture. First the already labelled cluster of the previous day were identified. Again, new clusters were labelled and thus the chain continued. To avoid any ambiguity, very small clusters with lifetime less than 12 hours were excluded. While tracking clusters from one day to the next, sizes, intensities and movements were recorded.

3.1 (e). *Trajectories* — Trajectories of a few typical "intense" clusters (*i.e.*, size SC_2 ; intensity C_4 & C_5 ; lifetime 12 hours) were plotted to investigate direction and speed of cloud clusters (Fig. 2 c).

3.2. *Kinematic features of selected intense cloud clusters in Lagrangian frame* — These studies were conducted by making use of FGGE level IIIb data with the satellite nephanalysis results. Two very large intense clusters of size: SB and intensity C_4/C_5 were selected for examination of their kinematic features, *e.g.*, mass transport and vorticity changes inside the cluster in the Lagrangian frame. Both these clusters 'A' & 'B' appeared in the Bay of Bengal, during 1-12 August (lifetime 228 hr) and 5-18 August (lifetime 276 hr) respectively. The daily grid point values of U -component and V -component of wind velocities around the mass-weighted centre of cloud clusters were read from the level IIIb data. The nine-point averaging was done to get the mean values at the centre of the cluster. The computation was done for both morning (00 GMT) and the evening (12 GMT), from surface (1000 mb) to 100 mb level. This exercise was repeated for each day of cluster's life-span. Kinematic methods were employed to compute the mean vertical velocity fields (\bar{w}). The horizontal velocity divergence ($D = \partial u/\partial x + \partial v/\partial y$) & $\zeta = \partial u/\partial y - \partial v/\partial x$ was analysed in the vertical so that vertical velocities at 1000 mb and 100 mb levels are zero.

4. Results and discussions

4.1. Characteristics of cloud clusters

4.1.1. *Distribution* — A great deal of zonal and meridional variation in the cluster distribution was observed. The three points emerge from these observations.

(i) The number and density (*i.e.*, clusters per unit area) of cloud clusters generally increased from west to east over the oceanic region:

(ii) The area 10° - 20° N of South China Sea (SCS) and the Bay of Bengal are most favourable for the generation and persistence of clusters (Fig. 1a).

The comparatively higher density of clusters in the Bay of Bengal than SCS may be due firstly, to the movement of clusters from SCS with the westward propagating monsoon disturbances (*i.e.*, depressions) and their persistence for a longer time in the Bay of Bengal. Secondly, to the high terrain in SCS, the SSTs are low as compared to the higher SSTs of Bay of Bengal reduction in the number of clusters west of 85° E during SMONEX, as revealed in the present study,

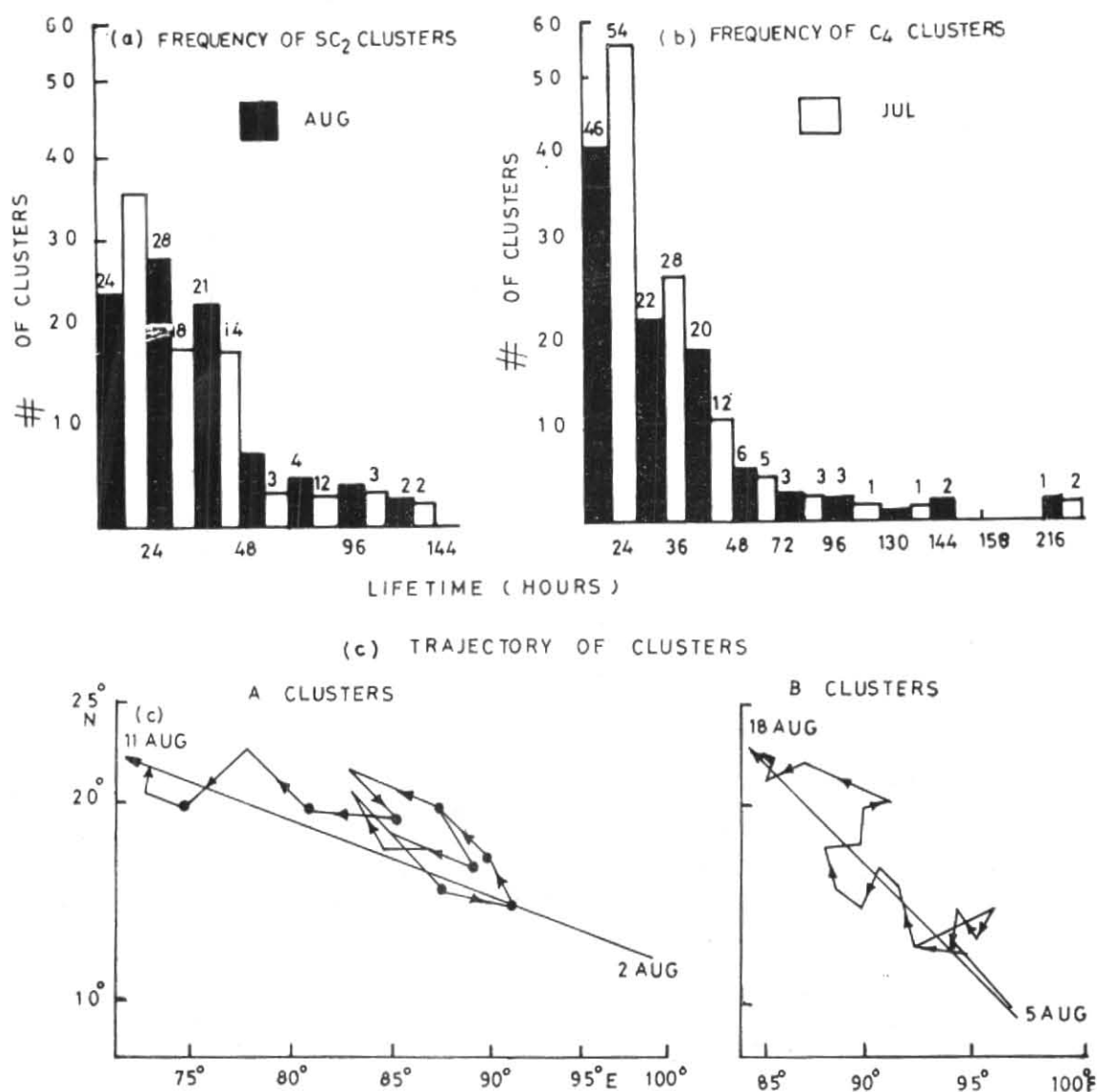


Fig. 2. (a) Frequency of SC₂ clusters, (b) Frequency of C₄ clusters and (c) Trajectory of clusters

appears to be due to spreading of cold waters in the area of significant upwelling in the southeast Arabian Sea off Kerala coast, which inhibits cloud development (Mishra 1981).

Houze (1982) observed that intense clusters are accompanied by organised convective activity and precipitation. It seems that the appearance of large intense clusters (SA-size) is an indication of the generation of monsoon depressions over these areas. The area 5°-15° and east of 85° E was found to produce most of the clusters with dominance of most intense clusters (SA/SB size) indicating deep convection over the area which might be related to the orographic features of this region. The influence of orography on cloud cluster activity was pointed out in the GATE area by Martin and Schreiner (1981).

4.1.2. *Size* — Most of the clusters maintained a size smaller than 2 units (13.25 deg²). Approximately, one third reached SC₂ size. Very few maintained SB/SA size throughout their life cycle.

Fig. 1 (a) shows the sum of all cluster sizes in the particular zone. From June to July there is a regular increase in number of clusters, followed by a decrease during August. This decrease in number is due to the occurrence of the second break in monsoon in the middle of August, after which the monsoon did not revive and practically ended in withdrawal.

4.1.3. *Intensity* — About 33% of the clusters reached a maximum intensity of C₅. Only 45% were classified as C₄, 12% as C₃ and the rest were C₃D. It is to be noted that slightly enhanced convection consisting of larger

TABLE 1

Average lifetime of cloud clusters (hr)

Size intensity	June			July			August		
	IR-day	IR-night	VR	IR-day	IR-night	VR	IR-day	IR-night	VR
	(a) size								
SC ₁	33	22	16	26	30	25	21	28	23
SC ₂	21	20	15	42	42	37	39	22	24
SB	54	30	24	49	75	52	54	61	82
SA	—	—	—	48	72	—	248	120	72
	(b) Intensity during June-August								
C ₃ D	12	31	14.1	20	—	25	—	—	23
C ₃	—	24	18	38	35	15	38	21	18
C ₄	26	23	12	36	33	32	39	23	32
C ₅	41	20	12	27	47	24	33	39	33

$$C_{3D} = 23, C_3 = 27, C_4 = 31, C_5 = 34.$$

C₄ and cumulus congestus (*i.e.*, C₃) which is indicative of early stage cloud cluster development, was almost negligible in June. The generation of clusters begins essentially in July with an increase of C₃, which further was inhibited in the later half of August (*i.e.*, decrease of C₃) due to withdrawal activity of the monsoon. The increase in July may be related to the active monsoon (Fig. 1c).

Increase in C₃D clusters along with C₄-C₅ in the area east of 85° and equator to 20° N during July consisted both stratiform and convective clouds due to baroclinity of these oceanic areas (Fig. 1b). The cluster intensity C₄-C₅ showed a maximum in the belt 10°-20° N over the most favourable regions of the Bay and Gulfs, indicating intense convection favourable for the occurrence of clusters. It can be conjectured that the baroclinity combined with terrain features helps in the development and intensification of cloud clusters. Cloud clusters may not intensify over cold waters, or if adequate moisture in the inflow layer is not available, as in June. The results of studies of present investigation show that the distribution, size and intensity, all increased during night more than during the day. Diurnal changes in cloud cluster characteristics may be attributed to the increased convective mass transport at 1230 hr (Sec. 4.3).

4.1.4. *Lifetime* — There was great variability in the lifetime of SMONEX clusters. The range was from 12 hours to more than 11 days.

Lifetime is a strong function of cluster size, *i.e.*, the lifetime increases with increasing cluster size. The average lifetime of clusters SC₁, SC₂, SB & SA are 23 hr, 32 hr, 56 hr and 92 hr respectively (Fig. 2 a). Lifetime is also a function of intensity of the cluster (Table 1). The more intense clusters lived longer than the less intense ones. A comparable intensitywise variation in the lifetime of clusters was observed with

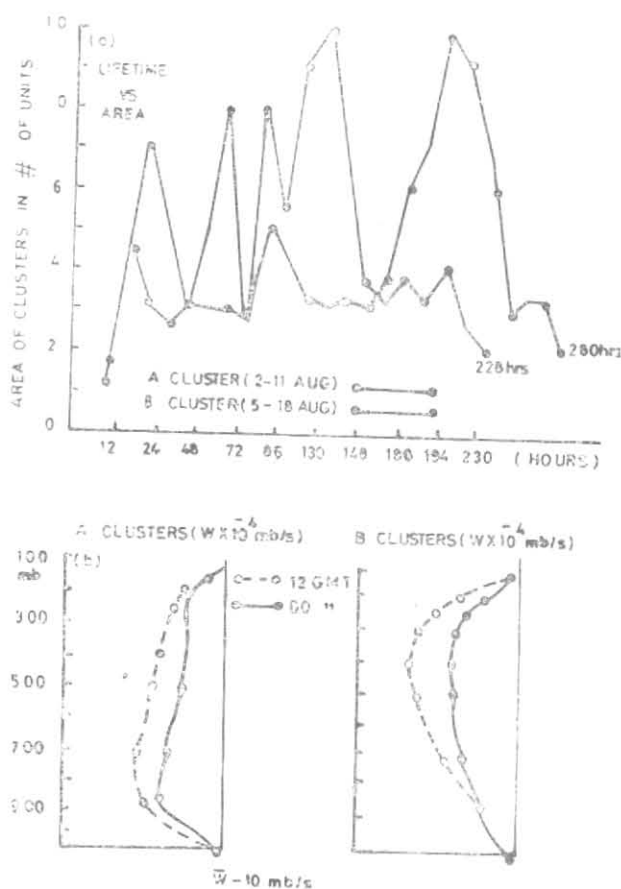
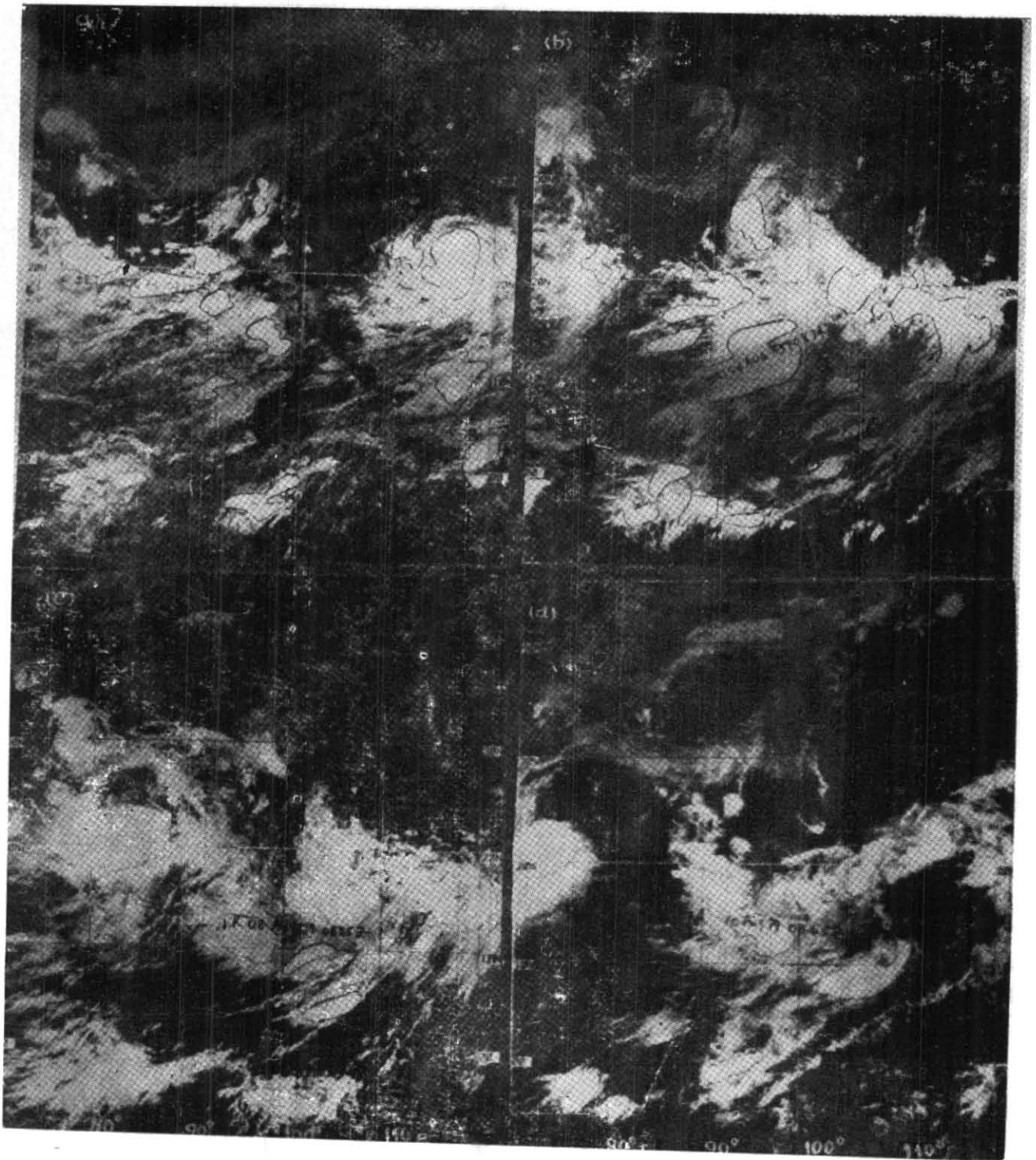


Fig. 3. (a) Diurnal oscillation of cloud cluster area and (b) Vertical velocity profiles cluster

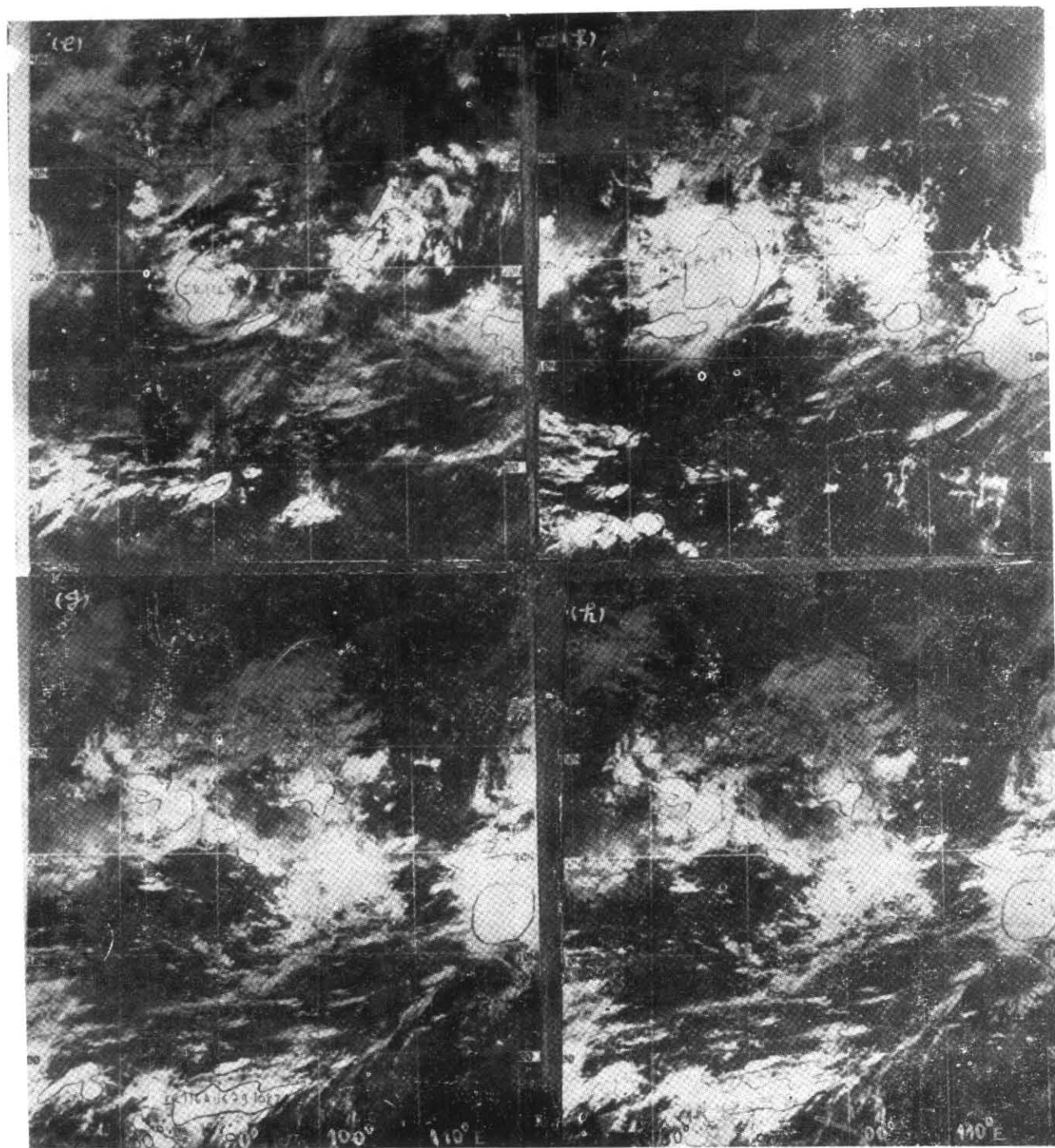
the progression of the monsoon. There is a noticeable increase in the average lifetime of C₃D, C₃, C₄, C₅ intensity categories from June to July, with a slight decrease in August (Fig. 2 b).

The reduction in average lifetime of these clusters in August may be interpreted as being due to the weakening of disturbances during the later half of August in association with breaks in monsoon that finally led to withdrawal. The other explanation of longer lifetime during Jul-Aug may be correlated with the location of heat source, *i.e.*, maximum SST in case of oceans, boundary layer pumping and moisture availability. In summer 1979 maximum SST occurred during July and first half of August over the Bay of Bengal (Mishra 1981).

The gradual increase in lifetime from C₃ to C₅ can be related to weak, moderate and intense convection. The transition from C₃ to C₅ implies a phase change in the cluster, activity analogous to the transition from developing to mature stage of an intense cluster. C₃D relates to the dissipating stage and obviously supports the shorter lifetime.



Figs. 4 (a-d). Satellite imagery during 2-16 August



Figs. 4 (e-h). Satellite imagery during 2-16 August

4.1.5. *Trajectories* — Trajectories of typical intense clusters which could be tracked for two days or more during June-August are shown in (Fig. 2 c). There is much variability in the trajectories especially over land and oceanic areas, yet the clear tendency is for clusters to move westward from SCS to the Bay of Bengal and northward from Bay of Bengal to the Indian land region. This northwest propagation of cloud clusters in July closely resembles the normal tracks of monsoon depressions over the Bay of Bengal and the Indian Peninsular region. The trajectory maps of Martin & Schreiner (1981, Figs. 6-8) are consistent with this result showing persistent westward movement of their GATE clusters.

The variability of cluster direction in SMONEX domain is much greater over water than over land. Observations show that during July-August, the larger intense clusters of longer lifetime which persisted in the Bay of Bengal were associated with predecessor intense clusters moving from SCS.

The highest density of trajectories, in general, was near 12° and 22° N between 85° & 110° E over the head Bay of Bengal, Gulf of Tonkin, Gulf of Thailand and SCS (central part). Clusters had a general tendency to move northwestward/westward. Speed computations were done from the trajectories and gave a mean speed of SMONEX intense clusters deduced to be $2.11^\circ/\text{day}$ (2.4 m/s). Speed is a function of cluster size and maximum speed recorded was 3.8° per day. Though these speeds are comparable with the speed of the monsoon depressions of 6 July 1979 ($2^\circ/\text{day}$) they are much lower than those of West Atlantic clusters 7° - $18.5^\circ/\text{day}$ (6-15 m/s) (Martin and Sikdar 1979). The maximum speed of clusters was observed more over the oceans ($2.3^\circ/\text{day}$) than over land ($1.9^\circ/\text{day}$). This could be attributed to the frictional stress which is less over oceans than lands.

4.2. *Comparative study of clusters* — Most of the SMONEX clusters developed where average SST exceeded 29° C in the region east of 85° E longitude and between 5° & 20° N latitudes. More than 90% of GATE clusters formed where average SSTs exceeded 26.5° C (Martin and Schreiner 1981). Both had mainly three sizes of clusters, viz., 10° , 10° - 50° and 50° square. Half of all the clusters remained smaller than 1° square throughout their lives. A very few SMONEX attained SA-size against the 10% maximum sized GATE clusters; 10% of the SMONEX clusters reached a maximum size of 10° - 50° square as against 40% of those in GATE. Lifetime was strong function of size in both locations, viz., SMONEX and GATE. The range of lifetime for GATE was 6 hr to 2 days, while SMONEX, as argued earlier, had much longer lifetime. e.g., the average lifetime was 31 hr (i.e., more than 1 day), with the maximum lifetime greater than 11 days. SMONEX clusters moved mostly in a westnorthwest direction and westward in a few cases with an average speed of 2.11° Long./day (2.4 m/s). The average speed of GATE clusters was 12 m/s with westward propagation.

4.3. *Kinematic features of selected intense cloud clusters in Lagrangian frame* — The life history of very intense of 2-11 Aug & 5-10 Aug clusters depicting their day-to-day characteristics is shown in the satellite photos (Fig. 4). Day-to-day changes in cluster area at 12 hours interval are shown in Fig. 3.

The cluster 'A' (2-11 Aug), originated in the Bay of Bengal on 2nd, moved into the land region on the 9th and crossed over to the Arabian Sea on the 10th and dissipated. The general direction of movement was westnorthwestward at the speed of $2.2^\circ/\text{day}$. The cluster 'B' (5-18 Aug) moved in a northwest direction with average speed of 1.75° Long./day. The movement of these clusters correspond to the monsoon depressions of 6 August and 12 August respectively. Another interesting feature seen in Fig. 3 is that there were day-night oscillations of cloud cluster area.

Fig. 3(b) shows the vertical velocity $\bar{\omega}$ profiles of cloud cluster 'A' for the period 2-11 August. It is observed that there is a peak at 800 mb in morning hrs (00 GMT) and at 700 mb in the evening hrs (12 GMT). The vertical velocity profile for cluster 'B' for the period 5-18 August showed a peak at 500 mb in morning hours and at 400 mb in the evening hours. In both cases the average convective mass transport was found greater in evening (12 GMT). In both of these cases, the average vorticity profile indicated a positive vorticity below 300 mb and negative vorticity above 300 mb (figure not shown).

5. Summary and conclusion

(i) A survey has been made of deep convective cloud systems using DMSP pictures; the clusters were identified as thick bright patches on satellite imagery occurring over southeast Asia during June to August 1979 of SMONEX.

(ii) The average size was SC_2 (13.25° square) Lifetime averaged more than a day (13 hr), but was highly variable and a strong function of size. The most intense clusters (SB/SA size) were found to be related with monsoon depressions.

(iii) Cluster frequency as per size, intensity and density was minimum between 5° & 20° N and east of 85° E longitude. The most favourable occurrence of clusters was over the warm waters and in the baroclinic zones. Oceanic clusters were found to be much larger in size and more intense than the land clusters. The intense cluster moved in westnorthwest direction with the average speed of $2.11^\circ/\text{day}$.

(iv) SMONEX clusters are, in general, slower, larger in size and longer in lifetime than the GATE clusters. Diurnal changes in cloud cluster characteristics may be attributed to the increased convective mass transport at 1230 hr.

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