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Dust storms in South West Asia

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ABSTRACT

Dust storms are widespread in the northern part of the Indian sub-continent and neighbouring areas. In this paper the frequencies of dust storms as portrayed by the mapping of surface observational data are compared with maps of aerosol conditions shown by the Total Ozone Monitoring Spectrometer (TOMS). Seasonal patterns are illustrated, and these are related to meteorological conditions that may affect dust storm generation.

Key words: dust storms, Asia

1. Introduction

Dust storms are of considerable geomorphological importance because of the large amount of erosion and deposition they represent (Goudie, 1978; Goudie, 1983; Pye, 1987). They are events when visibility is reduced to less than 1 km, and the task of identifying where, when and how often they occur is an important stage in the process of assessing their role as geomorphological agents.

Middleton (l986) has used ground station observations to examine the frequency and seasonality of dust storms in south-west Asia. Figure 1 is his map of dust storms in the region. It shows that the highest frequencies occur at the convergence of the common borders between Iran, Pakistan and Afghanistan. Other high frequency areas occur on the Arabian Sea coast of Iran (Makran) and across the Indus Plains of Pakistan into north-west India. Littmann (1991) has also mapped the frequency of Asian dust storms and has examined some of the climatic factors that control their seasonal occurrence. These data suggest that south west Asia is one of the most important dust raising areas in the world, exceeded in importance only by the Sahara, Arabia and the Taklamakan Desert of China (Washington et al. in press).

The purpose of this paper is to compare the portrayal of dust activity as revealed by analyses of surface data with that revealed by satellite observations using the Total Ozone Mapping Spectrometer (TOMS).

2. TOMS

The Total Ozone Mapping Spectrometer (TOMS) began taking measurements using the NIMBUS 7 satellite in 1978. Since 1996 TOMS has been carried on board the Earth Probe

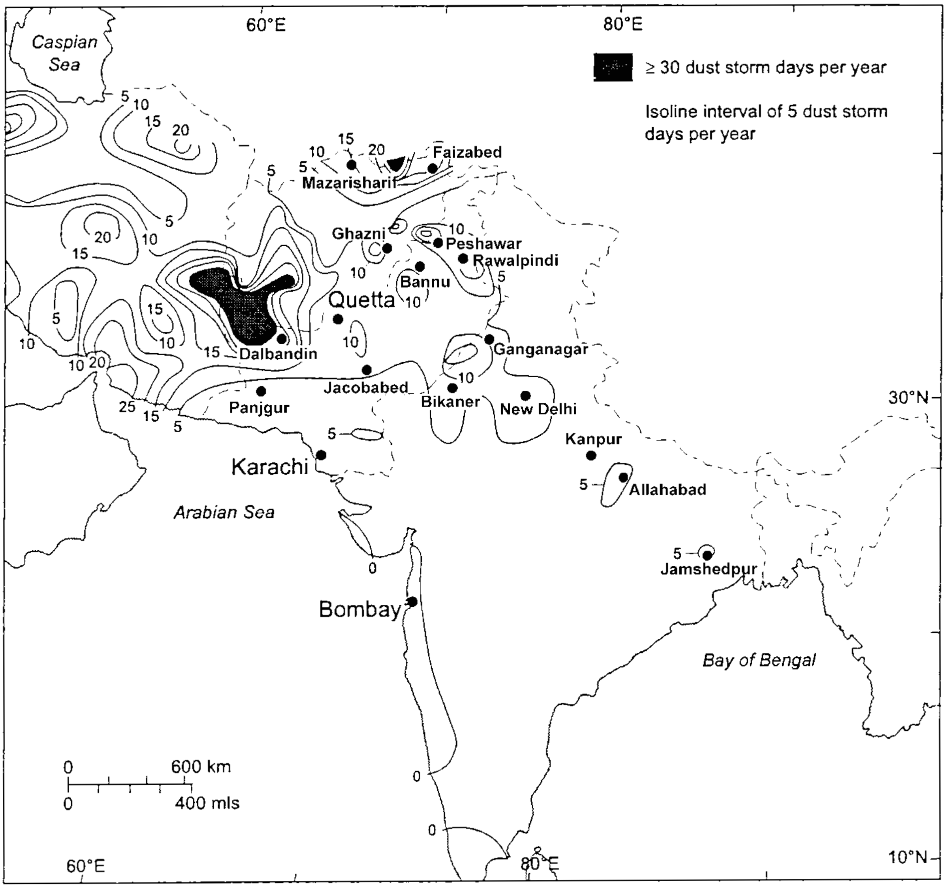

Figure 1: The number of dust storm days per year, based on ground observations (modified after Middleton, 1986).

Satellite. In addition to detecting ozone, TOMS can detect UV-absorbing aerosols in the atmosphere from the spectral contrast between the 340 and 380 nm channels. Details of this methodology and its successful application to the study of desert dust is provided by Herman et al. 1997 and Chiapello et al. (1999). In this study we employ available TOMS data from 1978 to 1999. The amount of dust in the atmosphere is expressed in terms of an Aerosol Index (AI), with the highest values representing the highest dust loadings.

3. The seasonal cycle of dust from ground observations

Dust storm activity has been monitored in the region for some decades. Table 1 presents data on dust storm seasonality for a range of stations in Afghanistan, India and Pakistan.

There is some variability in the month with maximum dust activity, with all months between March and October having at least one station where this occurs. Equally, no

Table 1: Seasonality of Dust Storms (frequency as % by month)

	J	F	M	A	M	J	J	A	S	O	N	D	Av. no. per year
Afghanistan													
Bust	4.7	9.5	10.4	13.7	10.4	8.5	10.4	**14.2**	5.7	4.3	3.3	4.7	30.1
Ghazni	0.0	0.0	2.2	**20.0**	13.3	11.1	13.3	14.8	8.1	10.3	5.2	1.5	19.3
Mazarisharif	0.8	0.8	4.8	4.8	4.0	15.9	15.1	13.5	7.1	**23.0**	8.7	1.6	18.7
Faizabed	0.0	0.0	1.4	7.1	4.3	14.3	20.0	**22.9**	8.6	17.1	4.3	0.0	17.5
Pakistan													
Bannu	0.0	1.2	5.9	4.7	19.6	15.7	**23.5**	15.7	11.8	2.0	0.0	0.0	25.5
Dalbandin	3.5	7.0	14.0	14.0	14.0	14.0	**17.5**	7.0	4.2	2.8	1.0	1.0	28.6
Jacobabed	1.1	0.0	16.3	12.0	18.5	12.0	**21.7**	12.0	4.3	0.0	0.0	2.2	9.2
Panjgur	3.4	17.2	**31.0**	3.4	6.9	17.2	13.8	3.4	0.0	3.4	0.0	0.0	3.6
Peshawar	0	7.4	1.5	3.7	**22.2**	14.8	**22.2**	14.8	12.6	6.7	7.4	0.0	13.5
Quetta	0.0	1.8	7.1	5.4	12.5	17.9	5.4	12.5	**19.6**	16.1	0	1.8	5.6
Rawalpindi	0.0	1.4	4.3	14.2	**21.3**	**21.3**	14.2	9.9	7.1	5.7	0.7	0.0	14.1
India													
Ganganagar	8.9	0.0	11.1	0.0	**33.3**	24.4	13.3	8.9	0.0	0.0	0.0	0.0	17.0
New Delhi	0.0	0.0	10.0	10.0	**40.0**	35.0	3.3	0.0	0.0	1.7	0.0	0.0	8.0
Kanpur	4.4	2.2	8.9	13.3	**44.4**	20.0	0.0	0.0	0.0	4.4	2.0	0.0	5.0
Jamshedpur	0.0	0.0	7.1	23.8	**50.0**	16.7	2.4	0.0	0.0	0.0	0.0	0.0	6.0
Bikaner	1.7	6.7	9.5	11.2	16.8	**27.9**	11.2	7.3	3.4	3.4	0.0	1.1	17.9
Allahabad	0.0	5.9	3.9	13.7	**39.2**	29.4	5.9	0.0	0.0	2.0	0.0	0.0	5.1
$\bar{X}$	1.68	3.59	8.79	10.29	21.81	18.60	12.54	9.23	5.44	6.05	1.72	0.81	–

Note: Months with largest frequency of dust storms are shown in bold

stations have maximum monthly frequencies between November and February. When one takes the mean for all 17 stations used, the dustiest period covers May and June, when just over 40% of all dust storms occur. Only 7.8% of dust storm activity occurs between November and February.

4. The seasonal cycle of dust from TOMS

In January, February and March (JFM), the area with reasonably high Aerosol Index (AI) values is small, and the highest AI values are less than 0.8 (Figure 2). There is one zone located on the Makran coast of Iran and another in the lower Indus plain where AI values lie between 0.6 and 0.8.

By March, April, May (MAM) (Figure 3), the situation is transformed and there is now a large belt from Iran across to north west India where AI values exceed 1.0.

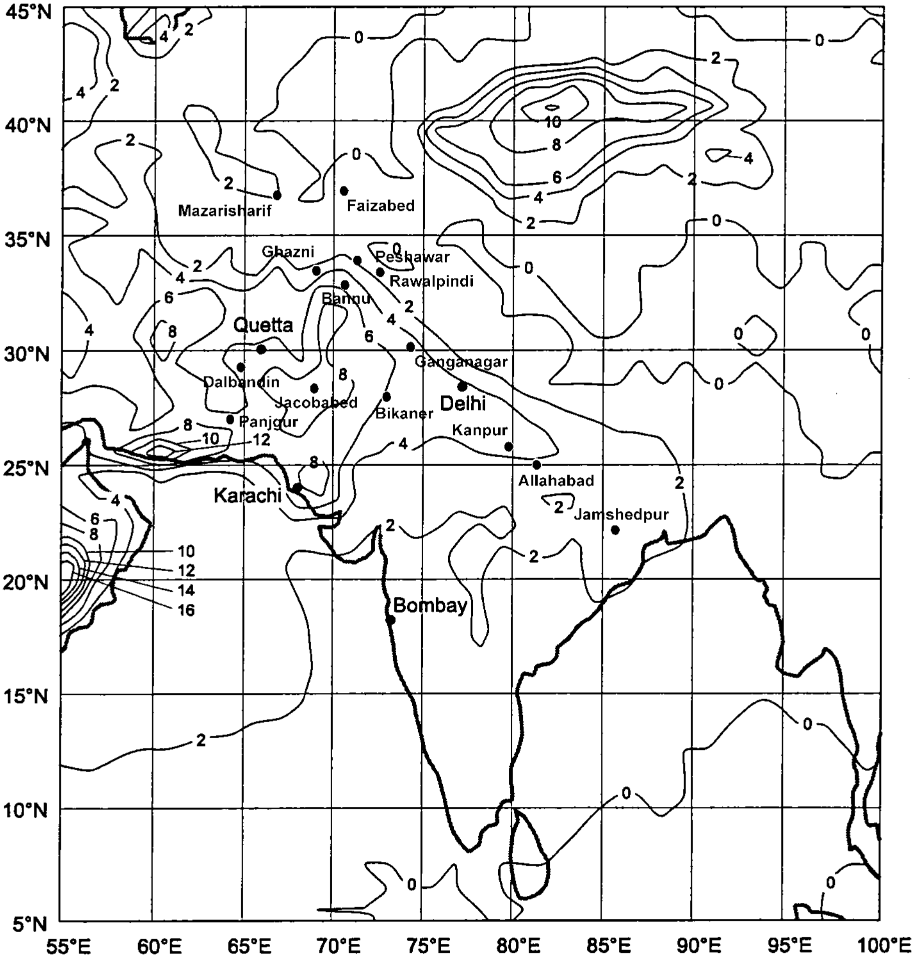

Figure 2: The annual TOMS mean. The scale ion this and subsequent figures shows the aerosol index (AI) x 10.

There is a strong zone of dust activity along the Makran coast, where AI values exceed 1.4, a large area in the Indus plains where values exceed 1.2 (and locally exceed 1.4), and another along the Ganges Plain where values exceed 1.2.

In April, May, June (AMJ) (Figure 4), the AI values reach their annual peaks. There is a large expanse of country where they are greater than 1.5 and two locations (the Makran coast and the Sibi Plain of Baluchistan), where values exceed 1.8.

By July, August, September (JAS) (Figure 5), the spread and intensity of the zone of high dust loadings has contracted. The Ganges Plain is no longer significant and AI values in the Indus Plain are less than 1.8. The Makran, however, continues to be important, with some AI values greater than that figure.

In October, November, December (OND) (Figure 6), the Indian region is at its least dusty condition during the annual cycle. AI values are low throughout the region, and do

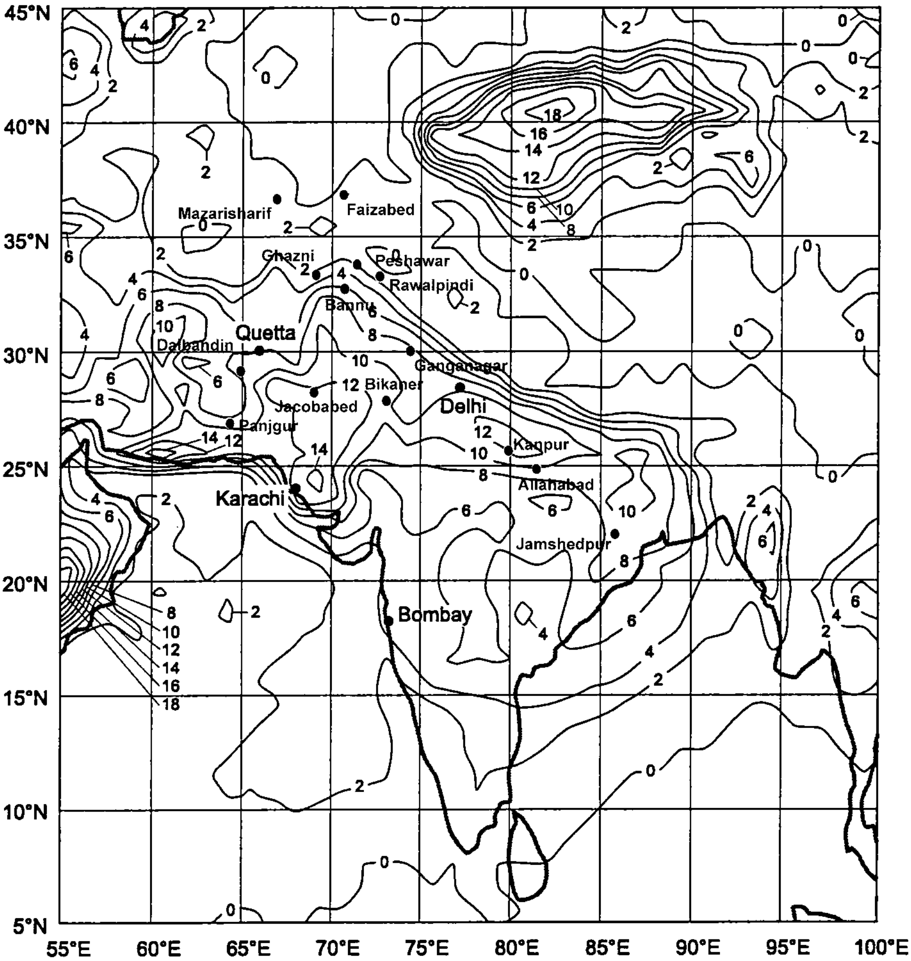

Figure 3: The TOMS monthly mean for March, April, & May.

not exceed 0.6. The two hot spots – the Makran coast and the southern Indus valley – are, however, evident.

5. Climatic relationships to dust seasonality

The explanation for the extreme seasonal variation in dust activity revealed both by ground observations and by TOMS lies with various climatic factors.

The basic factor is rainfall seasonality, which in turn controls soil moisture content (cohesiveness) and vegetation cover. The south-west summer monsoon brings a maximum of precipitation to the south and east of the dry zone, with July and August being especially wet. In the north and west of the region (e.g. in Baluchistan and the

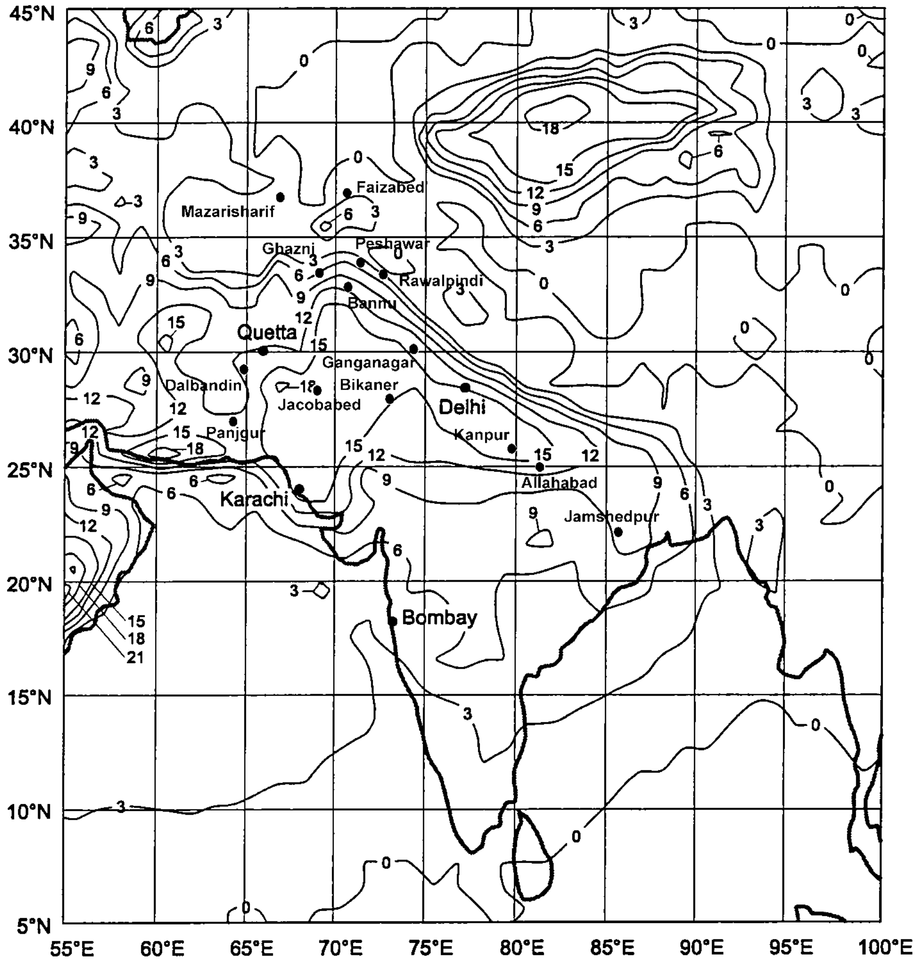

Figure 4: The TOMS monthly mean for April, May and June.

North West Frontier), the rainfall maximum may be in late winter. The contraction of the area of dust activity from the Ganges Plain and elsewhere in JAS (Figure 5) can be explained by the high number of rainy days at that time.

Another important control of dust storm activity is thunderstorm occurrence, for thunderstorms are one of the main factors that can generate dust from the ground surface. Although for the area as a whole (Table 2), the highest frequency of thunderstorms is during the wet months of July and August, there is also substantial thunderstorm activity in May and June, prior to major precipitation occurring.

Yet another important climatic control is windiness. A crude measure of this is mean wind velocity (Table 2). The highest mean wind velocities occur in MJJ. Also important are pressure conditions. The easterly movement of 'western disturbances', low pressure zones either at the surface or in the upper westerly wind regime north of the subtropical

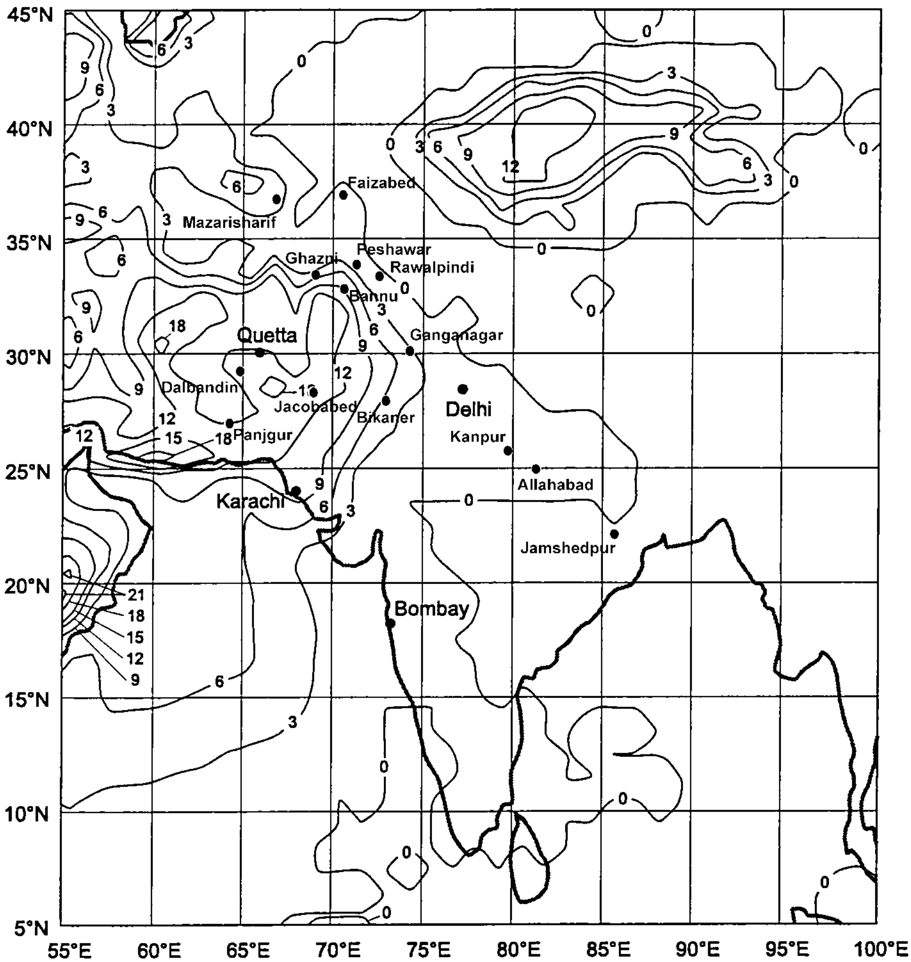

Figure 5: The TOMS monthly mean for July, August & September.

Table 2: Monthly Frequency of Dust Storms, Thunderstorms and Mean Wind Speeds for the Desert Regions of the Indian Sub-Continent

	J	F	M	A	M	J	J	A	S	O	N	D
Dust storms (frequency as % by month)	1.68	3.59	8.79	10.29	21.81	18.60	12.54	9.23	5.44	6.05	1.72	0.81
Thunderstorms (frequency as % by month)	2.35	2.55	7.85	9.31	10.35	14.07	18.64	16.14	10.84	4.46	1.02	2.40
Wind Speeds (Mean Velocity m.s^{-1})	1.6	1.8	2.1	2.3	2.8	3.2	3.1	2.6	2.2	1.5	1.3	1.3

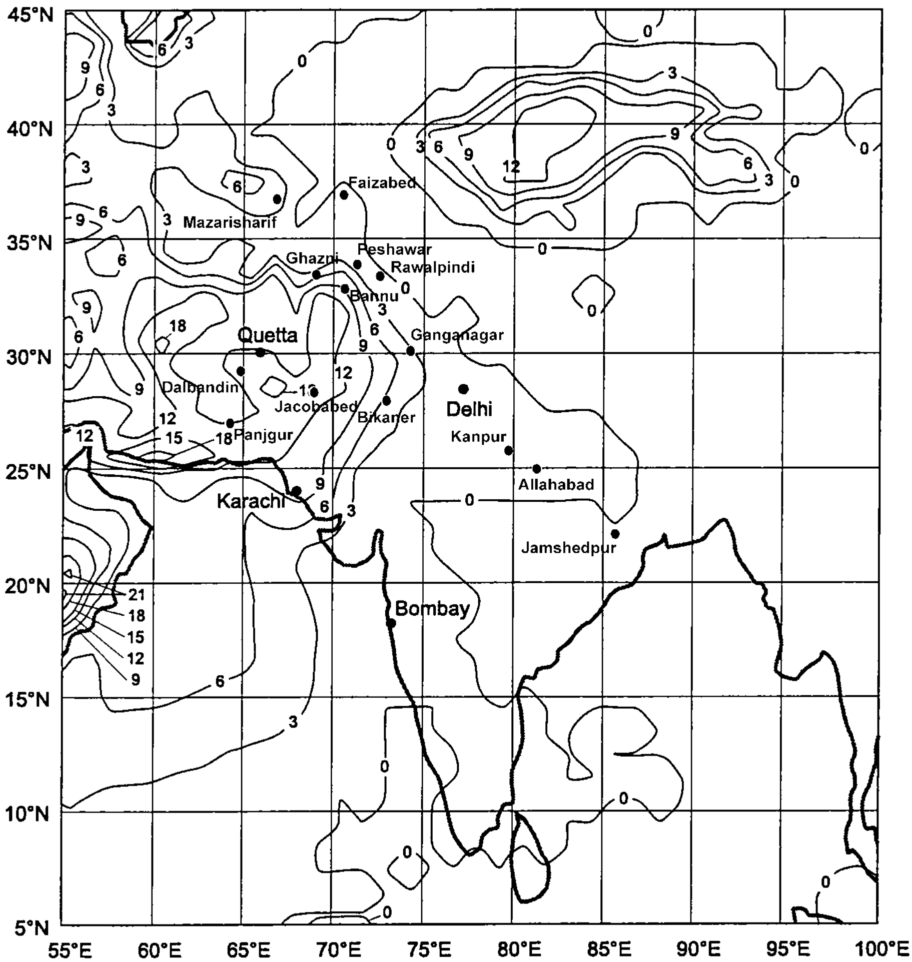

Figure 6: The TOMS monthly mean for October, November & December.

high pressure belt, are responsible for two distinct synoptic situations that cause dust-raising over much of the area. These troughs move across Iran and Turkmenistan to affect the Indian subcontinent north of 30 degrees N. Weak circulations, called induced lows, may simultaneously develop over central parts of Pakistan and Rajasthan and move ENEwards (Rao, 1981).

The two dust-raising situations commonly caused by these induced lows are the creation of a steep pressure gradient where strong winds may cause dust-raising from dry soils, and the creation of an area prone to thunderstorm generation, where dust storms are created by the dry thunderstorm downdraft.

The pressure gradient dust storms are synoptic scale features that can raise dust over large areas throughout Pakistan and northwestern India, often continuing for several days (Middleton, 1989). Once raised, dust can also remain in the atmosphere for several days,

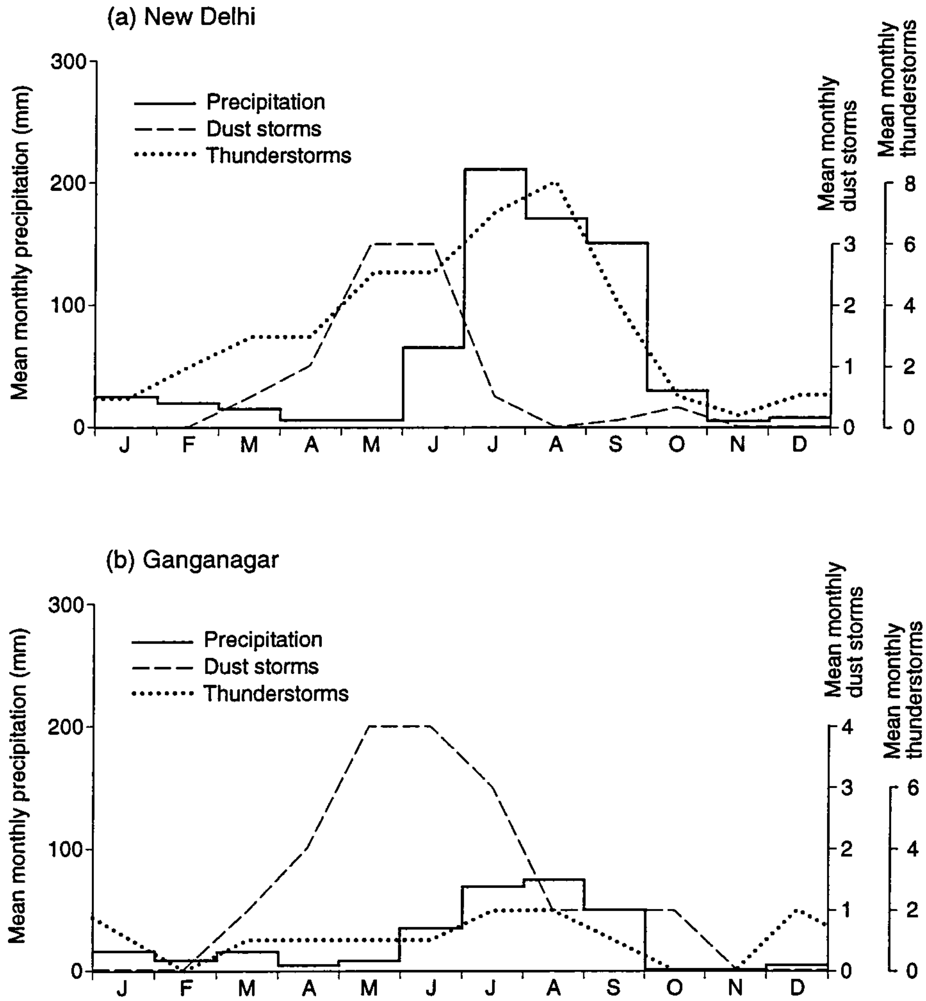

Figure 7: Plots of mean monthly dust storms, thunderstorms and rainfall for (A) New Delhi and (B) Ganganagar.

generally transported towards the east or north-east in the pressure gradient winds. Such material, when transported in lighter winds, creates dust haze conditions known in India as 'Loo'. Loo is typically experienced to the east and north-east of Rajasthan, in Delhi and down the Ganges plain as far as Bihar.

Dry, dust-raising thunderstorms are, by contrast, meso-scale phenomena, typically lasting less than an hour at any one spot, as the thunderstorm system moves with typical speeds of 60km/hr. These storms are most common in north-west India, where they are known as 'Andhi'. The large majority of Andhis occur during the pre-monsoon hot season (April-June).

To the north and east of Rajasthan, the loo's role becomes less important and that of the Andhis more important as causes of dust storms. Joseph et al. (1980) state that most of the dust storms occurring at New Delhi are of the Andhi type, a situation exemplified in Figure 7a which shows that the peak dust storm months of May and June correspond to a high fequency of thunderstorms. Although thunderstorm frequency rises further in July and August at New Delhi, these months are also associated with high monsoon rainfall totals. Maximum dust storm frequencies at Ganganagar are also experienced in May and June (Figure 7b) but these are not months of elevated thunderstorm frequency. Dust-raising here is more closely associated with the pressure-gradient winds.

To summarise, in the winter months, although it is dry over most of the region, dust storm activity is low. This is because of high pressure conditions, a lack of thunderstorm activity, and the absence of strong winds. In the pre-monsoon season, conditions are still dry, but wind velocities and thunderstorm activity increases. This is a time when strong heating of the landmass generates unstable conditions and convective low pressure systems. This is the time of maximum dust activity. The onset of the monsoonal period in July leads to a sharp decrease in dust activity. Soil water storage and the persistence of a vegetation cover ensures that dust storm activity remains at low levels into the winter months.

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PRAŠNÉ BOUŘE V JIHOZÁPADNÍ ASII

R é s u m é

Prašné bouře jsou v severní části Indického subkontinentu a v blízkých oblastech velmi časté. Tyto události mají podstatný geomorfologický význam pro rozsah eroze a sedimentace, které jsou s nimi spojeny. V této práci je četnost prašných bouří, zjištěná mapováním pozorovaných údajů, srovnána s mapami aerosolových podmínek měřených totálním ozonovým spektrometrem. Jsou znázorněny sezónní charakteristiky těchto souborů údajů a porovnány s meteorologickými podmínkami, které mohou vznik prašných bouří ovlivňovat.

V zimních měsících je na větší části území severní Indie sucho, přesto je však aktivita prašných bouří malá. Převládá totiž vysoký tlak, nejsou bouřky, ani silné větry. V předmonzunovém období je stále ještě sucho, zvyšuje se však rychlost větru a četnost bouřek. Je to období, kdy silné zahřívání pevniny vede k nestabilním podmínkám a konvekčním systémům s nízkým tlakem. V tomto období je nejvyšší prašnost ovzduší. Nástup monzunového období vede v červenci k podstatnému snížení prašnosti. Nasycení půdy vodou a stálý vegetační pokryv zajišťují, že aktivita prašných bouří zůstává nízká až do zimních měsíců.