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Variations of energy and aerodynamic terms at different stations of India

N. CHATTOPADHYAY and R. C. DUBEY*
Meteorological Office, Pune
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सार — भारत के विभिन्न केन्द्रों में ऊर्जा और वाष्पोत्सर्जन के वायुगतिक संबंधों में परिवर्तन तथा उनकी सापेक्ष भूमिका का इसमें अध्ययन किया गया है। निम्न अक्षांशों पर स्थित केन्द्रों में वर्ष के आरम्भ के कुछ सप्ताहों में ऊर्जा का मान उच्चतर रहा, जबकि थिरुवनन्तपुरम को छोड़कर उच्च देशांतरों में पड़ने वाले केन्द्रों में इसका मान उच्च रहा। उच्च अक्षांशों पर स्थित केन्द्रों में वायुगतिक संबंध उच्च पाया गया जबकि कलकत्ता को छोड़कर उच्च देशांतरों में स्थित केन्द्रों में इसका मान उच्चतर रहा। उच्च अक्षांशों पर स्थित केन्द्रों में वायुगतिक संबंधों और ऊर्जा के योगदान के प्रतिशत में पर्याप्त भिन्नता पाई गई है। निम्न अक्षांशों पर स्थित केन्द्रों में वर्ष के अधिकांश सप्ताहों में वायुगतिक संबंधों और ऊर्जा के योगदान की प्रतिशतता का मान उच्च और निम्न रहा। उच्च रेखांशों में स्थित केन्द्रों में ऊर्जा और वाष्पोत्सर्जन के संबंध की सापेक्ष हिस्सेदारी तुलनात्मक रूप से उच्च है, जबकि नागपुर को छोड़कर निम्न देशांतरों में स्थित केन्द्रों में वायुगतिक संबंधों का प्रतिशत अपेक्षाकृत उच्च पाया गया है।

ABSTRACT. Variations and relative contributions of energy and aerodynamic terms to evaporation, from different stations of India are studied. Energy term shows higher value during first few weeks from the beginning of the year, at stations located at lower latitude, while its value remains high at stations lying on higher longitude except for Thiruvananthapuram. Aerodynamic term is found to be high at stations located at higher latitude, while except for Calcutta, its value is seen to be higher for the stations situated on higher longitude. Considerable variations in the percentage contribution of the energy and the aerodynamic terms are observed at stations situated at higher latitude. Stations situated at lower latitude show high and low value of percentage contribution of the energy and the aerodynamic terms in most of the weeks during the year. Relative shares of the energy term to evaporation are comparatively high at stations situated in higher longitude, while a higher percentage contribution of the aerodynamic term, is observed at stations located at lower longitude, except for Nagpur.

Key words — Energy term, Aerodynamic term, Evaporation, Weekly variation, Relative contribution.

1. Introduction

The importance of evaporation in agriculture, water resource management, rainfall run-off modelling, estimation of crop water requirement, irrigation scheduling is well known. The knowledge of the evaporating power of radiation and other meteorological parameters, such as, wind and humidity is of major interest to the workers dealing with the subject of evaporation, especially agricultural scientists and irrigation engineers. To the meteorologist, the phenomenon of evaporation has a special appeal as all the moisture in the atmosphere, which is the working substance, is derived ultimately by evaporation from the ocean surface, the great lakes and rivers, the soil and the plant world (Raman and Satakopan 1936). India Meteorological Department published evaporation data for a number of stations in India [1970, (Parts I & II), 1980]. Besides, Ramalingam (1969) and Rathore and Biswas (1991) discussed evaporation data estimated for different stations in India.

There are a number of methods for determining evaporation, *e.g.*, by Dalton technique, Pan evaporimeter, atmometer etc. Based upon reasonable physical principles, Penman (1948) gave an expression for evaporation (E_0) from open water surface by combining aerodynamic and energy budget approach. The Penman equation consists of two terms : the energy (ENT) and the aerodynamic term (ADT). Penman formula can be used for direct measurement of potential evapotranspiration by using an appropriate value of reflection coefficient (r), for fresh green vegetation, which is taken as 0.25 for most crops (Michael *et al.* 1977). A number of workers (Padmanabhamurthy and Reddy 1970, Rao *et al.* 1971, Khambete and Biswas 1984, Venkataraman *et al.* 1984) worked on the potential evapotranspiration by using Penman formula.

The relative importance of the energy and the aerodynamic terms in Penman formula varies with the climatic conditions. Changes in climatic factors as affecting the ENT and the ADT terms, even as

* Present affiliation : Meteorological Centre, Lucknow

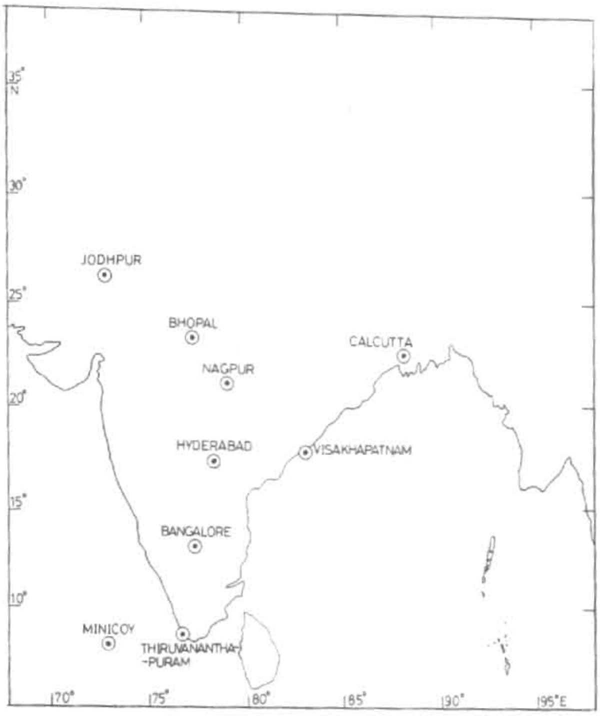


Fig. 1. Locator map

some of those climatic parameters are themselves affected, as the latitude and longitude changes in passing from one station location to another. The work done on the variations and relative contribution of these two terms to evaporation from free water surface, from different stations in India, is scanty. The present paper makes an attempt to study variation in the energy term, as well as in the aerodynamic term, for station pairs chosen to be (a) nearly on the same longitude but different latitudes and (b) at nearly same latitude, but different longitudes for examining the influence of variation in meteorological factors, such as, temperature (T), difference of saturation and actual vapour pressure ($e_a - e_d$), and wind speed etc. on the energy and the aerodynamic terms, which ultimately control and determine the evaporation from water surface in an area.

2. Data and methodology

The stations in India selected for the present study are shown in Fig. 1. The different pairs of stations, situated on nearly the same latitude but different longitudes, and, also on nearly the same longitude but different latitudes, are presented as follows :

(1) *Stations at nearly the same latitude, but on different longitudes*

A	Visakhapatnam	(17°43′N, 83°14′E)
	Hyderabad	(17°27′N, 78°28′E)
B	Thiruvananthapuram	(08°29′N, 76°57′E)
	Minicoy	(08°18′N, 73°09′E)
C	Calcutta	(22°32′N, 88°20′E)
	Nagpur	(21°06′N, 79°03′E)

(2) *Stations at nearly the same longitude but at different latitudes*

D	Bhopal	(23°17′N, 77°21′E)
	Bangalore	(12°58′N, 77°35′E)
E	Jodhpur	(26°18′N, 73°01′E)
	Minicoy	(08°18′N, 73°09′E)
F	Nagpur	(21°06′N, 79°03′E)
	Hyderabad	(17°27′N, 78°28′E)

The mathematical expressions for energy and aerodynamic terms of Penman formula,

$$E_0 = \frac{\Delta\, Qn + \gamma\, Ea}{\Delta + \gamma} \qquad (1)$$

are given as follows :

$$\text{Energy term (ENT)} = (1-r)\, R_A\,(a+b\, n/N) - 6T^4(0.56-0.092\sqrt{e_d})\,(0.10+0.90\, n/N) = QN \qquad (2)$$

$$\text{Aerodynamic term (ADT)} = 0.35\,(e_a - e_d)\,(1+U_2/100) = E_a \qquad (3)$$

where,

Q_n = Net. radiation

E_a = Aerodynamic component

γ = Psychrometric constant

Δ = Slope of saturation vapour pressure to temperature

R_A = Incident radiation outside the atmosphere on horizontal surface expressed in mm of evaporable water per day

r = Reflection coefficient taken as 0.06

n/N = Ratio of actual hours of sunshine to theoretical duration of sunshine

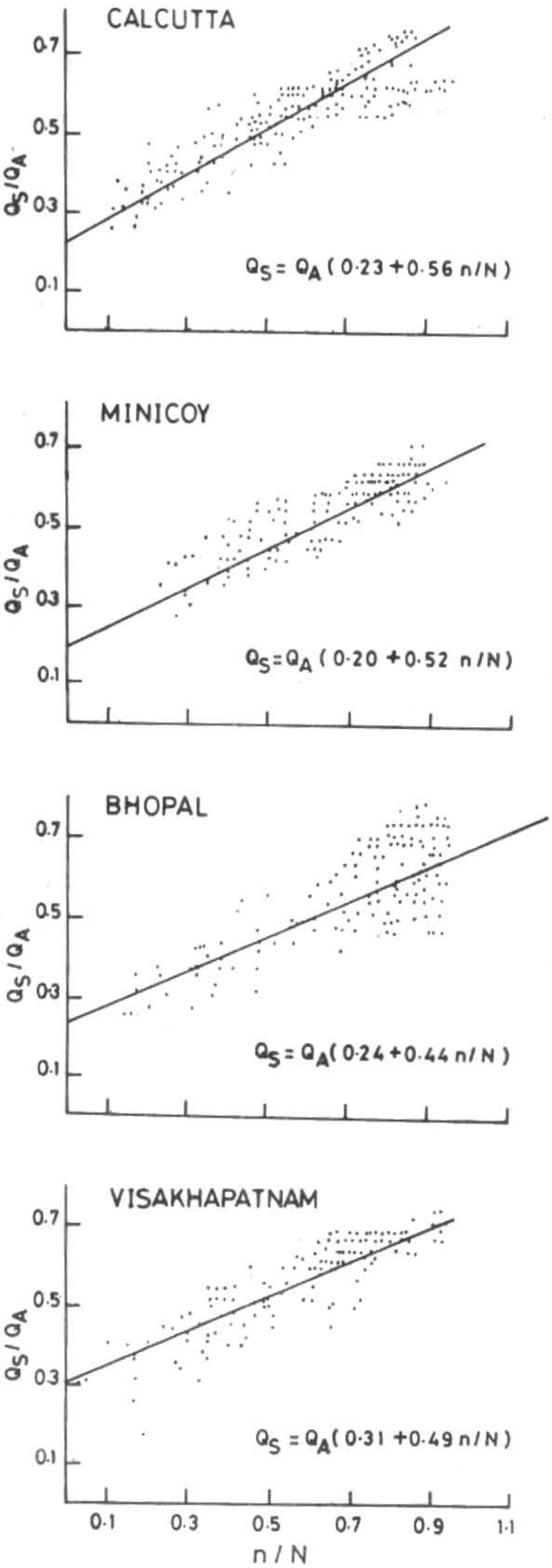


Fig. 2. Regression of mean weekly values of Q_S/Q_A upon n/N

T = Mean temperature in degree absolute.

σ = The Stefan – Boltzman constant, (5.746×10^{-5} erg cm^{-2} deg^{-4} sec^{-1})

e_a = Saturation vapour pressure in mm of mercury, at temperature T(°K)

e_d = Actual vapour pressure in mm of mercury

U_2 = Wind speed at 2 m above ground in miles per day

The values of a and b, which were considered as 0.18 and 0.55 respectively by Penman (1948), based on Rothamstead data over the period 1931-40, vary considerably from place to place (Gangopadhyay *et al.* 1970, Doorenbos and Pruitt 1975).

In the present study, the values of a and b for different stations were considered. Out of the nine stations considered for present study, for five stations namely Jodhpur, Nagpur, Hyderabad, Bangalore and Thiruvananthapuram, the values of a and b already computed by Gangopadhyay *et al.* (1970) were used. For the remaining four stations namely Calcutta, Minicoy, Bhopal and Visakhapatnam, the available mean daily values of global radiations (Q_s) and the actual hours of sunshine (n), were tabulated weekwise for the period 1982 to 1986. The corresponding observed mean daily values (Q_A) of the solar radiation received outside the atmosphere as well as the mean possible daily hours of sunshine (N), were also tabulated weekwise for these stations using the Smithsonian table. Fig. 2 presents the scatter diagram of Q_S/Q_A *versus* n/N (mean weekly values) together with the least square fit, of the form $Q_S/Q_A = a + b\ n/N$, determined for each station.

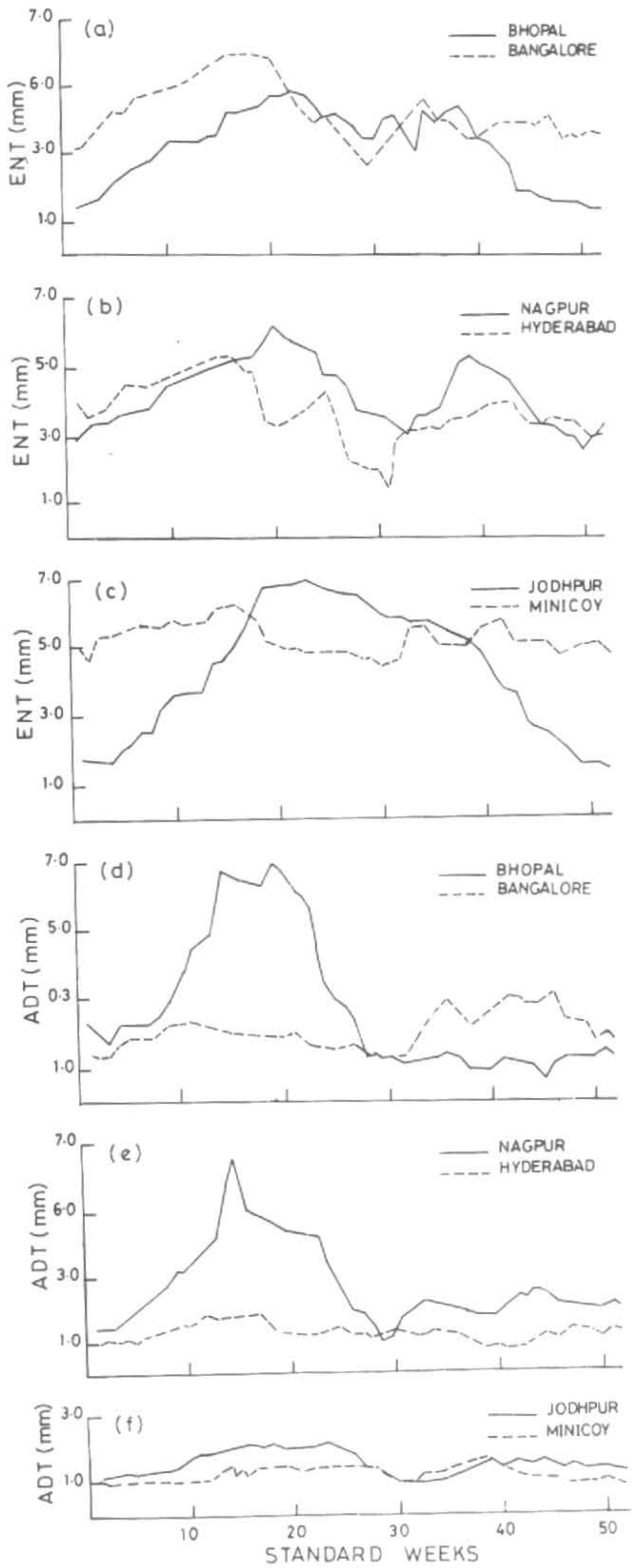
The daily data of maximum and minimum temperature, humidity, wind speed and sunshine hours for five years (1982-86) were used. The incident radiation outside the atmosphere (R_A) and saturation vapour pressure against temperature were tabulated from the tables given in FAO Irrigation and Drainage paper (Doorenbos and Pruitt 1975). The actual vapour pressure (e_d) at a particular temperature was calculated from the saturated vapour pressure (e_a) and humidity (RH) by the following formula

$$e_d = e_a \times \text{RH}/100 \qquad (4)$$

The wind speed obtained in kmph at 10 ft height was converted to miles per day, at 2 m level, by applying the following formula :

$$U = U_h\ (2/3)^{0.17} \times (5/8) \times 24 \text{ miles/day} \qquad (5)$$

where, U_h = wind speed in kmph.



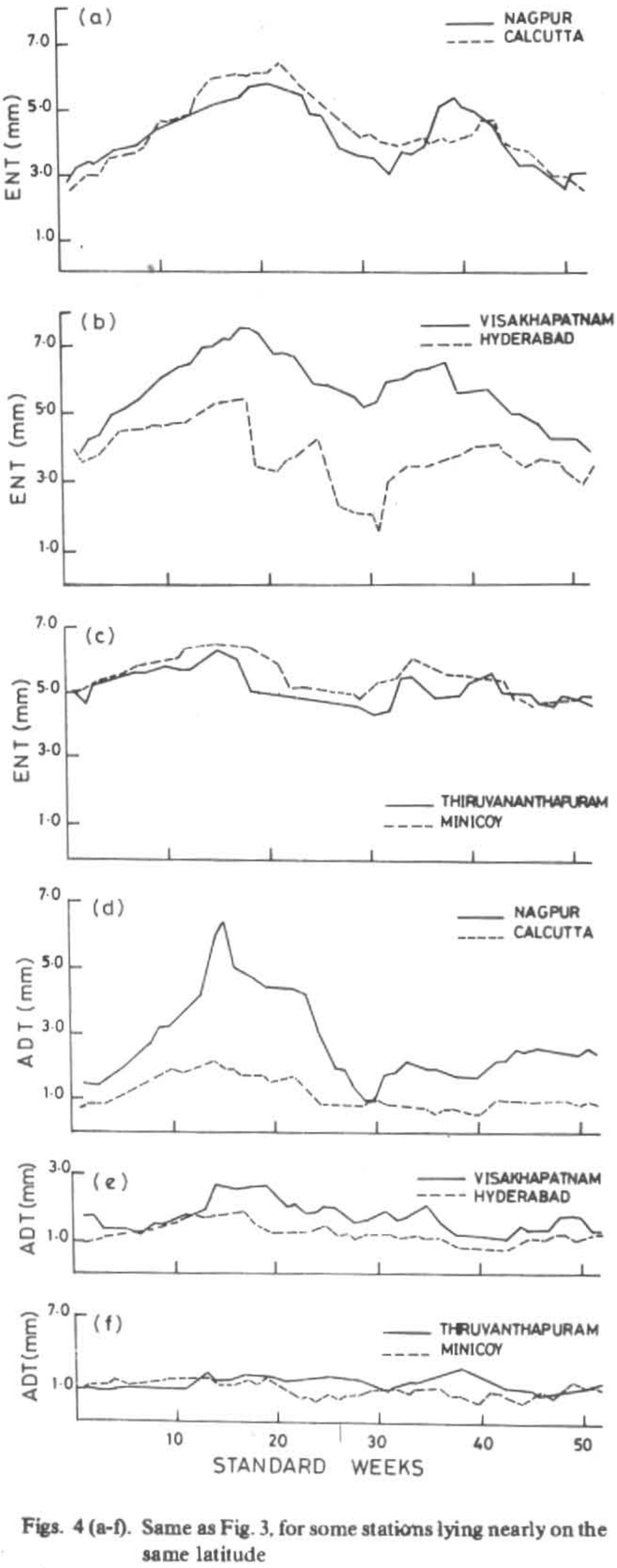
Figs. 3 (a-f). Values of the energy (ENT) and aerodynamic (ADT) terms in different standard weeks at a few stations lying nearly on the same longitude

From the actual, the normal and the derived parameters, values of energy and aerodynamic terms were computed, on daily basis, for five years (1982-86). Mean weekly values of these terms, for each standard week, were computed. The five years' averages of energy and aerodynamic terms for each standard week, was examined in the present study.

3. Results and discussion

Fig. 3 shows the variation of the energy term (ENT), in all the standard weeks, throughout the year, between the pairs of stations, that lie nearly on the same longitude but at different latitudes. A common trend in ENT values is observed at all the stations. Its value increases from the very first standard week, to couple of weeks and then decreases from pre-monsoon to major parts of southwest monsoon period and afterwards shows some increasing trend except for Jodhpur, where a continuous fall of ENT is observed after 27th standard week (2 to 8 July) till the end of the year. For example, for Minicoy, its value increases upto 15th standard week (9 to 15 April) and, afterwards decreases upto 31st standard week, (30 July to 5 August) and, shows a second maxima on 42nd standard week (15 to 21 October). Similarly for Nagpur, its value increases upto 20th standard week (14 to 20 May) and then decreases and attains minimum value for the 33rd standard week (13 to 19 August) and shows a second maxima for the 39th standard week (24 to 28 September). The initial increase in the ENT values is due to the increase of actual vapour pressure (e_d) experienced by the stations, while decrease of ENT is ascribed to the decrease of the ratio of actual to normal sunshine hours, which could be due to the thunderstorm activity, which starts from pre-monsoon season. Afterwards, the increase in the ENT is due to the simultaneous increase of e_d as well as n/N. Fig. 3, reveals that the ENT values are higher, for stations at lower latitude, at least upto 16th standard week (16 to 22 April). Thus its value is more upto 22nd week (28 May to 3 June) in Bangalore than Bhopal. Similar results are seen for Minicoy and Hyderabad, upto 17th (23 to 29 May) and 16th standard week (16 to 22 May) respectively, than the corresponding stations at higher latitude, *i.e.,* Jodhpur and Nagpur respectively. The comparative higher ENT value in Bangalore, Hyderabad and Minicoy is due to the higher value of e_d during this period.

The average e_d values from 1st-22nd, 1st-17th and 1st to 16th standard weeks for Bangalore, Minicoy and Hyderabad are 17.8, 27.9 and 24.9 mm



Figs. 4 (a-f). Same as Fig. 3, for some stations lying nearly on the same latitude

respectively, while the average values for the same period for Bhopal, Jodhpur and Nagpur are 10.6, 9.1 and 13.3 mm respectively. But during the pre-monsoon and major part of the southwest monsoon period, the ENT values for the stations at lower latitude, are comparatively low, due to the low value of n/N during this period. For example, for Minicoy, the average n/N value from 26th to 41st week (25 July to 14 October) is 0.53 while for the same period it is 0.61 for Jodhpur. Similar result is noticed for the other two pairs of stations.

The variations of the aerodynamic term (ADT), between the stations located nearly on the same longitude but at different latitudes is shown in Fig. 3. The aerodynamic term depends on the numerical values of wind speed (U_2) and the difference between the saturation and the actual vapour pressure (e_a-e_d). The greater the value of U_2 and e_a-e_d, the more will be the value of the ADT. The trend of ADT value throughout the year is almost same as that of ENT. The value of the aerodynamic term is found to be more in almost all the standard weeks at stations on the higher latitude except around 30th standard week (23 to 29 July). The higher value of ADT at Jodhpur, Nagpur and Bhopal is due to the large difference between saturation and actual vapour pressure as well as the greater wind speed experienced by these stations than Minicoy, Hyderabad and Bangalore respectively. For example on 23rd standard week (4 to 10 June) at Bhopal the value of e_a-e_d and U_2 are 37.6 m and 140.5 miles per day respectively while in the same standard week the values are 8.86 mm and 106.0 miles per day respectively in Bangalore. It is interesting to note that in each pair of stations ADT value closely follows each other, around 30th standard week, which corresponds to the brief period of southwest monsoon season. Moreover, e_a-e_d values prevailing for the different sets of the stations under study, during this period, are not very different.

Fig. 4 shows the variation of the energy term, between the sets of stations, located nearly on the same latitude but in different longitudes. Main purpose of selecting stations on different longitude, is to observe the sea and land effect, on energy and aerodynamic terms along the same latitude. Here also at first ENT value increases upto around the 20th standard week (14 to 20 May) and then decreases upto around 30th standard week and afterwards shows a second maxima. Except for Thiruvananthapuram, stations at higher longitude show higher value of ENT in most of the weeks throughout the year. The higher value of ENT at

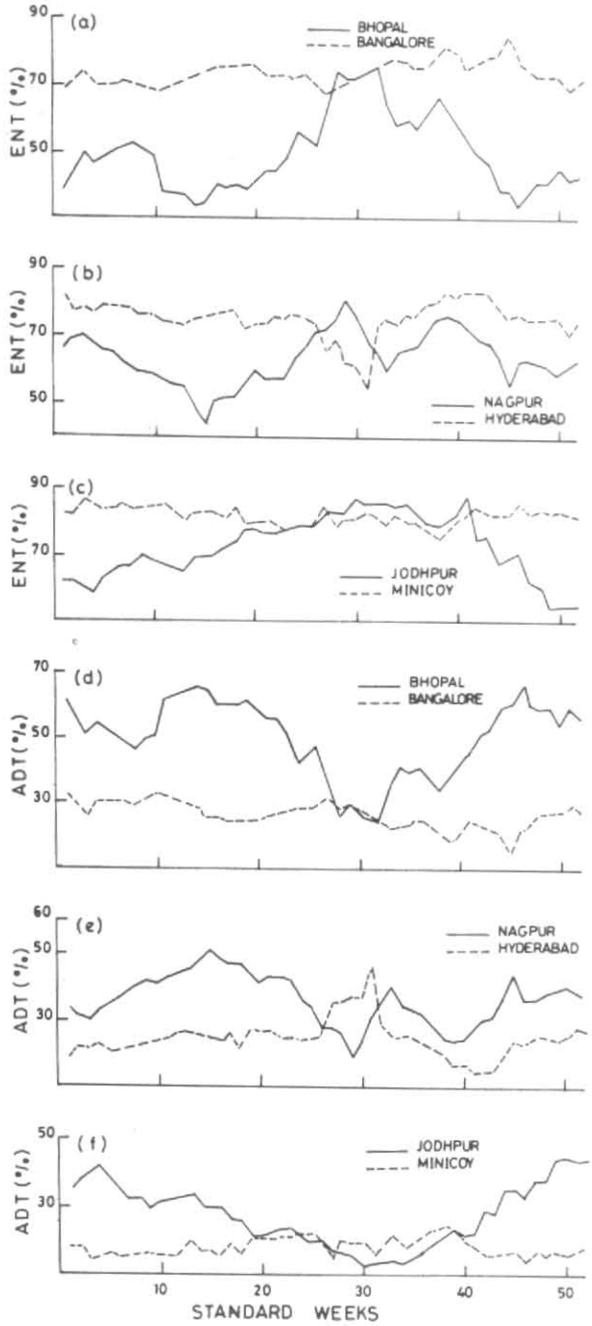


Fig. 5 (a-f). Percent contribution of energy (ENT) and aerodynamic (ADT) terms to evaporation (E_0) from open water in different standard weeks at some stations lying nearly on the same longitude

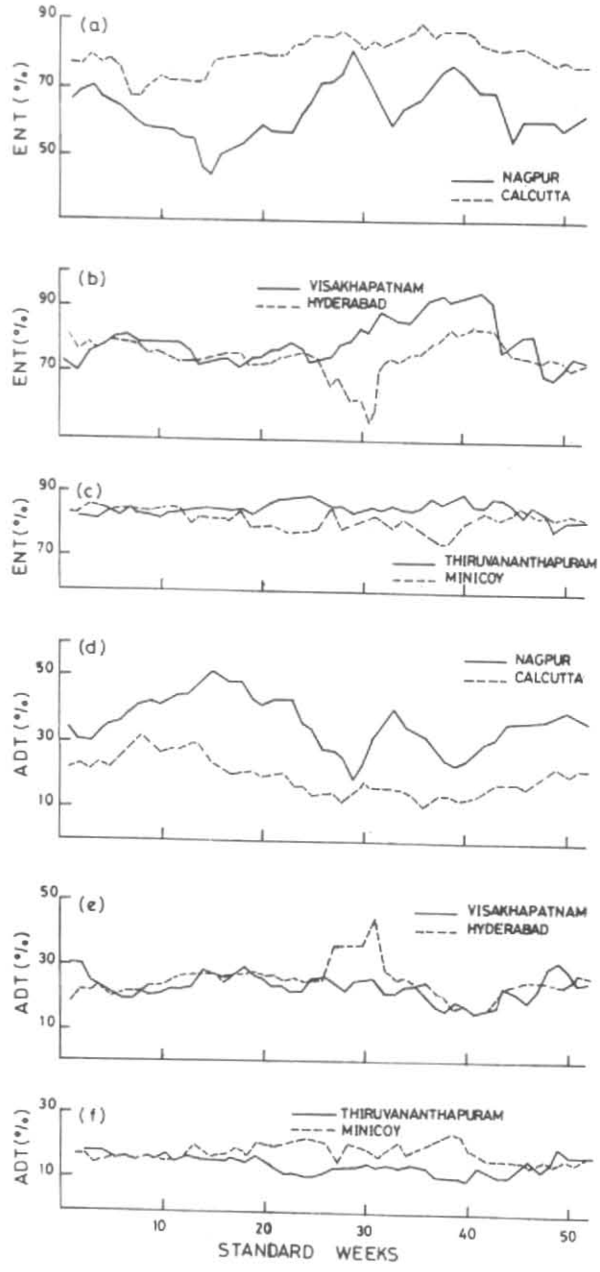


Fig. 6 (a-f). Same as Fig. 4, for some stations lying nearly on the same latitude

Visakhapatnam and Calcutta, than Hyderabad and Nagpur, is due to the higher actual vapour pressure experienced by these stations in most of the standard weeks of the year. The higher ENT values for Nagpur, than for Calcutta, from 38th to 41st standard week (17 September to 14 October) are due to the higher actual vapour pressure values for Nagpur than for Calcutta, during this period. The reason behind high ENT values at Minicoy, which is stationed on lower longitude, than Thiruvananthapuram is the higher actual vapour pressure at Minicoy than at Thiruvananthapuram almost in all the standard weeks of the year.

The effect of land and sea on aerodynamic terms, between the sets of stations located at nearly same latitude, but on different longitudes, is presented in Fig. 4. Aerodynamic term shows higher value in almost all the standard weeks throughout the year in Visakhapatnam and Thiruvananthapuram, being coastal stations, than Hyderabad and Minicoy respectively. This is due to the higher wind speed at these stations. Though stationed on a higher longitude, Calcutta shows low ADT value than Nagpur which is due to small difference of $e_a - e_d$ results from higher humidity prevailing over Calcutta throughout the year.

Fig. 5 represents the variation of the contributions of energy and aerodynamic terms to evaporation between sets of stations situated on nearly the same longitude but at different latitudes. High percentage variations of ENT and ADT are seen in stations situated in higher latitude, *i.e.*, Bhopal, Nagpur and Jodhpur. ENT varies from 33.6 to 75.9%, 44.2 to 81.0% and 54.3 to 87.0% in Bhopal, Nagpur and Jodhpur respectively. Except for Hyderabad and that too also for some period in monsoon season, the percentage variations in ENT and ADT values are less at stations lying in lower latitudes. Except for a brief period during monsoon season, percentage contribution of ENT to evaporation is seen to be comparatively less at Bhopal, Nagpur and Jodhpur than at Bangalore, Hyderabad and Minicoy respectively. Conversely the percentage contribution of the aerodynamic term to evaporation shows the reverse trend.

Fig. 6 shows the variation in the percentage contribution of the energy and the aerodynamic terms at stations nearly on the same latitude but in different longitudes. The stations at higher longitude show more or less high ENT percentage contribution to evaporation in most of the standard weeks of the year while the percentage contribution of the aerodynamic term to evaporation is found to be high at stations lying on lower longitudes except for Nagpur, almost throughout the year. Being inland stations, the percentage variations in ENT and ADT are comparatively more in Nagpur and Hyderabad than for the stations close to the coast and the island station such as Minicoy.

4. Conclusions

In the present study, the variations and relative contributions of energy and aerodynamic terms to evaporation from free water surface for several stations in India are studied. Stations selected for the study could be broadly grouped as (1) those lying on the same longitude but at different latitudes and (2) those lying nearly on the same latitude but on different longitudes. From this study the following broad conclusions may be drawn :

(*i*) Both energy and aerodynamic terms increase initially from January upto the beginning of monsoon and decrease during most parts of southwest monsoon period and thereafter again show an increasing trend at all stations.

(*ii*) The energy term at stations lying at lower latitudes is found to be high during first few standard weeks and low from pre-monsoon to most parts of monsoon season.

(*iii*) Aerodynamic term shows higher value at stations at higher latitude almost throughout the year mainly due to the large difference between saturation and actual vapour pressure, as well as greater wind speed experienced by stations situated on high latitude.

(*iv*) Except Thiruvananthapuram, stations at higher longitude exhibit high value of energy term for most parts of the year. Low value of energy term at Thiruvananthapuram in comparison to Minicoy is due to the low actual vapour pressure prevailing at Thiruvananthapuram.

(*v*) Except for Calcutta, for the stations Visakhapatnam and Thiruvananthapuram, aerodynamic term is found to be high because they are coastal stations. Low value of aerodynamic term at Calcutta, as compared to that at Nagpur, is due to the small difference of actual and saturation vapour pressure, resulting due to high humidity prevailing throughout the year.

(*vi*) Stations located at higher latitude show wide fluctuation in the percentage contributions of the energy and the aerodynamic terms throughout the year. Except for a brief period during monsoon season, the relative shares of energy and aerodynamic terms are less and high respectively at stations lying at higher latitude.

(*vii*) The stations that lie on higher longitudes, show more or less a high percentage contribution of the energy term, while except for Nagpur stations at lower longitude show a higher percentage of contribution of the aerodynamic term to evaporation.

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