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Identification of key parameters producing rainfall

RAJASRI SEN JAISWAL, V. S. NEELA, SONIA R. FREDRICK, M. RASHEED,
LEENA ZAVERI and V. SOWMYA
Centre for Study on Rainfall and Radio wave Propagation
Sona College of Technology, Salem – 636 005, Tamil Nadu, India
e mail : crrp.official@yahoo.com

सार – वर्षा के मुख्य प्राचलों का पता लगाने के लिए इस शोध पत्र से शोधकर्ताओं ने उष्णकटिबंधीय वर्षा मापन मिशन (टी. आर. एम. एम.) उपग्रह आँकड़ा आधार की जाँच की है। इस तथ्य को समझने के उपरान्त कि बढ़ने वाले वायु पार्सल के द्वारा पानी के वाष्पीकरण, वाष्प के संघनन और उष्मा ऊर्जा के संवहन से मेघ बनतें है और वर्षा होती है। शोधकर्ताओं ने वायुमंडल की विभिन्न ऊँचाईयों पर वर्षा प्रक्रिया के मुख्य सहयोगियों के रूप में मेघ द्रव जल (सी.एल.डब्ल्यू.), वर्षण जल (पी.डब्ल्यू.) तथा गुप्त उष्मा (एल.एच.) के बारे में जानकारी प्राप्त करनी आरंभ कर दी है। इन आँकड़ों को बहु समाश्रयण निदर्श में डाला गया है। यह पाया गया है कि वर्षा और इन प्राचलों में महत्वपूर्ण सहसंबंध है। इससे स्थापित हुए कार्यात्मक संबंधों से किसी भी समय वर्षा का आकलन किया जा सकता है बशर्ते कॉलमनर सी.एल.डब्ल्यू., पी.डब्ल्यू. और एल.एच. मान उपलब्ध हों। एक या दो के स्थान पर इन सभी तीनों प्राचलों को बहु समाश्रयण निदर्श में शामिल करने के फलस्वरूप वर्षा का बेहतर पूर्वानुमान लगाया जा सका है। सी. एल. डब्ल्यू., एल. एच. और पी. डब्ल्यू. के बीच महत्वपूर्ण सहसंबंध हैं।

ABSTRACT. In search of the key parameters causing rainfall, the authors have explored Tropical Rainfall Measuring Mission (TRMM) satellite data base. By realizing the fact that evaporation of water, condensation of vapour and transport of heat energy by a rising air parcel are all about formation of cloud and rain, the authors have started their quest considering cloud liquid water (CLW), precipitation water (PW) and latent heat (LH) at different altitudes of the atmosphere as major contributors to rainfall mechanism. These data have been fitted to multiple regressions. It is found that significant correlations exist between rainfall and these parameters. The functional relationships so established are able to estimate surface rainfall at any instant, provided columnar CLW, PW and LH values are available. Inclusion of all the three parameters in multiple regression leads to better predictability of rainfall, instead of one or two. Significant correlations exist between CLW, LH and PW.

Key words – Cloud liquid water, Precipitation water, Latent heat, Rainfall.

1. Introduction

Rainfall has been being a puzzle since time immemorial. Being the major controlling factor in agriculture, it largely influences the economy of a country, apart from its importance in climatology. Being a potential absorber of high frequency waves, rainfall poses a major problem in mobile and satellite communication, disrupting the link. In dual polarization satellite channels it causes unwanted cross-polarization. Hence, undoubtedly, study of rainfall is of immense importance in the field of Science and Technology.

Rainfall, as we know, occurs because of evaporation of water bodies due to solar radiation, followed by the condensation of the water vapour at higher altitude. The amount of solar radiation received at the earth's surface depends on the latitude of a place, season and hour of the day. As the solar rays fall vertically on the equatorial region, the energy incident per unit area in the equatorial region is very high. As we go away from the equator towards the poles, the solar rays start being incident more obliquely, *i.e.*, making lesser and lesser angle to the ground, there by intercepting larger area. Hence, as we approach the poles, energy received per unit area goes on reducing (Singh 2007). A part of the incoming shortwave solar radiation incident at the top of the atmosphere is absorbed by Ozone. A part is scattered by the atmosphere and the remaining radiation reaches the earth. The earth's surface absorbs the incoming radiation and re-radiates long wave radiation, called as ground wave, back to the atmosphere, which then absorbs it and re-radiates back to the earth's surface. This back radiation is known as sky radiation. It may be pointed out here that the atmosphere is almost transparent to the incoming short wave radiation, but does not allow the long wave ground radiation to

TABLE 1

Relationship between surface rainfall (*y*) and CLW (*x*)

Station	2007	2008
Chennai	$y = -1.587 + 31.711\ x - 59.366\ x^2 + 34.879\ x^3$	$y = -0.487 + 13.175\ x - 19.261\ x^2 + 10.563\ x^3$
Kakdwip	$y = 0.025 + 6.711\ x + 18.382\ x^2 - 9.066\ x^3$	$y = -2.778 + 41.133\ x - 51.485\ x^2 + 21.036\ x^3$
Karaikal	None suits	$y = e^{1.573 - 0.234/x}$
Machilipatnam	$y = -0.526 + 10.855\ x + 16.310\ x^2 - 17.009\ x^3$	$y = -1.428 + 28.682\ x - 18.759\ x^2$
Mangalore	$y = e^{2.223 - 0.290/x}$	$y = e^{2.124 - 0.237/x}$
Mumbai	$y = e^{2.063 - 0.265/x}$	$y = e^{2.517 - 0.314/x}$
Panjim	$y = e^{2.083 - 0.270/x}$	$y = 9.346\ x^{1.5313}$
Puri	$y = -3.539 + 50.251\ x - 71.986\ x^2 + 30.730\ x^3$	$y = -1.060 + 21.399\ x - 22.758\ x^2 + 8.735\ x^3$
Trivandrum	$y = e^{1.915 - 0.254/x}$	None suits
Vishakhapatnam	$y = 1.778 - 29.452\ x + 159.802\ x^2 - 118.325\ x^3$	$y = 7.275\ x^{1.190}$
Costa Rica	$y = e^{2.207 - 0.275/x}$	$y = e^{1.797 - 0.218/x}$
Indian Ocean	$y = -2.907 + 49.194\ x - 86.955\ x^2 + 43.996\ x^3$	$y = 5.983\ x^{1.285}$
Pacific Ocean	$y = -0.971 + 19.045\ x - 34.637\ x^2 + 22.110\ x^3$	$y = e^{1.486 - 0.203/x}$
Taiwan	$y = e^{1.744 - 0.223/x}$	$y = -1.249 + 18.857\ x - 14.249\ x^2 - 5.806\ x^3$
Panama	$y = -0.063 + 0.461\ x + 50.417\ x^2 - 38.877\ x^3$	$y = -0.282 + 8.936\ x - 5.405\ x^2 + 2.578\ x^3$
Mozambique	$y = -2.051 + 33.974\ x - 52.248\ x^2 + 25.263\ x^3$	$y = 2.183 - 28.914\ x + 78.004\ x^2 - 39.633\ x^3$
East China Sea	$y = 0.084 + 5.994\ x + 7.988\ x^2$	$y = -0.399 + 14.954\ x - 31.407\ x^2 + 30.498\ x^3$
Mediterranean Sea	$y = -0.501 + 13.897\ x - 20.176\ x^2 + 12.423\ x^3$	$y = 0.902 - 6.278\ x + 50.804\ x^2 - 43758\ x^3$
Gulf of Mexico	$y = e^{1.796 - 0.225/x}$	$y = -1.368 + 24.097\ x - 28.215\ x^2 + 11.655\ x^3$
Papua New Guinea	$y = e^{1.527 - 0.195/x}$	$y = 7.781\ x^{1.365}$
South China Sea	$y = -1.407 + 23.049\ x - 17.620\ x^2$	$y = -2.374 + 41.101\ x - 112.052\ x^2 + 100.142\ x^3$

escape to space. About 90% of the long wave radiation is absorbed by water vapour, Carbon-di-oxide, Ozone etc. (Singh 2007). To conclude, the ground radiation contributes more to heat the atmosphere than the insolation (incoming solar radiation) (Singh 2007).

As one approaches the poles, more and more radiation incident on the ocean surface gets reflected back. At the poles, most of the radiation incident on the ocean surface gets reflected back, as the ocean is fully covered with ice. Thus, there is a net gain in energy in the tropical region, and there is a net deficit in energy at the poles (Singh 2007). As one approaches the poles from the equator, the net energy deficit increases. The energy imbalance between the equator and the poles is counterbalanced by ocean currents which flow from the equator to the poles. The ocean currents are generated by atmospheric circulations. Atmospheric circulation, on the other hand, is generated by latent heat and sensible heat (Singh 2007).

There exists an energy imbalance between the earth's surface and the atmosphere too, as 90% of the energy re-radiated by the earth's surface is absorbed by the atmosphere, and most of the radiation received at the top of the atmosphere reaches the earth's surface (Singh 2007). The energy imbalance between the earth and the atmosphere is counterbalanced by the vertical transport of sensible and latent heat through ascending air parcel. The mechanism of ascent of an air parcel is basically governed by temperature lapse rate, moisture content and latent heat profile of the atmosphere. Hence, exchange of water vapour and latent heat between the earth's surface (both land and water bodies) and the atmosphere drives the entire global circulation, which also controls all the weather phenomena, including their creation, maintenance and dissipation.

TABLE 2

Relationship between surface rainfall (*y*) and PW (*x*)

Station	2007	2008
Chennai	$y = 1.786\ x^{1.201}$	$y = 0.009 + 0.993\ x + 1.050\ x^2 - 0.149\ x^3$
Kakdwip	$y = 0.129 + 0.970\ x + 0.357\ x^2 - 0.023\ x^3$	$y = 1.700\ x^{1.213}$
Karaikal	$y = -0.035 + 16.353\ x - 31.832\ x^2 + 13.412\ x^3$	$y = 1.911\ x^{1.199}$
Machilipatnam	$y = -0.347 + 2.631\ x - 0.061\ x^2$	$y = 1.607\ x^{1.175}$
Mangalore	$y = 1.826\ x^{1.221}$	$y = 1.783\ x^{1.178}$
Mumbai	$y = 1.677\ x^{1.186}$	$y = 1.633\ x^{1.163}$
Panjim	$y = 1.737\ x^{1.181}$	$y = 1.789\ x^{1.186}$
Puri	$y = 0.016 + 0.999\ x + 0.929\ x^2 - 0.120\ x^3$	$y = 1.741\ x^{1.216}$
Trivandrum	$y = 2.081\ x^{1.228}$	$y = 1.965\ x^{1.241}$
Vishakhapatnam	$y = 1.613\ x^{1.171}$	$y = 1.750\ x^{1.213}$
Costa Rica	$y = 1.656\ x^{1.190}$	$y = 1.859\ x^{1.202}$
Indian Ocean	$y = 1.906\ x^{1.241}$	$y = -0.145 + 1.960\ x + 0.394\ x^2 - 0.050\ x^3$
Pacific Ocean	$y = 1.981\ x^{1.244}$	$y = 1.789\ x^{1.185}$
Taiwan	$y = 1.782\ x^{1.212}$	$y = -\ 0.180 + 2.371\ x - 0.045\ x^2$
Panama	$y = 0.040 + 2.904\ x - 0.129\ x^2$	$y = 1.887\ x^{1.242}$
	$y = 0.169 + 1.954\ x - 0.417\ x^2 - 0.064\ x^3$	
Mozambique	$y = 1.818\ x^{1.202}$	$y = -\ 0.018 + 1.176\ x + 1.235\ x^2 - 0.233\ x^3$
East China Sea	$y = 0.257 + 1.311\ x + 0.129\ x^2$	$y = 0.406 + 0.550\ x + 1.023\ x^2 - 0.088\ x^3$
	$y = 0.235 + 1.421\ x + 0.017\ x^2$	
Mediterranean Sea	$y = 0.471 - 1.260\ x + 6.506x^2 - 2.249\ x^3$	$y = 0.717 - 1.325\ x + 5.029\ x^2 - 1.638\ x^3$
Gulf of Mexico	$y = 1.888\ x^{1.235}$	$y = 1.897\ x^{1.203}$
Papua New Guinea	$y = 1.827\ x^{1.209}$	$y = -\ 0.163 + 2.026\ x + 0.244\ x^2 - 0.031\ x^3$
South China Sea	$y = 1.875\ x^{1.222}$	$y = -\ 0.080 + 1.672\ x + 0.110\ x^2$

The latent heat and the water vapour available in the atmosphere are the two key parameters in cloud formation. Rainfall study shows that the total precipitable water is responsible for the formation of convective cloud (Battan and Kassander 1960). Cloud liquid water is another important parameter to estimate rainfall. Studies (Khain *et al.*, 2001) show that presence of huge amount of cloud liquid water up to the level of 9-10 km indicates presence of deep tropical convective cloud.

From the above discussion it appears that cloud liquid water (CLW), precipitation water (PW) and latent heat (LH) are the key parameters in estimating rainfall.

2. Data and methodology

In this paper the authors aim at finding out how well the above three parameters describe surface rainfall. For this purpose, CLW, PW, LH and rainfall data have been obtained from the data product 2A12 (TRMM 1998) of Tropical Rainfall Measuring Mission Microwave Imager (TMI) onboard Tropical Rainfall Measuring Mission (TRMM) satellite. The study has been performed over few Indian stations, namely, Mumbai (18.55° N, 72.54° E), Trivandrum (8.29° N, 76.59° E), Panjim (15.3° N, 73.55° E), Chennai (13.03° N , 80.71° E), Machilipatnam (15.98° N, 81.32° E), Vishakhapatnam (17.61° N, 83.81° E),

TABLE 3

Relationship between surface rainfall (*y*) and LH (*x*)

Station	2007	2008
Chennai	$y = 0.840 + 0.133\,x + 0.029\,x^2 -0.001\,x^3$	$y = 0.554 + 0.086\,x + 0.013\,x^2 + 0\,x^3$
Kakdwip	$y = 0.187 + 1.384\,x\ 3.298\,x^2 + 1.023\,x^3$	$y = 1.679 + 1.346\,x – 0.057\,x^2 + 0.001\,x^3$
Karaikal	$y = 1.590 + 0.535\,x - 0.007\,x^2 + 2.96 \times 10^{-5}\,x^3$	$y = 0.824 + 0.522\,x - 0.040\,x^2 + 0.001\,x^3$
Machilipatnam	$y = 0.831 + 0.295\,x - 0.004\,x^2 + 2.92 \times 10^{-5}\,x^3$	$y = 1.089 + 0.149\,x + 0.113\,x^2 -0.005\,x^3$
Mangalore	$y = 0.854 + 0\,x + 0.076\,x^2 -0.004\,x^3$	$y = 1.207 + 0.411\,x - 0.005\,x^2 + 2.09 \times 10^{-6}x^3$
Mumbai	$y = 0.938 + 38.914\,x - 26.712\,x^2$	$y = 1.329 + 0.352\,x – 0.003\,x^2$
Panjim	$y = 2.316 + 0.161\,x + 4.31 \times 10^{-7}\,x^3$	$y = 0.605 + 0.349\,x -0.003\,x^2 + 1.16 \times 10^{-6}\,x^3$
Puri	$y = -0.404 - 0.718\,x + 0.129\,x^2 -0.003\,x^3$	$y = 1.287 + 0.244\,x- 0.001\,x^2$
Trivandrum	$y = 0.799 + 0.304x - 0.001\,x^2 – 7.5 \times 10^{-6}\,x^3$	$y = 0.599 + 0.248\,x + 0.012\,x^2 + 0\,x^3$
Vishakhapatnam	$y = 0.796 + 0.313\,x - 0.001\,x^2$	$y = 0.450 – 0.022\,x + 0.035\,x^2 -0.001\,x^3$
	$y = 1.155 + 0.795\,x - 0.029\,x^2 + 0\,x^3$	
Costa Rica	$y = 1.015 + 0.450\,x - 0.001\,x^2 – 6.7 \times 10^{-5}\,x^3$	$y = 1.245 + 0.489\,x - 0.019\,x^2 + 0\,x^3$
Indian Ocean	$y = 0.\ 455 + 0.077\,x + 0.033\,x^2 – 0.001\,x^3$	$y = 0.649 + 0.335\,x -0.002\,x^2$
Pacific Ocean	$y = 0.755 + 0.381\,x - 0.004\,x^2$	$y = 1.003 + 0.421\,x -0.007\,x^2$
Taiwan	$y = 0.867 + 0.349\,x - 0.009\,x^2 + 0\,x^3$	$y = 0.521 + 0.136\,x + 0.008\,x^2 + 0\,x^3$
Panama	$y = 0.590 + 0.514\,x - 0.022\,x^2 + 0\,x^3$	$y = 0.666 + 0.365\,x -0.005\,x^2 + 2.47 \times 10^{-5}\,x^3$
Mozambique	$y = 0.795 + 0.326\,x - 0.001\,x^2$	$y = 0.379 + 0.067\,x + 0.002\,x^2 +0\,x^3$
East China Sea	$y = 0.747 -0.039\,x + 0.003\,x^2$	$y = 0.779 + 0.102\,x + 0.012\,x^2 + 0\,x^3$
Mediterranean Sea	$y = 0.153 + 0.149\,x + 0.055\,x^2 – 0.002\,x^3$	$y = 0.446 -0.102x + 0.125\,x^2 -0.006\,x^3$
Gulf of Mexico	$y = 0.643 + 0.254\,x + 0.006\,x^2 + 0\,x^3$	$y = 0.415 + 0.377\,x -0.004\,x^2 + 1.45 \times 10^{-5}\,x^3$
Papua New Guinea	$y = 1.024 + 0.291x + 0.001\,x^2 – 2.6 \times 10^{-5}\,x^3$	$y = 0.720 + 0.331\,x -0.002\,x^2$
South China Sea	$y = 0.657 + 0.206\,x + 0.063\,x^2 – 0.004\,x^3$	$y = 0.389 – 0.171\,x + 0.130\,x^2 – 0.003\,x^3$

Mangalore (12.83° N, 74.71° E), Kakdwip (21.47° N, 87.87° E), Karaikal (10.92° N, 80.24° E), Puri (19.48° N, 85.88° E) and a few foreign stations, namely, Costa Rica (9.18° N, 85.43° W), the Indian Ocean (0°, 90° E), the Pacific Ocean (17° S , 164° W), Taiwan (25° N, 121° E), Panama (8.5° N , 79.5° W), Mozambique (17.8° S, 38.18° E), the East China Sea (30° N , 123° E), the South China Sea (18.97° N , 113.4° E), the Mediterranean Sea (35.67° N , 12.12° E), Gulf of Mexico (22.9° N, 94.2° W) and Papua New Guinea (4° S, 147° E) for ten years (1999-2008). It is noteworthy that while selecting the stations, care has been taken so that the corresponding geo locations fall over the ocean. This precaution is necessary as TMI data are not reliable over land (TRMM 1998). For each instantaneous field of view TMI provides CLW, PW, LH and rainfall values on a pixel by pixel basis at 14 vertical levels (TRMM 1998). The values of PW and CLW are multiplied by 1000 and stored as 2-byte integers (TRMM 1998). The values of LH are multiplied by 10 and stored as 2-byte integers (TRMM 1998). The CLW, PW, LH and surface rainfall values obtained from version V6 of data product 2A12 (TRMM 1998) of TRMM in HDF have been converted to ASCII prior to further analysis.

Daily surface rainfall, total CLW, PW and LH data so obtained have been fitted against different models *viz*., cubic, power, s, logarithmic, quadratic, linear, exponential, compound, inverse, growth and logistic. The validity of the model is judged by F test at 5% level of significance.

TABLE 4

Relationship between surface rainfall (y) and CLW (C), PW (P) and LH (L)

Station	1999	2000
Chennai	$y = 0.003 - 0.046 C + 1.776 P + 0.121 L$	$y = - 0.200 + 2.227 C + 1.524 P + 0.036 L$
Karaikal	$y = - 0.218 + 1.468 C + 1.657 P + 0.027 L$	$y = - 0.033 + 0.346 C + 1.705 P + 0.100 L$
Kakdwip	$y = - 0.293 + 0.501 C + 2.140 P + 0.021 L$	$y = - 0.189 + 2.169 C + 1.542 P + 0.046 L$
Machilipatnam	$y = - 0.183 + 1.996 C + 1.527 P + 0.039 L$	$y = - 0.240 + 1.050 C + 1.905 P + 0.017 L$
Mangalore	$y = - 0.066 + 0.803 C + 1.637 P + 0.073 L$	$y = - 0.058 +0.745 C + 1.640 P + 0.080 L$
Mumbai	$y = 0.020 - 0.332 C + 1.806 P + 0.131 L$	$y = 0.021 - 0.375 C + 1.891 P + 0.155 L$
Panjim	$y = - 0.139 + 1.426 C + 1.605 P + 0.045 L$	$y = - 0.214 + 1.402 C + 1.748 P + 0.022 L$
Puri	$y = - 0.245 + 2.053 C + 1.614 P + 0.030 L$	$y = - 0.265 + 0.799 C + 2.105 P + 0.016 L$
Trivandrum	$y = - 0.105 + 0.744 C + 1.714 P + 0.063 L$	$y = - 0.141 + 1.227 C + 1.608 P + 0.044 L$
Vishakhapatnam	$y = - 0.031 + 0.400 C + 1.681 P + 0.102 L$	$y = - 0.019 - 0.171 C + 1.863 P + 0.114 L$
Costa Rica	$y = - 0.234 + 1.237 C + 1.868 P + 0.013 L$	$y = - 0.197 + 1.381 C + 1.756 P + 0.029 L$
Papua New Guinea	$y = - 0.256 + 1.215 C + 1.928 P + 0.016 L$	$y = - 0.182 + 1.242 C + 1.747 P + 0.036 L$
Pacific Ocean	$y = - 0.197 + 1.136 C + 1.796 P + 0.037 L$	$y = - 0.105 + 0.652 C + 1.779 P + 0.071 L$
Taiwan	$y = - 0.209 + 1.215 C + 1.702 P + 0.051 L$	$y = - 0.380 + 1.964 C + 2.070 P + 0.003 L$
Panama	$y = - 0.164 + 0.930 C + 1.812 P + 0.020 L$	$y = - 0.271 + 1.609 C + 1.737 P + 0.021 L$
Mozambique	$y = - 0.203 + 1.343 C + 1.731 P + 0.037 L$	$y = - 0.222 + 1.339 C + 1.745 P + 0.027 L$
East China Sea	$y = - 0.118 + 0.782 C + 1.696 P + 0.055 L$	$y = - 0.146 + 1.117 C + 1.662 P + 0.064 L$
Mediterranean Sea	$y = - 0.335 + 0.849 C + 1.914 P + 0.162 L$	$y = 0.144 + 0.776 C + 0.946 P + 0.154 L$
Gulf of Mexico	$y = - 0.339 + 0.973 C + 2.177 P + 0.008 L$	$y = - 0.261 + 1.642 C + 1.801 P - 0.002 L$
Indian Ocean	$y = - 0.226 + 1.052 C + 1.853 P + 0.034 L$	$y = - 0.211 + 1.264 C + 1.800 P + 0.030 L$
South China Sea	$y = - 0.202 + 0.873 C + 1.917 P + 0.034 L$	$y = - 0.126 + 0.851 C + 1.632 P + 0.063 L$

Station	2001	2002
Chennai	$y = - 0.215 + 1.726 C + 1.650 P + 0.029 L$	$y = - 0.192 + 1.936 C + 1.619 P + 0.029 L$
Karaikal	$y = - 0.192 + 2.436 C + 1.501 P + 0.048 L$	$y = - 0.193 + 1.616 C + 1.666 P + 0.031 L$
Kakdwip	$y = - 0.211 + 2.751 C + 1.531 P + 0.030 L$	$y = - 0.158 + 1.533 C + 1.634 P + 0.038 L$
Machilipatnam	$y = 0.005 + 1.038 C + 1.417 P + 0.082L$	$y = - 0.252 + 2.441 C + 1.593 P - 0.004 L$
Mangalore	$y = - 0.104 + 0.449 C + 1.780 P + 0.045 L$	$y = - 0.139 + 1.156 C + 1.706 P + 0.052 L$
Mumbai	$y = - 0.134 + 1.217 C + 1.622 P + 0.048 L$	$y = - 0.036 + 0.370 C + 1.723 P + 0.118 L$
Panjim	$y = - 0.133 + 0.934 C + 1.755 P + 0.044 L$	$y = - 0.096 + 0.870 C + 1.672 P + 0.079 L$
Puri	$y = - 0.175 - 0.520 C + 2.239 P + 0.049 L$	$y = - 0.192 + 1.456 C + 1.742 P + 0.032 L$
Trivandrum	$y = - 0.096 + 1.019 C + 1.590 P + 0.064 L$	$y = - 0.043 + 0.369 C + 1.679 P + 0.074 L$
Vishakhapatnam	$y = - 0.178 + 1.108 C + 1.766 P + 0.034 L$	$y = - 0.232 + 2.436 C + 1.551 P + 0.037 L$
Costa Rica	$y = - 0.249 + 1.408 C + 1.862 P + 0.019 L$	$y = - 0.221 + 1.405 C + 1.781P + 0.021 L$
Indian Ocean	$y = - 0.174 + 0.976 C + 1.785 P + 0.048 L$	$y = - 0.159 + 0.977 C + 1.762 P + 0.043 L$
Pacific Ocean	$y = - 0.100 + 0.873 C + 1.659 P + 0.070 L$	$y = - 0.199 + 1.243 C + 1.808 P + 0.021 L$
Taiwan	$y = - 0.256 + 1.127 C + 1.815 P + 0.054 L$	$y = - 0.239 + 1.448 C + 1.706 P + 0.038 L$
Panama	$y = - 0.139 + 1.112 C + 1.811 P + 0.041 L$	$y = - 0.127 + 0.871 C + 1.836 P + 0.049 L$
Mozambique	$y = - 0.186 + 1.380 C + 1.695 P + 0.036 L$	$y = - 0.202 + 1.168 C + 1.777 P + 0.048 L$
East China Sea	$y = - 0.092 + 0.794 C + 1.595 P + 0.077 L$	$y = - 0.134 + 1.002 C + 1.647 P + 0.053 L$
Mediterranean Sea	$y = - 0.303 + 8.142 C + 2.716 P - 0.145 L$	$y = - 0.492 + 2.230 C + 1.061 P + 0.264 L$
Gulf of Mexico	$y = - 0.151 + 0.975 C + 1.689 P + 0.039 L$	$y = - 0.224 + 0.820 C + 1.906 P + 0.047 L$
Papua New Guinea	$y = - 0.175 + 1.082 C + 1.767 P + 0.043 L$	$y = - 0.185 + 1.491 C + 1.655 P + 0.044L$
South China Sea	$y = - 0.253 + 1.451 C + 1.848 P + 0.026 L$	$y = - 0.220 + 1.363 C + 1.767 P + 0.036 L$

TABLE 4 (*Contd*.)

Station	2003	2004
Chennai	$y = -0.086 + 0.391C + 1.853P + 0.092L$	$y = -0.181 + 1.860C + 1.695P + 0.028L$
Karaikal	$y = -0.298 + 2.021C + 1.691P + 0.015L$	$y = -0.116 + 0.773C + 1.703P + 0.059L$
Kakdwip	$y = -0.133 + 1.163C + 1.661P + 0.054L$	$y = -0.276 + 3.107C + 1.573P + 0.024L$
Machilipatnam	$y = -0.184 + 0.485C + 1.919P + 0.035L$	$y = -0.030 + 0.006C + 1.783P + 0.109L$
Mangalore	$y = -0.173 + 1.656C + 1.654P + 0.021L$	$y = -0.111 + 1.272C + 1.579P + 0.060L$
Mumbai	$y = -0.367 + 0.403C + 0.147P + 0.019L$	$y = -0.162 + 1.346C + 1.630P + 0.050L$
Panjim	$y = -0.144 + 1.470C + 1.656P + 0.044L$	$y = -0.166 + 0.916C + 1.814P + 0.052L$
Puri	$y = -0.344 + 1.705C + 1.932P - 0.001L$	$y = 0.260 - 8.193C + 3.040P + 0.216L$
Trivandrum	$y = -0.098 + 0.802C + 1.711P + 0.052L$	$y = -0.188 + 1.108C + 1.803P + 0.039L$
Vishakhapatnam	$y = -0.235 + 2.079C + 1.673P + 0.030L$	$y = -0.301 + 2.952C + 1.529P + 0.024L$
Costa Rica	$y = -0.167 + 1.244C + 1.734P + 0.038L$	$y = -0.255 + 0.893C + 2.249P - 0.012L$
Indian Ocean	$y = -0.170 + 1.025C + 1.781P + 0.033L$	$y = -0.152 + 1.122C + 1.750P + 0.046L$
Pacific Ocean	$y = -0.160 + 1.396C + 1.638P + 0.036L$	$y = -0.204 + 1.415C + 1.778P + 0.024L$
Taiwan	$y = -0.226 + 1.364C + 1.795P + 0.033L$	$y = -0.240 + 2.179C + 1.600P + 0.038L$
Panama	$y = -0.130 + 0.822C + 1.752P + 0.048L$	$y = -0.116 + 0.474C + 1.838P + 0.047L$
Mozambique	$y = -0.270 + 2.785C + 1.492P + 0.015L$	$y = -0.136 + 0.684C + 1.776P + 0.062L$
East China Sea	$y = -0.200 + 2.062C + 1.625P + 0.029L$	$y = -1.112 + 1.128C + 1.652P + 0.065L$
Mediterranean Sea	$y = -0.437 - 3.147C + 2.579P + 0.331L$	$y = -0.001 + 2.913C + 0.477P + 0.171L$
Gulf of Mexico	$y = -0.138 + 0.756C + 1.768P + 0.059L$	$y = -0.132 + 0.691C + 1.796P + 0.060L$
Papua New Guinea	$y = -0.215 + 1.217C + 1.806P + 0.027L$	$y = -0.280 + 1.354C + 1.864P + 0.016L$
South China Sea	$y = -0.215 + 1.506C + 1.741P + 0.023L$	$y = -0.677 + 1.864C + 3.006P - 0.176L$

Station	2005	2006
Chennai	$y = -0.106 + 1.012C + 1.683P + 0.064L$	$y = -0.141 + 0.903C + 1.741P + 0.036L$
Karaikal	$y = -0.233 + 1.442C + 1.827P + 0.012L$	$y = -0.163 + 1.283C + 1.664P + 0.027L$
Kakdwip	$y = -0.230 + 1.541C + 1.653P + 0.038L$	$y = -0.235 + 1.873C + 1.734P + 0.034L$
Machilipatnam	$y = -0.211 + 1.390C + 1.752P + 0.040L$	$y = -0.228 + 2.918C + 1.532P + 0.053L$
Mangalore	$y = -0.263 + 1.645C + 1.789P + 0.017L$	$y = -0.143 + 1.235C + 1.673P + 0.047L$
Mumbai	$y = -0.165 + 1.444C + 1.647P + 0.050L$	$y = -0.148 + 1.142C + 1.747P + 0.060L$
Panjim	$y = -0.100 + 0.955C + 1.651P + 0.064L$	$y = -0.068 + 0.775C + 1.579P + 0.084L$
Puri	$y = -0.250 + 1.779C + 1.732P + 0.019L$	$y = -0.271 + 1.766C + 1.756P + 0.028L$
Trivandrum	$y = -0.145 + 1.041C + 1.719P + 0.040L$	$y = -0.246 + 1.068C + 1.958P + 0.021L$
Vishakhapatnam	$y = -0.168 + 1.612C + 1.597P + 0.038L$	$y = -0.246 + 1.068C + 1.958P + 0.021L$
Costa Rica	$y = -0.158 + 1.067C + 1.790P + 0.037L$	$y = -0.181 + 0.594C + 1.920P + 0.049L$
Indian Ocean	$y = -0.215 + 1.500C + 1.745P + 0.025L$	$y = -0.219 + 1.408C + 1.814P + 0.018L$
Pacific Ocean	$y = -0.201 + 1.558C + 1.648P + 0.035L$	$y = -0.148 + 1.033C + 1.765P + 0.046L$
Taiwan	$y = -0.221 + 2.173C + 1.516P + 0.051L$	$y = -0.222 + 1.429C + 1.712P + 0.034L$
Panama	$y = -0.346 + 2.011C + 1.907P - 0.009L$	$y = -0.233 + 1.735C + 1.825P + 0.004L$
Mozambique	$y = -0.154 + 1.562C + 1.578P + 0.046L$	$y = -0.061 + 0.562C + 1.526P + 0.107L$
East China Sea	$y = -0.094 + 0.503C + 1.721P + 0.087L$	$y = -0.134 + 1.288C + 1.587P + 0.051L$
Mediterranean Sea	$y = -0.062 + 0.207C + 1.627P + 0.157L$	$y = -0.295 + 2.537C + 1.949P + 0.021L$
Gulf of Mexico	$y = -0.298 + 0.725C + 2.113P + 0.025L$	$y = -0.309 + 1.885C + 1.895P + 0.006L$
Papua New Guinea	$y = -0.164 + 1.203C + 1.696P + 0.044$	$y = -0.212 + 1.616C + 1.722P + 0.029L$
South China Sea	$y = -0.174 + 1.310C + 1.652P + 0.039L$	$y = -0.176 + 1.065C + 1.739P + 0.047L$

TABLE 4 (*Contd.*)

Station	2007	2008
Chennai	$y = - 0.196 + 1.399 C + 1.657 P + 0.031 L$	$y = 0.362 + 2.128 C - 0.037 P + 0.150 L$
Kakdwip	$y = - 0.248 + 2.555 C + 1.561 P + 0.031 L$	$y = - 0.367 + 2.653 C + 1.782 P + 0.004 L$
Karaikal	$y = - 0.195 + 1.385 C + 1.636 P - 0.011 L$	$y = - 0.137 + 0.907 C + 1.750 P + 0.042 L$
Machilipatnam	$y = 0.362 + 2.128 C -0.037 P + 0.150 L$	$y = - 0.284 + 2.681 C + 1.561 P - 0.024 L$
Mangalore	$y = - 0.099 + 0.931 C + 1.692 P + 0.069 L$	$y = - 0.294 + 1.854 C + 1.803 P + 0.024 L$
Mumbai	$y = - 0.165 + 1.740 C + 1.556 P + 0.046 L$	$y = - 0.114 + 1.126 C + 1.623 P + 0.045 L$
Panjim	$y = 0.503 + 0.439 C + 0.748 P + 0.115 L$	$y = - 0.162 + 1.544 C + 1.606 P + 0.041 L$
Puri	$y = - 0.261 + 1.637 C + 1.766 P + 0.008 L$	$y = - 0.083 + 0.530 C + 1.737P + 0.064 L$
Trivandrum	$y = 0.283 + 0.515 C + 1.149 P + 0.131 L$	$y = - 0.132 + 1.157 C + 1.658 P + 0.052 L$
Vishakhapatnam	$y = - 0.037 - 0.327 C + 1.733 P + 0.056 L$	$y = - 0.112 + 0.824 C + 1.645 P + 0.060 L$
Costa Rica	$y = - 0.172 + 1.212 C + 1.687 P + 0.027 L$	$y = - 0.177 + 1.255 C + 1.789 P + 0.031 L$
Indian Ocean	$y = - 0.074+ 0.607 C + 1.701 P + 0.081 L$	$y = - 0.279 + 1.753 C + 1.813 P + 0.014 L$
Pacific Ocean	$y = - 0.222 + 1.000 C + 2.010 P + 0.018 L$	$y = - 0.077 + 0.728 C + 1.691 P + 0.061 L$
Taiwan	$y = 0.389 - 2.188 C + 1.330 P + 0.276 L$	$y = - 0.145 + 1.522 C + 1.567 P + 0.044 L$
Panama	$y = - 0.034 + 1.414 C + 1.188 P + 0.101 L$	$y = - 0.183 + 1.175 C + 1.890 P + 0.027 L$
Mozambique	$y = - 0.153 + 1.631 C + 1.555 P + 0.046 L$	$y = - 0.112 + 0.422 C + 1.866 P + 0.055 L$
East China Sea	$y = - 0.103 + 2.633 C + 1.347 P + 0.050 L$	$y = - 0.252 + 4.206 C + 1.484 P + 0.027L$
Mediterranean Sea	$y = - 0.299 + 1.619 C + 2.469 P + 0.007 L$	$y = 0.019 - 0.635 C + 1.811 P + 0.137 L$
Gulf of Mexico	$y = - 0.152 + 0.646 C + 1.875 P + 0.062 L$	$y = - 0.055 + 0.493 C + 1.582 P + 0.098L$
Papua New Guinea	$y = - 0.158 + 1.291 C + 1.704 P + 0.042 L$	$y = - 0.226 + 1.599 C + 1.716 P + 0.024L$
South China Sea	$y = - 0.210 + 1.368 C + 1.793 P + 0.030 L$	$y = - 0.258 + 1.633 C + 1.758 P + 0.041L$

TABLE 5(a)

Relationship between surface rainfall (*y*) and CLW (C), PW (P) and LH (L)

1	Mangalore	$y = - 0.145 + 1.175 C + 1.695 P + 0.049 L$
2	Papua New Guinea	$y = - 0.205 + 1.331 C + 1.761 P + 0.032 L$
3	Pacific Ocean	$y = - 0.161 + 1.103 C + 1.757 P + 0.042 L$
4	Mozambique	$y = - 0.170 + 1.288 C + 1.674 P + 0.048 L$
5	East China Sea	$y = - 0.239 + 1.552 C + 1.602 P + 0.056 L$
6	Indian ocean	$y = - 0.188 + 1.168 C + 1.780 P + 0.037 L$

TABLE 5(b)

Relationship between surface rainfall (*y*) and CLW (C), PW (P) and LH (L)

1	Chennai	$y = - 0.095 + 1.354 C + 1.516 P + 0.062 L$
2	Kakdwip	$y = - 0.205 + 1.693 C + 1.685 P + 0.032 L$
3	Karaikal	$y = - 0.178 + 1.368 C + 1.680 P + 0.035 L$
4	Machilipatnam	$y = - 0.125 + 1.613 C + 1.495 P + 0.050 L$
5	Mumbai	$y = - 0.125 + 0.808 C + 1.539 P + 0.072 L$
6	Panjim	$y = - 0.072 + 1.073 C + 1.583 P + 0.059 L$
7	Puri	$y = - 0.183 + 0.301 C + 1.966 P + 0.046 L$
8	Trivandrum	$y = - 0.091 + 0.905 C + 1.659 P + 0.058 L$
9	Vishakhapatnam	$y = - 0.149 + 1.151 C + 1.696 P + 0.054 L$
10	Costa Rica	$y = - 0.199 + 1.249 C + 1.818 P + 0.025 L$
11	Taiwan	$y = - 0.175 + 1.223 C + 1.681 P + 0.062 L$
12	Panama	$y = - 0.174 + 1.215 C + 1.760 P + 0.035 L$
13	Mediterranean Sea	$y = - 0.206 + 1.549 C + 1.755 P + 0.126 L$
14	Gulf of Mexico	$y = - 0.206 + 0.961 C + 1.860 P + 0.040 L$
15	South China Sea	$y = - 0.251 + 1.328 C + 1.885 P + 0.016 L$

3. Results and discussion

Surface rainfall is found to bear significant correlations with CLW (Table 1). Over the Indian stations, the relationship is mostly cubic and s; over foreign stations the relationship is mostly cubic. Over Papua New Guinea in 2007, it is s and in 2008 a power relation is seen. Over Costa Rica, CLW and surface rainfall bear an s relation in both the years. Surface rainfall bears significant correlations with PW over all the stations studied (Table 2). Over the Indian stations, the two quantities mostly bear a power or a cubic relation. Over stations other than India, the relationship is mostly found to be cubic. Surface rainfall bears a significant correlation with latent heat (Table 3). The two bear mostly a cubic relation over Indian and foreign stations.

Table 4 shows the functional relationship between daily surface rainfall and CLW, PW and LH. It is found out from Table 4 that surface rainfall can be well explained on the basis of CLW, PW and LH together, and predictability of surface rainfall increases if all three parameters are included in the regression, instead of including one, or two of the parameters (Tables 1-4). The predictability of surface rainfall on the basis of two parameters is not shown. It is noteworthy that the constants and coefficients of the functional relationships

TABLE 6(a)

Relationship between CLW (*x*) and PW (*y*)

Station	2007	2008
Chennai	$y = e^{0.907 - 0.167/x}$	$y = -0.205 + 7.302x - 11.239x^2 + 5.590x^3$
Kakdwip	$y = 0.033 + 4.805x + 6.448x^2 - 3.846x^3$	$y = -1.444 + 22.85x - 31.421x^2 + 12.985x^3$
Karaikal	$y = -0.925 + 15.088\text{ x} + 0x^2 - 28.156x^3$	$y = e^{0.717 - 0.188/x}$
Machilipatnam	$y = 4.485x^{1.181}$	$y = -0.966 + 16.918x - 11.963x^2$
Mangalore	$y = e^{1.134 - 0.2057/x}$	$y = e^{1.288 - 0.198/x}$
Mumbai	$y = e^{1.276 - 0.220/x}$	$y = e^{1.715 - 0.267/x}$
Panjim	$y = e^{1.212 - 0.220/x}$	$y = e^{2.124 - 0.237/x}$
Puri	$y = e^{1.187 - 0.222/x}$	$y = -0.382 + 10.516x - 11.725x^2 + 4.204x^3$
Trivandrum	$y = e^{0.849 - 0.193/x}$	$y = e^{0.647 - 0.189/x}$
Vishakhapatnam	$y = -0.652 - 9.915x + 68.314x^2 - 52.893x^3$	$y = 2.843x^{0.914}$
Costa Rica	$y = e^{1.373 - 0.225/x}$	$y = e^{0.935 - 0.176/x}$
Indian Ocean	$y = -1.385 + 24.743x - 44.133x^2 + 21.887x^3$	$y = 2.344x^{0.998}$
Pacific Ocean	$y = -0.404 + 9.461x - 18.005x^2 + 11.131x^3$	$y = e^{0.695 - 0.165/x}$
Taiwan	$y = -0.738 + 13.854x - 16.542x^2 + 6.155x^3$	$y = -0.607 + 10.050x - 4.304x^2 - 1.983x^3$
Panama	$y = 0.256 - 3.714x + 33.882x^2 - 24.970x^3$	$y = -0.068 + 4.632x - 4.290x^2 + 1.889x^3$
Mozambique	$y = -1.008 + 18.085x - 28.097x^2 + 12.938x^3$	$y = 1.097 - 13.279x + 35.085x^2 - 17.965x^3$
East China Sea	$y = 0.174 + 1.751x + 4.426x^2$	$y = -0.389 + 10.176x - 25.469x^2 + 21.108x^3$
Mediterranean Sea	$y = -0.121 + 5.524x - 10.139x^2 + 6.463x^3$	$y = 0.839 - 8.953x + 40.363x^2 - 33.120x^3$
Gulf of Mexico	$y = -0.681 + 14.700x - 27.449x^2 + 15.313x^3$	$y = -0.759 + 14.157x - 18.421x^2 + 7.367x^3$
Papua New Guinea	$y = e^{0.716 - 0.157/x}$	$y = 0.153 + 3.658x - 7.500x^2 + 8.000x^3$
South China Sea	$y = -0.845 + 14.913x - 18.231x^2 + 5.670x^3$	$y = -1.213 + 22.369x + 52.678x^2 - 61.356x^3$

TABLE 6(b)

Relationship between PW (*y*) and LH (*x*)

Station	2007	2008
Chennai	$y = 0.539 + 0.053x + 0.011x^2 + 0x^3$	$y = 0.309 - 0.019x + 0.008x^2 + 0x^3$
Kakdwip	$y = 0.935 + 0.263x - 0.004x^2 + 1.99 \times 10^{-5}x^3$	$y = 0.844 + 0.563x - 0.024x^2 + 0x^3$
Karaikal	$y = 0.556 + 0.504x + 0.260x^2 - 0.075x^3$	$y = 0.455 + 0.204x - 0.014x^2 + 0.001x^3$
Machilipatnam	$y = -0.401 - 0.644x + 0.051x^2 + 0x^3$	$y = 0.653 + 0.078x + 0.073x^2 - 0.003x^3$
Mangalore	$y = 0.637 + 0.112x + 0x^2 - 2.8 \times 10^{-5}x^3$	$y = 0.669 + 0.166x - 0.002x^2 + 9.42 \times 10^{-6}x^3$
	$y = 0.646 + 0.124x - 0.001\underline{\text{x}}^2$	
Mumbai	$y = 0.558 + 0.182x - 0.001x^2 - 6.7 \times 10^{-6}x^3$	$y = 0.819 + 0.190x - 0.01x^2 + 0x^3$
Panjim	$y = 0.545 + 0.056x + 0.001x^2 - 1.9 \times 10^{-6}x^3$	$y = 0.357 + 0.116x + 0x^2$
Puri	$y = -0.279 - 0.497x + 0.077x^2 - 0.002x^3$	$y = 0.727 + 0.076x + 0x^2 - 5.1 \times 10^{-6}x^3$
Trivandrum	$y = 0.424 + 0.113x - 0.001x^2$	$y = 0.352 + 0.085x + 0.004x^2 + 0x^3$
Vishakhapatnam	$y = 0.708 + 0.445x - 0.017x^2 + 0x^3$	$y = -0.267 - 0.072x + 0.022x^2 + 0x^3$
Costa Rica	$y = 0.614 + 0.212x + 0x^2 - 3.9 \times 10^{-5}\text{ x}^3$	$y = 0.685 + 0.200x - 0.010x^2 + 9.69 \times 10^{-5}x^3$
Indian Ocean	$y = 0.256 - 0.029x + 0.020x^2 + 0x^3$	$y = 0.367 + 0.134x - 0.001x^2 + 1.07 \times 10^{-5}x^3$
Pacific Ocean	$y = 0.405 + 0.130x - 0.001x^2$	None suits
Taiwan	$y = 0.530 + 0.154x - 0.002x^2$	$y = 0.345 + 0.040x + 0.002x^2$
Panama	$y = 0.444 + 0.342x - 0.023x^2 + 0x^3$	$y = 0.374 + 0.124x - 0.002x^2 + 7.01\,x\,10^{-6}x^3$
Mozambique	$y = 0.480 + 0.115x + 0x^2$	$y = 0.215 - 0.030x + 0.013x^2 + 0x^3$
East China Sea	$y = 0.445 - 0.022x + 0.002x^2$	$y = 0.460 - 0.004x + 0.005x^2 - 3.8 \times 10^{-5}x^3$
Mediterranean Sea	$y = 0.204 + 0.007x + 0.024x^2 - 0.001x^3$	$y = 0.324 - 0.162x + 0.072x^2 - 0.003x^3$
Gulf of Mexico	$y = 0.389 + 0.080x + 0.002x^2 - 4.5 \times 10^{-5}x^3$	$y = 0.276 + 0.192x - 0.005x^2 + 5.69 \times 10^{-5}x^3$
Papua New Guinea	$y = 0.572 + 0.069x + 0.003x^2 - 3.3 \times 10^{-5}x^3$	$y = 0.413 + 0.117x - 0.000x^2$
South China Sea	None suits	$y = 0.296 - 0.118x + 0.062x^2 - 0.001x^3$

TABLE 6(c)

Relationship between CLW (*y*) and LH (*x*)

Station	2007	2008
Chennai	$y = 0.197 + 0.079\,x - 0.002\,x^2 + 1.61 \times 10^{-5}\,x^3$	$y = 0.168 + 0.09\,x - 0.003\,x^2 + 2.48 \times 10^{-5}\,x^3$
Kakdwip	$y = 0.149 + 0.034\,x + 0\,x^2$	$y = 0.192 + 0.111\,x - 0.004\,x^2 + 3.87 \times 10^{-5}\,x^3$
Karaikal	$y = 0.091 - 0.004\,x + 0.007\,x^2 + 0.004\,x^3$	$y = 0.184 + 0.101\,x - 0.011\,x^2 + 0\,x^3$
Machilipatnam	$y = 0.162 + 0.076\,x - 0.002\,x^2 + 8.73 \times 10^{-6}\,x^3$	$y = 0.114 + 0.009\,x + 0.003\,x^2 - 6.8 \times 10^{-5}\,x^3$
Mangalore	$y = 0.139 + 0.05\,x + 0.001\,x^2 - 4.1 \times 10^{-6}\,x^3$	$y = 0.67 + 0.05\,x - 0.001\,x^2 + 3.41 \times 10^{-6}\,x^3$
Mumbai	$y = 0.150 + 0.068\,x - 0.002\,x^2 + 1.53 \times 10^{-5}\,x^3$	$y = 0.104 + 0.016\,x + 0.012\,x^2 + 0\,x^3$
Panjim	$y = 0.172 + 0.043\,x + 0\,x^2 + 6.8 \times 10^{-7}\,x^3$	$y = 0.135 + 0.068\,x - 0.001\,x^2 + 6.61 \times 10^{-6}\,x^3$
Puri	$y = 0.208 + 0.087\,x - 0.004\,x^2 + 7.65 \times 10^{-5}\,x^3$	$y = 0.178 + 0.059\,x - 0.001\,x^2 + 6.82 \times 10^{-6}\,x^3$
Trivandrum	$y = 0.15 + 0.096\,x - 0.003\,x^2 + 2.87 \times 10^{-5}\,x^3$	$y = 0.144 + 0.087\,x - 0.001\,x^2$
Vishakhapatnam	$y = 0.112 + 0.019\,x + 0\,x^2 - 7.2 \times 10^{-6}\,x^3$	$y = 0.142 + 0.055\,x - 0.001\,x^2$
Costa Rica	$y = 0.135 + 0.065\,x - 0.004\,x^2 + 6.00 \times 10^{-5}\,x^3$	$y = 0.164 + 0.076\,x - 0.001\,x^2$
Indian Ocean	$y = 0.161 + 0.098\,x - 0.007\,x^2 + 0\,x^3$	$y = 0.157 + 0.077\,x - 0.001\,x^2 + 5.36 \times 10^{-6}\,x^3$
Pacific Ocean	$y = 0.179 + 0.106\,x - 0.004\,x^2 + 4.24 \times 10^{-5}\,x^3$	$y = 0.154 + 0.076\,x - 0.004\,x^2 + 7.560 \times 10^{-5}\,x^3$
Taiwan	$y = 0.105 + 0.021\,x + 0.004\,x^2 - 1.0 \times 10^{-4}\,x^3$	$y = 0.082 + 0.021\,x + 0.003\,x^2 - 6.8 \times 10^{-5}\,x^3$
Panama	$y = 0.100 + 0.047\,x - 0.001\,x^2 - 3.2 \times 10^{-5}\,x^3$	$y = 0.140 + 0.090\,x - 0.003\,x^2 + 2.1 \times 10^{-5}\,x^3$
Mozambique	$y = 0.126 + 0.061\,x + 0\,x^2$	$y = 0.173 + 0.099\,x - 0.005\,x^2 + 8.37 \times 10^{-5}\,x^3$
East China Sea	$y = 0.095 + 0.007\,x + 0\,x^2$	$y = 0.081 + 0.034\,x + 0\,x^2$
Mediterranean Sea	$y = 0.022 + 0.056\,x - 0.002\,x^2 + 7.56 \times 10^{-5}\,x^3$	$y = 0.066 + 0.004\,x + 0.008\,x^2 + 0\,x^3$
Gulf of Mexico	$y = 0.147 + 0.113\,x - 0.005\,x^2 + 7.14 \times 10^{-5}\,x^3$	$y = 0.096 + 0.052\,x + 0\,x^2$
Papua New Guinea	$y = 0.162 + 0.097\,x - 0.003\,x^2 + 2.15 \times 10^{-5}\,x^3$	$y = 0.157 + 0.083\,x - 0.002\,x^2 + 1.02 \times 10^{-5}\,x^3$
South China Sea	$y = 0.089 + 0.018\,x + 0.012\,x^2 - 0.001\,x^3$	$y = 0.076 + 0.008\,x + 0.014\,x^2 + 0\,x^3$

described in Table 4 maintain consistency over years. From Table 4, it is further found out that over certain stations, namely, the Indian Ocean, the East China Sea, Mangalore, Mozambique, Papua New Guniea and the Pacific Ocean, the constants and coefficients of the functional relationships maintain consistency in both magnitude and sign. Table 5(a) shows the functional relationships averaged over ten years over these stations. Table 5(b) describes the functional relationships averaged over ten years for those stations where in few cases inconsistency is found out.

In order to find out whether there exists any correlations between CLW, PW and LH, the CLW, PW and LH values have been fitted against cubic, power, logarithmic, logistic, s, compound, inverse, linear, growth, exponential and quadratic model. The validity of the model is judged by F test at 5% level of significance. It is found out that significant correlations exist between CLW, PW; PW, LH and CLW, LH [Table 6(a-c)]. The correlation between CLW and PW [Table 6(a)] is found to be mostly cubic and s. However, over Machilipatnam in 2007, Vishakhapatnam in 2008 and the Indian Ocean in 2008, a power relation is found suitable between the two. PW and LH are mostly found to bear a cubic and sometimes a quadratic relation [Table 6(b)]. A cubic relation is found to be suitable between CLW and LH [Table 6(c)] over most of the stations studied, except at the Gulf of Mexico in 2008 and Kakdwip in 2007, when a quadratic relation is found to be suitable.

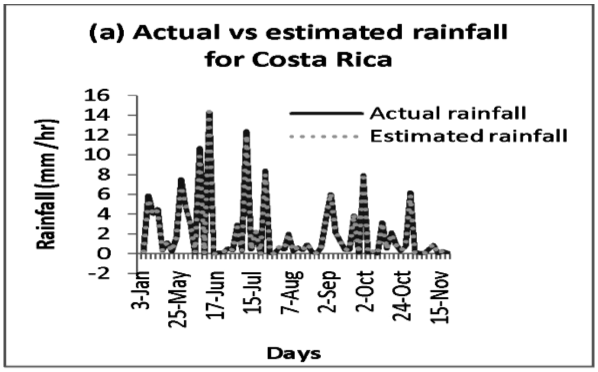


Fig. 1(a). Actual *vs*. estimated rainfall over Costa Rica

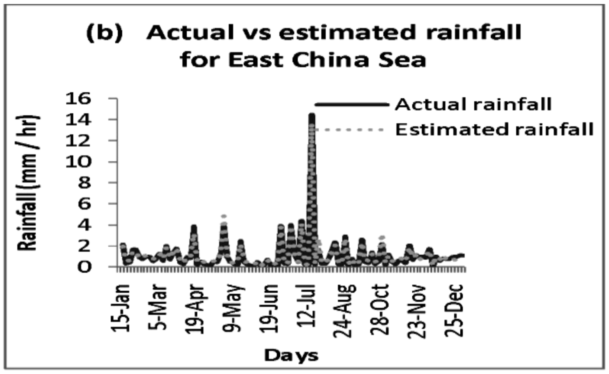


Fig. 1(b). Actual *vs*. estimated rainfall over the East China Sea

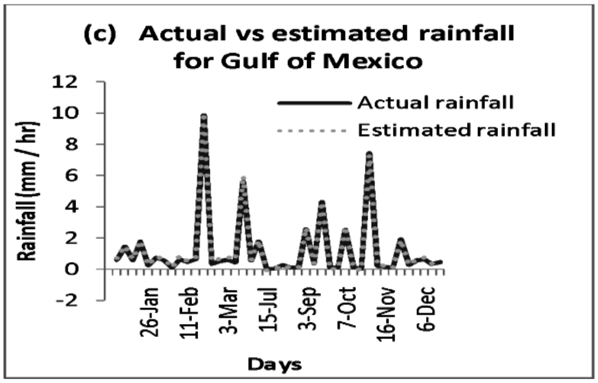


Fig. 1(c). Actual *vs*. estimated rainfall over the Gulf of Mexico

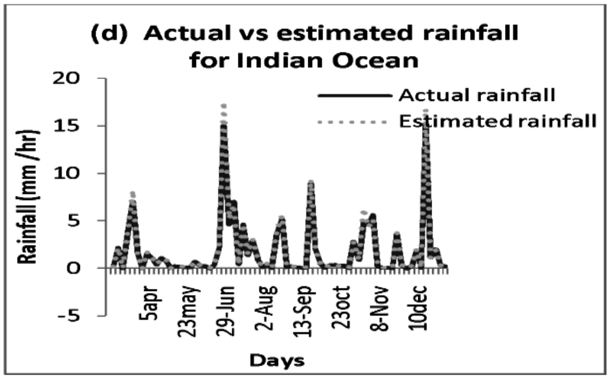


Fig. 1(d). Actual *vs*. estimated rainfall over the Indian Ocean

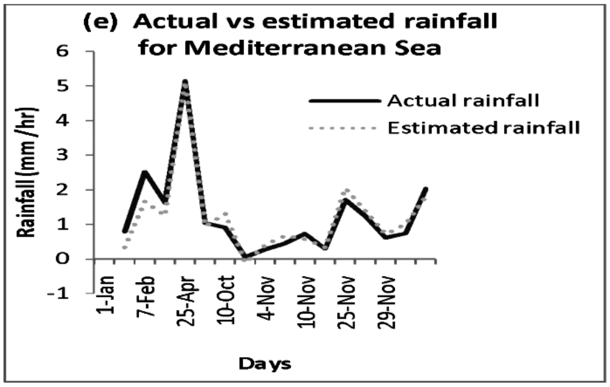


Fig. 1(e). Actual *vs*. estimated rainfall over the Mediterranean Sea

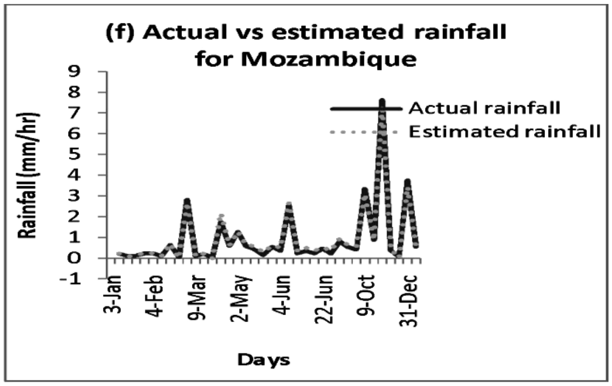


Fig. 1(f). Actual *vs*. estimated rainfall over Mozambique

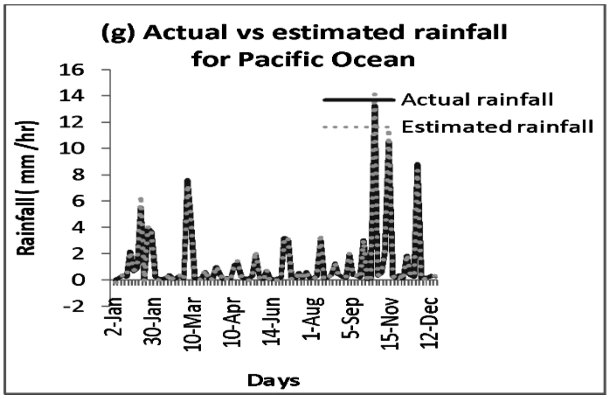


Fig. 1(g). Actual *vs*. estimated rainfall over the Pacific Ocean

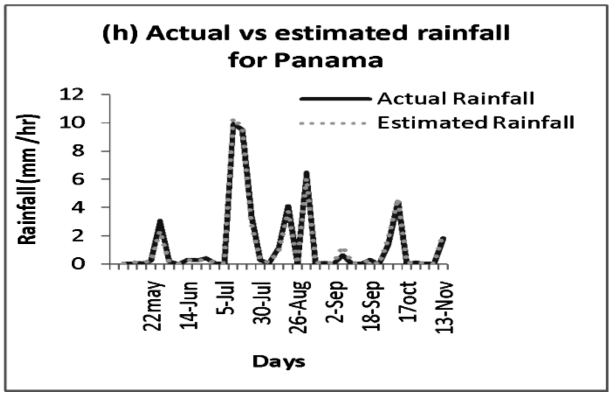


Fig. 1(h). Actual *vs*. estimated rainfall over Panama

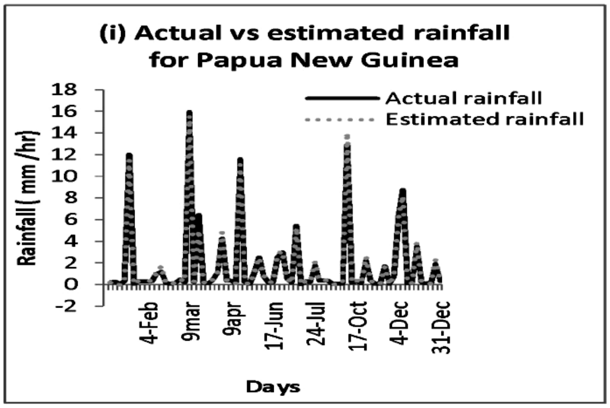


Fig. 1(i). Actual *vs.* estimated rainfall over Papua New Guinea

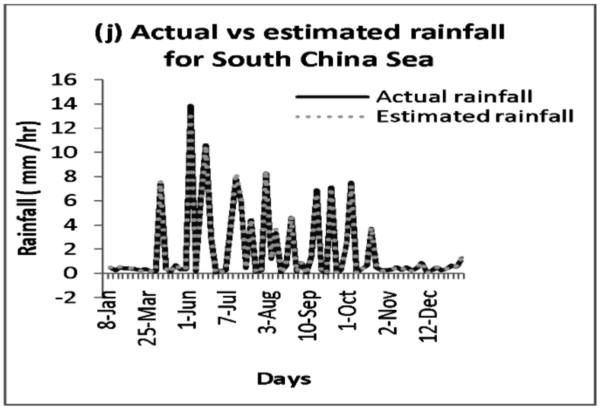


Fig. 1(j). Actual *vs.* estimated rainfall over the South China Sea

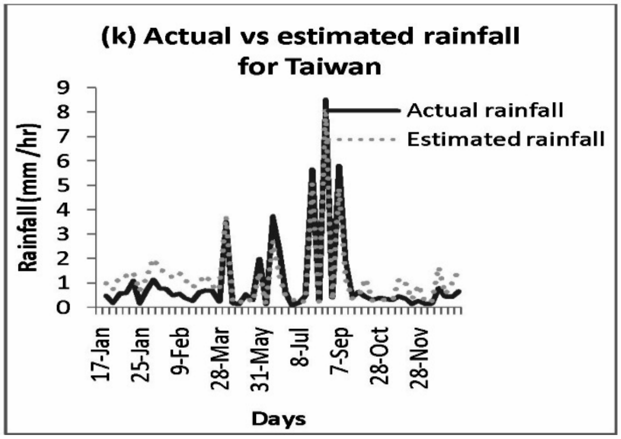


Fig. 1(k). Actual *vs.* estimated rainfall over Taiwan

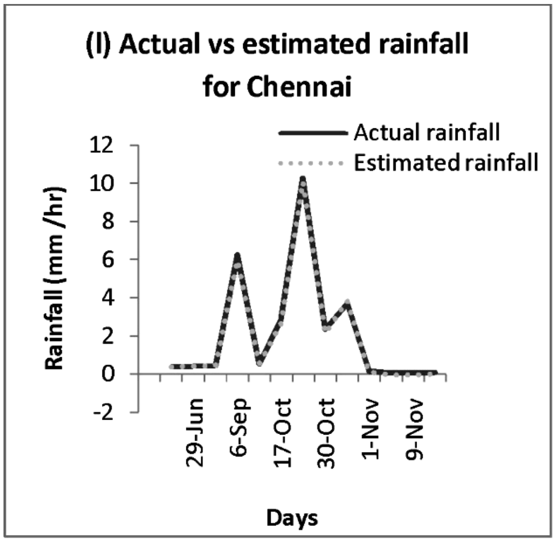


Fig. 1(l). Actual *vs.* estimated rainfall over Chennai

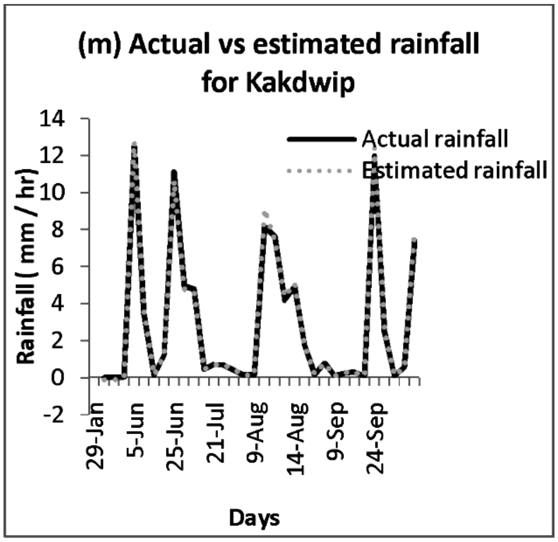


Fig. 1(m). Actual *vs.* estimated rainfall over Kakdwip

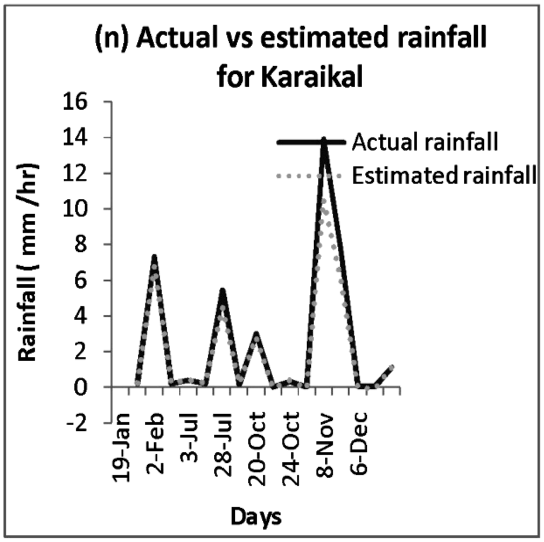


Fig. 1(n). Actual *vs.* estimated rainfall over Karaikal

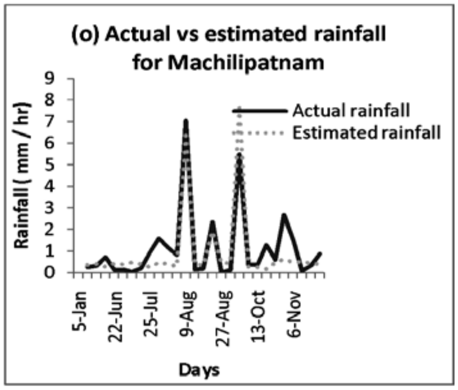


Fig. 1(o). Actual *vs*. estimated rainfall over Machilipatnam

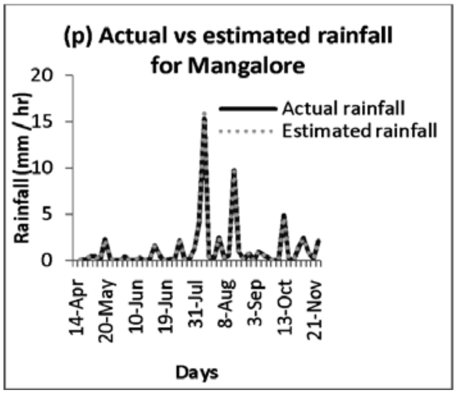


Fig. 1(p). Actual *vs*. estimated rainfall over Mangalore

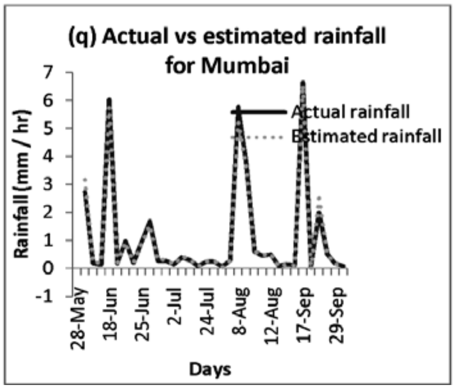


Fig. 1(q). Actual *vs*. estimated rainfall over Mumbai

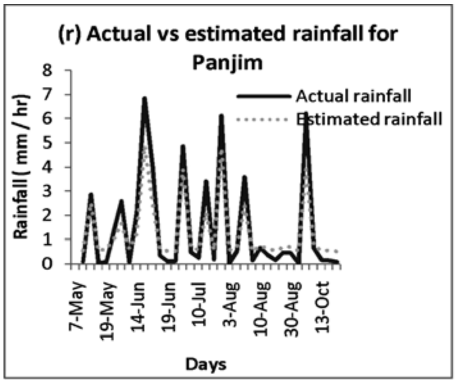


Fig. 1(r). Actual *vs*. estimated rainfall over Panjim

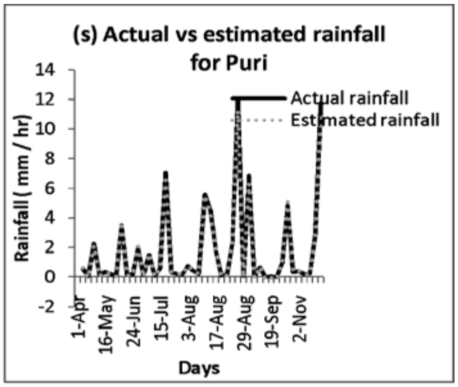


Fig. 1(s). Actual *vs*. estimated rainfall over Puri

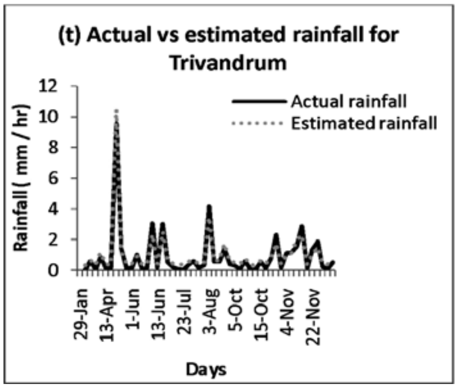


Fig. 1(t). Actual *vs*. estimated rainfall over Trivandrum

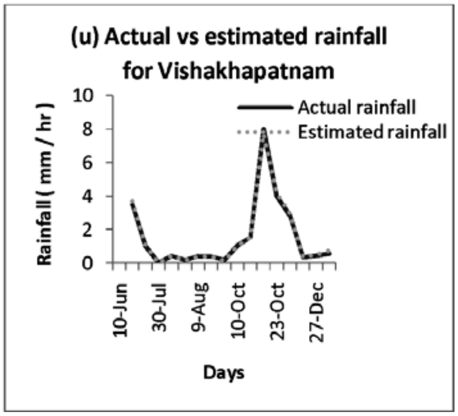
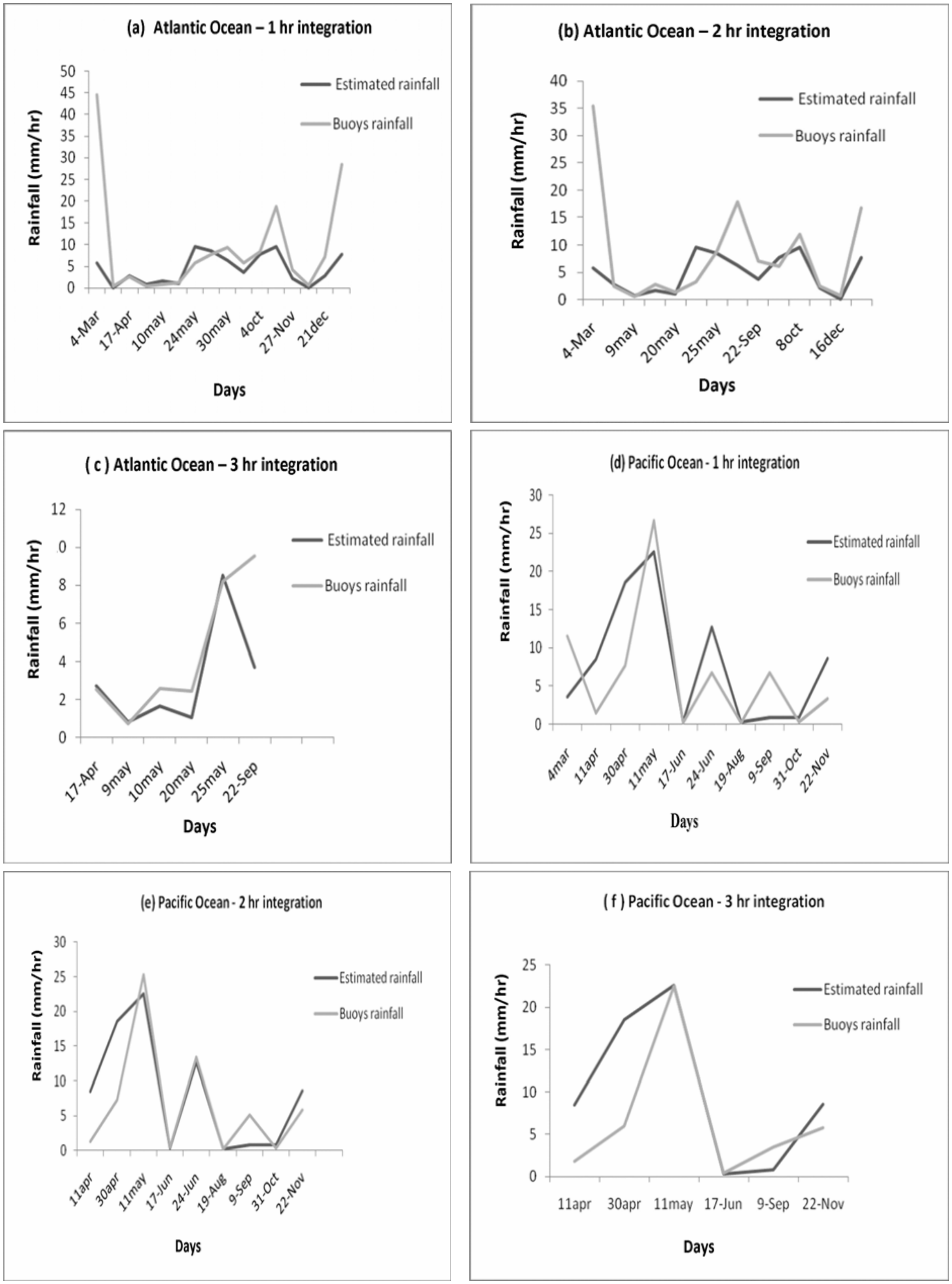
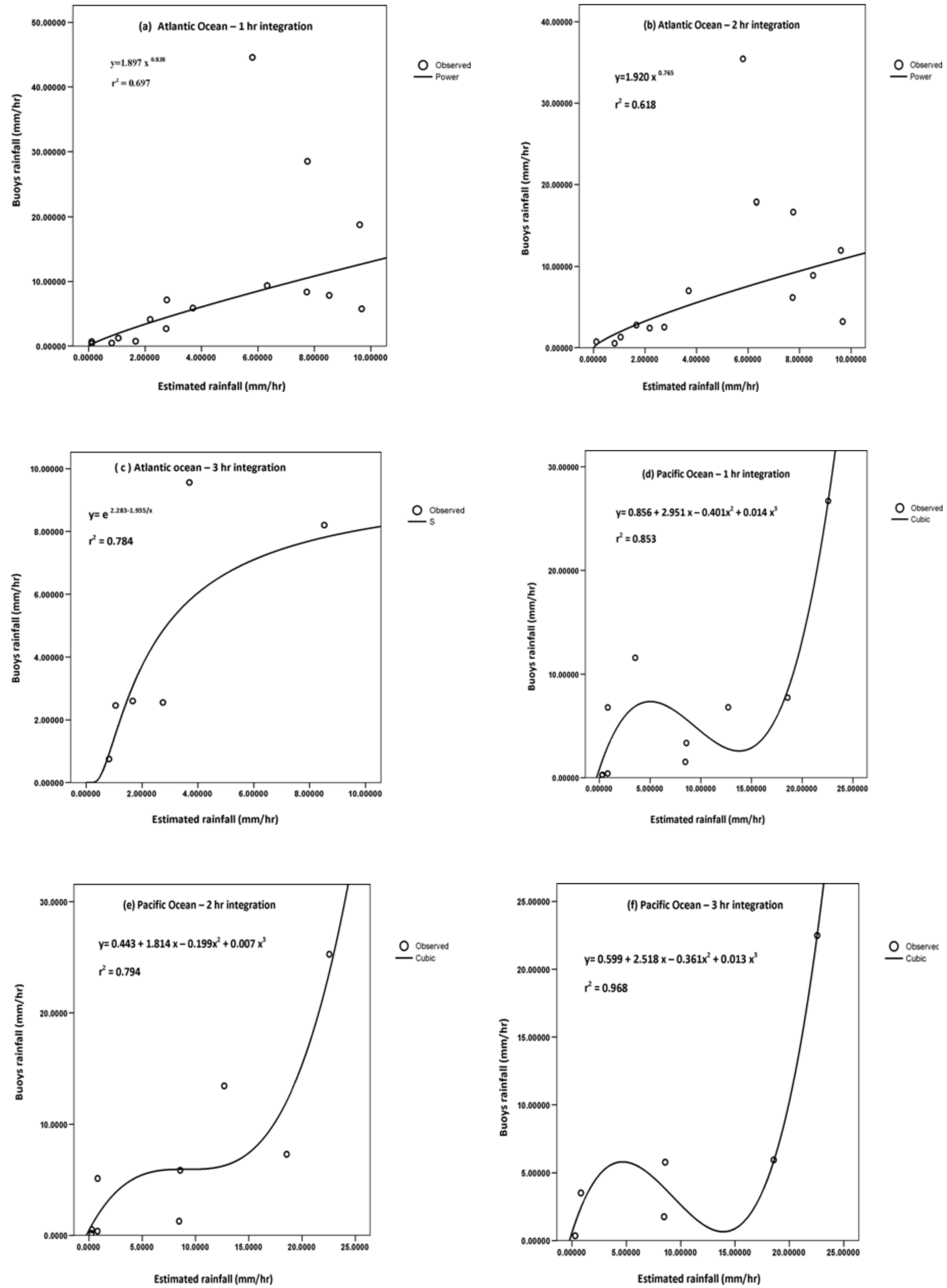


Fig. 1(u). Actual *vs*. estimated rainfall over Vishakhapatnam



Figs. 2(a-f). Comparison of estimated and buoy rainfall over the Atlantic Ocean for (a) 1 hr integration time, (b). 2 hr integration time, (c) 3 hr integration time, and over the Pacific Ocean (d) 1 hr integration time, (e) 2 hr integration time, (f) 3 hr integration time



Figs. 3(a-f). Correlation between estimated and buoy rainfall over the Atlantic Ocean for (a) 1hr integration time, (b) 2 hr integration time, (c) 3 hr integration time, and over the Pacific Ocean (d) 1 hr integration time, (e) 2 hr integration time, (f) 3 hr integration time

Figs. 1(a-u) shows the validity of the functional relationships established relating surface rainfall and CLW, PW and LH. It is seen that the functional relationships so established are able to predict surface rainfall of 2002 very accurately. It appears that the relationships so established are able to predict rainfall for any day of any year. It is worth mentioning here that the validity of the functional relationships proposed in this article has been tested against rainfall values derived from TRMM (Fig. 1). As the latter differs to some extent from that recorded by rain gauge, disdrometer etc., the proposed relationships will also differ to some extent from that derived from ground truth. Nevertheless, the novelty of the article lies in properly identifying the key parameters governing rainfall, and proposing the technique to estimate rainfall on the basis of the identified parameters. If it be possible to measure the columnar CLW, PW and net LH, the functional relationships proposed will be able to estimate surface rainfall very accurately.

In order to find out the accuracy of the suggested functional relationships the authors have also compared the simultaneous rainfall values estimated from the functional relationships as described in Tables 4 and 5 with that recorded by Ocean buoys over the Pacific Ocean (4° N, 165° E) and the Atlantic Ocean (4° N, 23° W). It is noteworthy that the Ocean buoys record data at 10 min integration time, while the TMI estimates instantaneous rainfall. In fact, it is very difficult to compare TMI and ground truth data. Firstly, the two measure two different quantities (Kenneth 2004). TMI estimates area-averaged rainfall surrounding a particular geo location, while rain gauges measure point rainfall rate. Moreover, for a particular geo location there is only one TRMM overpass per day, while rain gauges measure rainfall at much higher resolution. Thus, rain gauges have larger temporal resolution but less spatial resolution (Kenneth 2004). On the contrary, TRMM provides poor temporal resolution but better spatial resolution (Kenneth 2004). It may be mentioned here that it often rains between TRMM over passes. Hence though it may be raining at the gauge, TRMM may over look it. It is noteworthy that due to non availability of data at the same instant from the two sources, in this paper the buoy rainfall data averaged over 1 hour, 2 hour and 3 hour duration have been calculated and then compared with TRMM data lying within the same interval of time.

In order to compare the two, in this paper the scan time of each instantaneous field of view of TMI has been noted for the year 2007 and simultaneous buoy data lying within 30 minutes before and after TRMM scan time have been averaged for a particular day. For a particular scan time of TMI the CLW, PW and LH values have been noted and rainfall values have been estimated using the suggested functional relationship over the site. These rainfall values have been compared with the time averaged buoy data. Fig. 2(a) and Fig. 2(d) shows the comparison between estimated rainfall and buoy rainfall with 1 hour integration time over the Atlantic and the Pacific Ocean, respectively. The comparison has also been made between the two with 2 hour and 3 hour integration time. Fig. 2(b) and Fig. 2(e) respectively shows the comparison between the two with 2 hour integration time over the Atlantic and the Pacific Ocean. Fig. 2(c) and Fig. 2(f) respectively shows the comparison between the two with 3 hour integration time over the Atlantic and the Pacific Ocean.

In order to find out the correlation between the ground truth and that estimated from the functional relations so developed, the two have been fitted against different models, *viz*., linear, cubic, logarithmic, logistic, s, power, compound, inverse, exponential, growth and quadratic. Figs. 3(a-f) show the result of the study. It is found out that the two bear a power relation with 1 hour and 2 hour integration time and an s relation with 3 hour integration time over the Atlantic Ocean [Fig. 3(a), Fig. 3(b) and Fig. 3(c) respectively]. Over the Pacific Ocean, the two bear a cubic relation independent of integration time [Fig. 3(d), Fig. 3(e) and Fig. 3(f) respectively]. The validity of the model is judged by F test at 5% level of significance. This shows that the functional relations so established are able to predict rainfall quantitatively with good accuracy.

4. Conclusions

The study shows that CLW, PW and LH bear significant correlations with each other, and the functional relations are mostly cubic. Surface rainfall is found to be strongly dependent on LH, CLW and PW, and it is possible to estimate surface rainfall on the basis of the above parameters. The applicability of the suggested relationships is two-fold. Firstly, the relationships can be used to estimate the rainfall at a site provided the total columnar CLW, PW and LH values are available over the site. Secondly, as the r^2 values suggest, the functional relationships between the estimated rainfall and ground truth at a site are able to predict rainfall quantitatively.

Acknowledgements

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References

Battan, L. J., and Kassander, A. R., 1960, "Design of a program of randomized seeding of orographic cumuli", *J. Atmos. Sc.*, **17**, 58, 583-590.

Kenneth, P. B., 2004, "Comparison of TRMM prediction retrievals with rain gauge data from Ocean buoys", *J. Climate*, **18,** 178-190.

Khain, A. P., Rosenfeld, and Pokrovsky A., 2001, "Simulating convective clouds with sustained super cooled liquid water down to -37.50° C using a spectral micro physics model", *Geophys. Res. Lett*., **28,** 20, 3887-3890.

Singh, S., 2007, Climatology, Prayag Pustak Bhawan, Allahabad, India, 15-171.

TRMM website, 1998, http://mirador.gsfc.nasa.gov/cgi-in/mirador/presentNavigation.pl?tree=project&project=TRMM