A Study of Dew Water Yields on Galvanized Iron Roof in Kothara (North-West India)

Girja Sharan
D. Beysens
I. Milimouk

W.P. No. 2005-12-05
December 2005

INDIAN INSTITUTE OF MANAGEMENT
AHMEDABAD-380 015
INDIA

A Study of Dew Water Yields on Galvanized Iron Roof in Kothara (North-West India)

G. Sharan[1, 2], D. Beysens[2, 3, 4], I. Milimouk[2, 5]

[1] Indian Institute of Management, 434, IIM Campus, Vastrapur, Ahmedabad - 380 015 Gujarat Ahmedabad (India).

Email : gsharan@iimahd.ernet.in

[2] International Organization for Dew Utilization, 60, rue Emeriau, 75015 Paris (France)

Email : opur@icmcb.u-bordeaux.fr

[3] Equipe du Supercritique pour l'Environnement, les Matériaux et l'Espace, SBT, CEA-Grenoble, 17, rue des Martyrs, 38504 Grenoble Cedex 09 (France)

Email : daniel.beysens@cea.fr

[4] Laboratoire de Physique et Mécanique des Milieux Hétérogènes, Ecole Supérieure de Physique et Chimie Industrielle, 10, rue Vauquelin, 75231 Paris Cedex 05 (France)

[5] Equipe du Supercritique pour l'Environnement, les Matériaux et l'Espace, CNRS - ICMCB, 87, Av. du Dr. Schweitzer, 33608 Pessac (France) Email : im@pmmh.espci.fr

Abstract

In order to determine what amount of dew water can be collected without much investment during the dry season (October –May) in north - west India, a study was performed on plain, un-insulated, corrugated galvanized iron roofs that are common in this rural region. Between October 1, 2004 and May 31, 2005, the cumulative dew yield on a 18 m^2 double - sloped (30°) test roof was 113.5 L. The west side gave 35 % higher water yield than the east side.

The use of thermal insulation and more IR radiative materials would have increased this yield by 40 % (160 L). An analysis of dew events is made with meteorological data. It shows that the variable relative humidity is the most important parameter, which in turn is strongly correlated with the average wind direction with respect to monsoon direction. The cumulative dew water yield (6.3 mm) remains modest when compared with the average rain fall (300 mm). But dew occurs far more frequently than rain and it forms precisely during the dry season when water is most scarce.

Keywords: dew collection, water production, radiative condenser, water vapor.

1. Introduction

Dew water is widely used by plants and small animals where, in arid and semi-arid environment, it provides the necessary amount of water for life to continue to exist and even develop (Gindel, 1965, Steinberger et al, 1989). Dew comes from atmospheric humidity that transforms into liquid water by (passive) radiative cooling (Monteith, 1957; Beysens, 1995). The maximum dew yield that can be expected is of order 0.7 L/m^2 as limited by the available cooling energy (25 – 100 Wm^{-2}) with respect to the latent heat of condensation (2.5 KJg^{-1}). The question whether this water can be used by human population by improving dew water yield has been asked long ago. In the last century, several experiments with large massive condensers produced small water quantities through atmospheric water condensation (Anonymous, 1915; Knapen, 1929; Chaptal, 1932; Jumikis, 1965; Nikolayev et al., 1996). More recently, systematic investigation of high yield radiative materials with hydrophilic properties for drop recovery and adapted condensing architecture was performed with respect to local meteorological parameters as wind speed, wind direction, relative humidity, etc. (Nilson, 1996; Muselli et al., 2002, 2006; Sharan and Prakash , 2003; Beysens et al. 2003, 2005a-b; Berkowicz et al., 2004). For a plane condensing structure the "best" tilt angle with horizontal has been found to be 30 ° (Beysens et al. 2003). The maximum dew yield was measured of order 0.6 Lm^{-2} (Berkowicz, 2004), close to the expected maximum. Although special dew water condensing roofs have been built with success (Beysens et al., 2005d), constructing large practical dew harvesting systems using these is not easily feasible on account of supplementary costs. While efforts continue to bring the costs down, some of the existing buildings – especially their roofs - present opportunity to produce dew water without any financial investment, except a small amount for the collection gear. An additional advantage for the user is that water would be produced right on their own roof top. It is thus the object of this study to determine to what extent the use of already existing roofs can provide a substantial amount of water. If the amount is found to be appreciable, it can easily be enhanced further by insulating these roofs by inexpensive and readily available material (e.g. sawdust).

The place where the study has been carried out is Kothara (φ 23° 14 N, λ 68° 45 E, at 21 m a.s.l, within 20 km from the Arabian Sea, on a gulf (Fig. 1). It is located in the Rann of Kutch area and near the city of Bhuj, in the Gujarat state (main city: Ahmedabad). The location is typical of rural north - west India. Annual rain fall is low (300 mm) and very erratic – the coefficient of variation is 75%. Annual pan - evaporation in comparison is 2000 mm. In other words, the area is extremely arid.

Water is drawn from open wells as most of the population has no access to water at home. The pressure of the population is such that the level of the phreatic aquifer is constantly receding. In addition, salt water is now entering the phreatic zone. Water level in the well in Kothara is now at 60 m from ground level and the amount is very small.

Dew is abundant in this area during 8 – 9 months of the year (from late September to early May). During the other months, the Monsoon season makes the sky cloudy and dew does not form. It is in this season that some rain occurs with number of rainy days being as few as 5 or less.

Fig.1.

There are many buildings in Kutch that use corrugated galvanized iron (GI) sheets for roofing -hay warehouses, factory sheds, cattle barns, occasionally schools, etc. Some condensation is visible over these roofs in the season. It was decided therefore to make systematic measurements on plain, un-insulated, corrugated galvanized iron test roof so as to determine the dew water quantity and frequency and see if the quantity is significant for practical use.

2. The condensing roof

Two sloping surfaces were erected on a triangular framed support as shown in Fig. 2. The ridge is oriented north-south and is at 4m from the ground. Roofing sheet is made of commercially available corrugated galvanized iron of thickness 1.5 mm. The sheet was new with shiny surface with measured IR emissivity 0.23. With aging, these sheets become dull with a slight increase in emissivity to 0.3 after many years. Roof was not insulated.

Roof slope is 30^o, left half - slope (9 m^2 area) towards west, right (9 m^2 area) towards east. There is separate provision of gutter and collection cylinder for each side. Condensate was measured at about 8:00 am (local time: UT + 06:30) each day for one entire season (October 1, 2004 –May 31, 2005). Air temperature and relative humidity, windspeed (5m above the ground) are measured and recorded on site every hour by a data logger. Cloud cover observations were obtained from the Indian Meteorological Observatory, Naliya, 10 km north – east of Kothara.

Fig. 2.

Wind speed is measured at 5 m above the ground. Wind direction data used here was obtained from data logger installed at Suthari, 15 km - west of Kothara. This sensor was also placed 5 m above the ground. Records are for period between November 1, 2004 and May 31, 2005. The terrain between the two sites and in the neighbourhood is flat and lands nearly bare of vegetation; there are no topographical undulations. Thus the wind direction in Kothara is taken to be the same as in Suthari.

3. Dew yield data

The dew yield data are shown in Figs. 3 (evolution) and 4 (histograms) and the statistics are summarized in Table 1. One notes that the dew yields remain modest (they do not exceed 0.18 mm east and 0.24 mm west), as expected from the fact that the roof has a low emissivity and it is not isolated beneath. In addition, the structure is open, which favours air warming from below. The cumulative yield from the west side exceeded by 35% that from the east side. The histograms (Fig. 4) show a clear shift of amplitude in favour of west side. The reason of such a difference can be found in the side orientation with respect to main nocturnal wind and/or orientation with respect to sunrise, the west side remaining longer in the shadow. The wind orientation is discussed below and its main influence is on bringing relative humidity, which concerns both sides. Thus the shadow effect is the main reason and a rough calculation gives a longer dew condensation time of order 20%. Clearly evidenced is a time period where dew does not form, during the months of December and January. The reason of this absence is discussed below when analysing the influence of the relevant atmospheric parameters.

Fig. 3.

Table 1.

Fig. 4.

4. Influence of atmospheric factors

In the following the dew yield is correlated with the main atmospheric parameters: air temperature Ta, relative humidity RH, windspeed V, wind direction and cloud cover N. As the dew duration is not known, only data at 05:00 in the morning have been considered. This time is well representative of dew formation conditions as it is always before sunrise and near the cooler air temperature and maximum relative humidity when dew has greater chance to form.

Climate in north – India is characterized by a prolonged hot and dry season and a mild winter. The main seasons are: (i) summer, from February to May, with wind blowing mainly from west or south-west during nights; (ii) monsoon season, from June to September; (iii) winter, from October to January, where wind is from north or north-east during nights. Day temperatures even in winter are in the neighbourhood of 31 °C and can rise up to 45 °C in the summer. In general, days are dry but the night time humidity is large, especially in the period from March to July. Although the rainy season is nominally four month long, the number of rainy days is generally only about 5 in normal years. The sky does have cloud cover that prevents dew from forming in this season.

4.1. Cloud cover

Night time cloud cover observations were obtained from Indian Meteorology Department, Observatory at Naliya (Kutch), 10 km. north-east of Kothara. Fig. 5 shows the data of total cloud cover over Naliya on the 1^{st},7^{th}, 15^{th}, 23^{rd} and 30th of each month during the period under investigation. Observations of cloud coverage were taken at 20:30 and 23:30. The data show that the sky is generally clear. Cloud cover begins to appear from the month of June and continues through September. Total cloud cover in August and September was found to be 4 Octas. After October the sky is again generally clear.

Fig. 5.

4.2. Temperatures

In Fig. 6 are shown the evolution of air temperature and dew point temperature as calculated from Ta and RH. One notices that the shortfall in dew during December and January is due to a significant deficit in RH that makes dew temperature too far from air temperature when accounting to the cooling possibility of the non -insulated galvanized iron roof. This point is developed below. The reason of this low RH (and somewhat larger windspeed) corresponds to different regime of atmospheric circulation related to seasons, air from north being less humid according to the season (see below Fig. 11). We study in the following the RH influence.

Fig. 6

4.3. Relative humidity

Dew yield is strongly correlated with the temperature difference Ta –Td. Fig. 7 shows the dew yield data correlated with Ta –Td or alternatively with RH as these quantities are nearly proportional in the studied range. The line is a linear fit to

$$h = h'[(Td-Ta) - \Delta T0] . \qquad (1)$$

ΔT0 has the meaning of a maximum cooling temperature and h' of a yield per °C. For west side, ΔT0 = (-2 ± 0.15) °C and h' = (0.10 ± 0.012) mm/°C. For east side, ΔT0 = (-2 ±0.2) °C and h' = (0. 07 ± 0.01) mm/°C (all errors are one standard deviation). East and west side present the same maximum cooling temperature ΔT0 but the west side exhibits a larger yield h'. The dispersion of data means that, although Ta – Td or RH is the main parameter that drives the dew yield, other factors as wind speed, cloud coverage also matter.

The cooling ΔT0 = -2°C is a rather small cooling, as condensers equipped with thermally isolated condensing foil of higher emissivity gives cooling temperatures of order 3.4 – 3.7 °C (Muselli et al., 2006). Assuming that a proper coating and thermal isolation is made so as cooling till -3.5 °C is performed, the number of dew days could increase to 107, resulting in a gain of dew days of 42 %. The gain in water yield, although somewhat less, should remain of the same order of magnitude, corresponding to a cumulated yield of ≈ 9.0 mm (≈ 160 L) in the 8 months period. As a matter of fact, nearly 100 dew days were found on 1 m^2 pilot condensers made of thermally isolated galvanized iron and foil coating.

Fig. 7.

4.4. Windspeed

High windspeed increases the heat exchange by convection and turbulence and prevents dew from forming. In Figs. 8 are reported the histogram of windspeed and the correlation between dew yield and windspeed. In order to correlate with standard measurements at 10 m above the ground, the data are corrected by using the classical logarithmic variation (see e.g. Monteith and Unsworth, 1990):

$$V(z) = V10 \ln(z/zc)/\ln(10/zc), \quad (2)$$

where zc is the roughness length (measured in m) and taken equal to 0.1 m. This value corresponds to an open landscape obstacle of height, H, separated by at least 15 H. Eq. 2 gives V (z = 5m) = 0.85 V(z = 10m).

Most data are obtained for windspeed below 4 m/s (5 m elevation) or 4.7 m/s (10 m elevation) as obtained from the histogram in Fig. 8. The shape of the histogram is similar to found in other places, with a peak for lowest values and a bell shaped curve with maximum near the mean value at 2 m/s (5 m elevation). Compared to other places (Beysens, 2005a; Muselli, 2006), such windspeeds are less than the values found in islands that are clearly higher, with dew harvested till windspeed of 6 m/s at 10 m (3m/s measured at 1 m).

Fig. 8.

4.5. Wind direction

The statistics of wind direction at 05:00 is shown in Fig. 9a, and statistics corresponding to dew events is in Fig. 9b. It is seen that dew forms mainly for wind directed 240° - 360° and 0° – 100° (from SW to NE). It is paradoxical that sea breeze, which corresponds to wind direction between 130° and 310° (SW to NW), does not give rise to the maximum of dew events. However, the 250° direction (SW) corresponds indeed to a peak in dew yields as seen in Fig.10. The number of dew events and dew yield depends primarily of relative humidity and then on the regime of wind corresponding to seasons, as seen in Fig. 11. Relative humidity decreases after monsoon till December, to increase till end of May, when monsoon starts. Accordingly, mean wind main direction increases from 50 ° to 300 °. More than the sea breeze, what mainly matters is the wind regime associated to monsoon. This is an interesting result as it anticipates large dew yields even far from the coastal area.

Fig. 9.

Fig. 10.

Fig.11

5. Concluding remarks

This study of dew yield from conventional, un-insulated, corrugated galvanized iron roofs that are common in north - west rural region of India shows that, with only a small investment in collection gear, appreciable amount of dew water can be obtained. The cumulated yield on a small two sided roof of 18 m^2 area gave during the dew (dry) season 113 L, corresponding to 6.3 mm rain water. This amount is modest when compared with the average rain fall (300 mm). However, water is obtained precisely where people are living and during the dry season from late September to early May when it is most needed. For larger roofs of 100 – 300 m^2 that are common in this region, dew water can provide 600 to 1800 L, a volume that should provide a small but critical water security to the population. This is all the more true as the dew water has been shown to be low mineralized and potable water once disinfected for security (Muselli et al., 2004; Beysens et al., 2005c).

Acknowledgments

Funding support for this work was received from the World Bank and the Gujarat Energy Development Agency, Baroda. Mr Kamalesh Jethava and Mr Shashank Singh provided assistance in data collection. Indian Institute of Management, Ahmedabad provided facilities for work. We thank M. Muselli and O. Clus for their comments and a critical reading of the manuscript.

References

Anonymous, 1915. Proceedings of the inspection of the condenser, which was built in the Feodosia forest, 19.06.1915. French Translation: Rapport CEA-Saclay, 1995, DIST, No. 95002495 (in Russian, manuscript kept in the Feodosian Museum).

Berkowicz, S., Beysens, D., Milimouk, I. Heusinkveld, B., Jacobs, A., 2004. Dew and Fog Collection in a Grassland Area. Proceedings of the Third International Conference on Fog, Fog Collection and Dew, Cape Town, South Africa, October 11 - 15, 2004.

Berkowicz, S., Beysens, D., Milimouk, I. Heusinkveld, Muselli, M., Wakshal, E., Jacobs, A., 2004. Urban dew collection under semi-arid conditions: Jerusalem. Proceedings of the Third International Conference on Fog, Fog Collection and Dew, Cape Town, South Africa, October 11 - 15, 2004.

Beysens, D., 1995. The formation of dew. Atmospheric Research 39, 215–237.

Beysens, D., Milimouk, I., Nikolayev, V., Muselli, M., Marcillat, J., 2003. Using radiative cooling to condense atmospheric vapor: a study to improve water yield. Journal of Hydrology 276, 1–11.

Beysens, D., Muselli, M., Nikolayev, V., Narhe, R., Milimouk, I., 2005a. Measurement and modelling of dew in island coastal and alpine areas. Atmospheric Research 73 (1/2), 1–22.

Beysens, D., Muselli, M., Milimouk, I., Ohayon, C., Berkowicz, S., Soyeux, E., Mileta, M., Ortega, P., 2005b. Application of passive radiative cooling for dew condensation. Energy (in press).

Beysens, D., Ohayon, C., Muselli, M., Clus, O., 2005c. Chemical and bacterial characteristics of dew and rain water in an urban coastal area (Bordeaux, France). Preprint.

Beysens, D., Clus, 0., Mileta, M., Milimouk, I., Nikolayev, V., 2005d. Collecting dew to improve water resources: the D.E.W. project in Biševo (Croatia). Proceedings of 3rd Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems, 5-10 June 2005, Dubrovnik (in press).

Chaptal, L., 1932. La captation de la vapeur d'eau atmosphérique. Annales Agronomiques 4, 540–555.

Gindel, I., 1965. Irrigation of plants with atmospheric water within the desert. Nature 5002, 1173–1175.

Jumikis, A.R., 1965. Aerial wells: secondary sources of water. Soil Science, 100: 83-95.

Knapen, M.A., 1929. Dispositif intérieur de puits aériens Knapen, Extraits des mémoires de la Société des Ingénieurs civils de France (bulletin de Janvier-Février). Imprimerie Chaix, Paris.

Monteith, J.L., 1957. Dew. Quarterly Journal of the Royal Meteorological Society 83, 322– 341.

Monteith, J.L., Unsworth, M.H., 1990. Principles of Environmental Physics, second ed. Routledge, Chapman and Hall, Inc., New York.

Muselli, M., Beysens, D., Marcillat, J., Milimouk, I., Nilsson, T., Louche, A., 2002. Dew water collector for potable water in Ajaccio (Corsica island, France). Atmospheric Research 64, 297–312.

Muselli, M., Beysens, D., Soyeux, E., 2004. Chemical composition of dew water from passive radiative condenser in Corsica Island (France). preprint.

Muselli, M., Beysens, Milimouk, I., 2006. A comparative study of two large radiative dew water condensers. Journal of Arid Environments 64, 54–76

Nikolayev, V., Beysens, D., Gioda, A., Milimouk, I., Katiushin, E., Morel, J.-P., 1996. Water recovery from dew. Journal of Hydrology 182, 19–35.

Nilsson, T., 1996. Initial experiments on dew collection in Sweden and Tanzania. Solar Energy Materials and Solar Cells 40, 23-32.

Sharan, G., Prakash H (2003) Dew Condensation on greenhouse roof at Kothara, Journal of Agricultural Engineering 40:4, October-December 2003 pp 75-76.

Steinberger, Y., Loboda, I., Garner, W., 1989. The influence of autumn dewfall on spatial and temporal distribution of nematodes in the desert ecosystem. Journal of Arid Environments 16: 177–183.

Tables captions

Table 1. Statistics of dew events and dew yields.

Dew days	East side (9 m2)		West side (9 m2)		Total (18 m2)	
	Number	%	Number	%	Number	%
	72	29.6	74	30.5	74	30.5
Yield (day-1)	mm	Liter	mm	Liter	mm	Liter
Min. yield	0.0044	0.040	0.0044	0.040	0.044	0.080
Max. yield	0.1811	1.63	0.2378	2.14	0.209	3.77
Mean yield	0.0745	0.67	0.0979	0.88	0.0861	1.55
Cumulative	5.37	48.3	7.24	65.16	6.30	113.46

Figures captions

Fig.1. The region of the Rann of Kutch (north - west India). The arrow indicates the village of Kothara.

Fig. 2. The roof erected at Kothara for measurement of dew condensation. The arrows indicate the east (E) and west (W) surfaces.

Fig. 3 Evolution of dew yield (in mm) for the west (a) and east (b) sides of the roof.

Fig. 4. Histogram of dew yields for the west (a) and east (b) sides of the roof.

Fig. 5. Cloud cover data N (in Octas) for the year 2004 (black). The year 2005 (grey) is extrapolated from the 2004 data.

Fig. 6. Correlated evolution of dew yield in mm (roof east side: thin black line; west side: bold black line), air temperature Ta in °C (grey line), dew point temperature Td in °C (grey dotted line), windspeed V in m/s (dark grey). The data have been smoothened out.

Fig. 7. Correlation dew yield – Ta – Td (°C, lower scale) or relative humidity RH (%, upper scale) for west (a) or east (b) roof sides. The straight line is a linear fit to the data.

Fig. 8. (a) Windspeed histogram for dew events. (b) Dew yield with respect to windspeed. Roof east side: dots and interrupted lines. Roof west side: open squares and full lines. The bold grey (east side) and black (west side) lines correspond to the smoothening of the data, except for two non representative events at high wind. (Lower scale: measured at 5 m; upper scale: extrapolated at 10 m).

Fig. 9. Histograms of wind direction at 05:00. (a) all data; (b) corresponding only to dew events.

Fig. 10. Dew yield with respect to wind direction (roof east side: x; west side: +).

Fig.11. Evolution of mean relative humidity and mean wind direction.

Fig. 1


PAKISTAN
RANN OF KACHCHH
Map of Kutch
Khavda
Khadir
Lodrani
Bela
N
KORI CREEK
Kali
Lakhpat
Koteshwar
Ghaduli
Panandhro
Narayan Sarovar
Baranda
Chinkatra
Abhyaranya
Mota-no-madh
Ravapar
Hajipur
Bhojardo
Fatehgadh
Rav
Gedi
Rapar
Adesar
Bhimasar
Chobari
Ratadiya
Khari
Sarva
Niruna
Manfera
Adhoi
15
Palasava
Little Rann Of Kachch
Ramvadi
Netra
Khanbhdi
Bhimpar
Hai
Vadasar
Nakhatrana
Lodai
Taper
Wandh
Chitrod
Lakadla
Abdash
Bitta
Desalpar
Rudramata
Bhachau
Samakhiyari
Motara
Chirai
Nayro
Naliya
Vizan
Roha
BHUJ
Lakhapar
Suraj Bari
Jakhau
Rukmavati
Ratnal
Bhimasar
8A
Kothara
Kotdi
Madhapar
Anjar
Sunthari
Kankavati
Godhsisa
Kera
Adipur
Gandhidham
Koday
Asambia
Mota
Patri
To Malia
Sai
Kharod
Nagmati
Gundora
Dumra
Rayan
Tuna
Kandla
Bhadreshwar
RAJKOT
Mundra
Bidada
Mandvi
Map not to Scale
Dew Harvesting Project - IIIMA
JAMNAGAR

Fig. 2

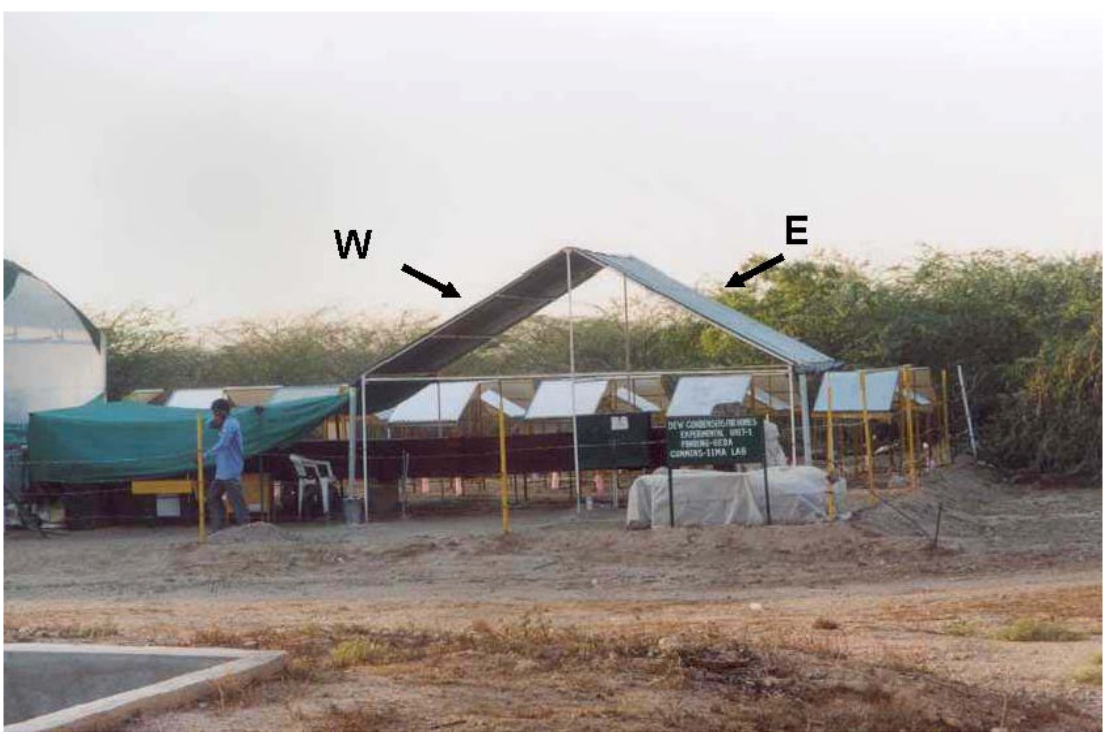

W
E

Fig. 3

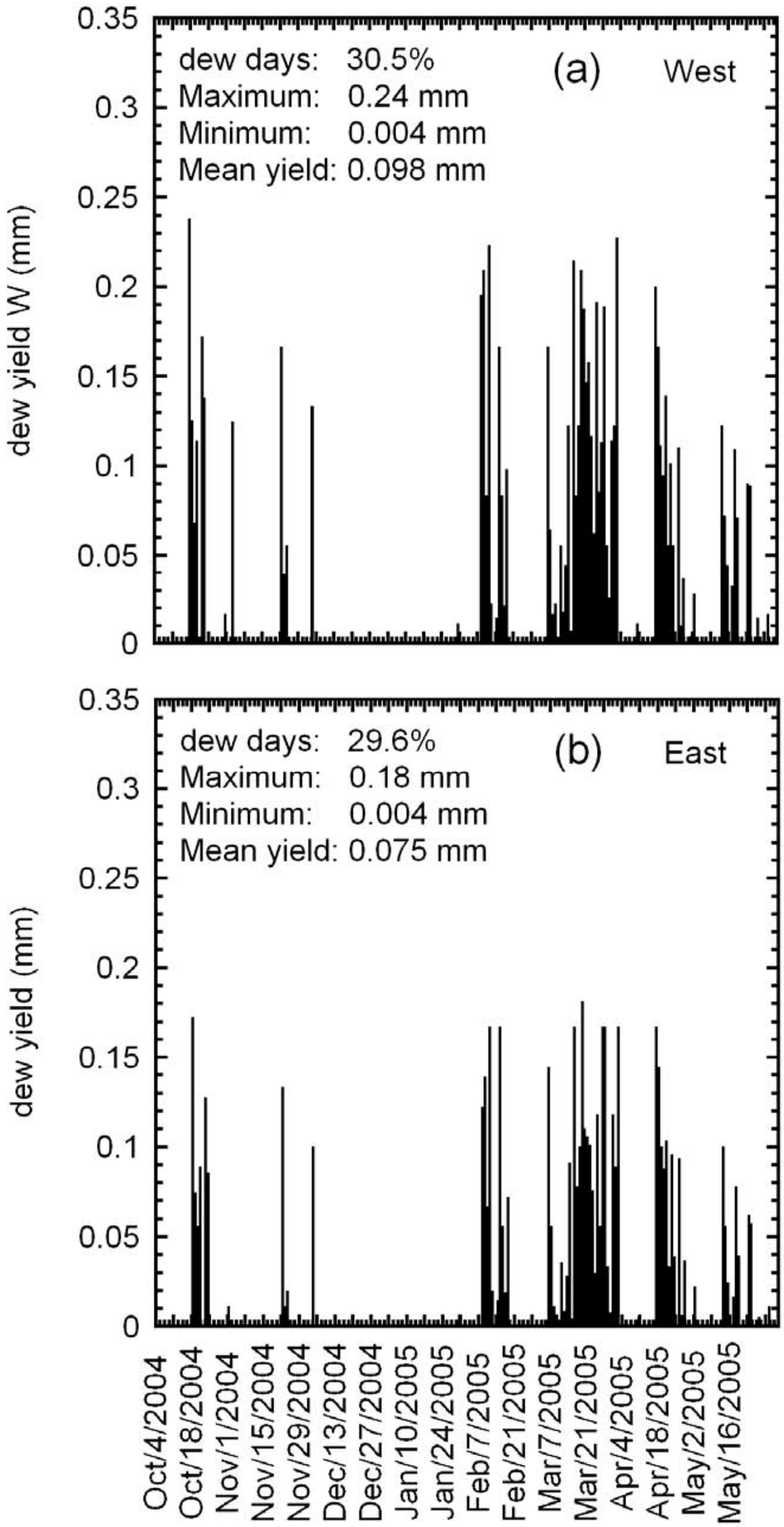

dew days: 30.5%
Maximum: 0.24 mm
Minimum: 0.004 mm
Mean yield: 0.098 mm
(a)
West
dew yield W (mm)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
dew days: 29.6%
Maximum: 0.18 mm
Minimum: 0.004 mm
Mean yield: 0.075 mm
(b)
East
dew yield (mm)
Oct/4/2004
Oct/18/2004
Nov/1/2004
Nov/15/2004
Nov/29/2004
Dec/13/2004
Dec/27/2004
Jan/10/2005
Jan/24/2005
Feb/7/2005
Feb/21/2005
Mar/7/2005
Mar/21/2005
Apr/4/2005
Apr/18/2005
May/2/2005
May/16/2005

Fig. 4

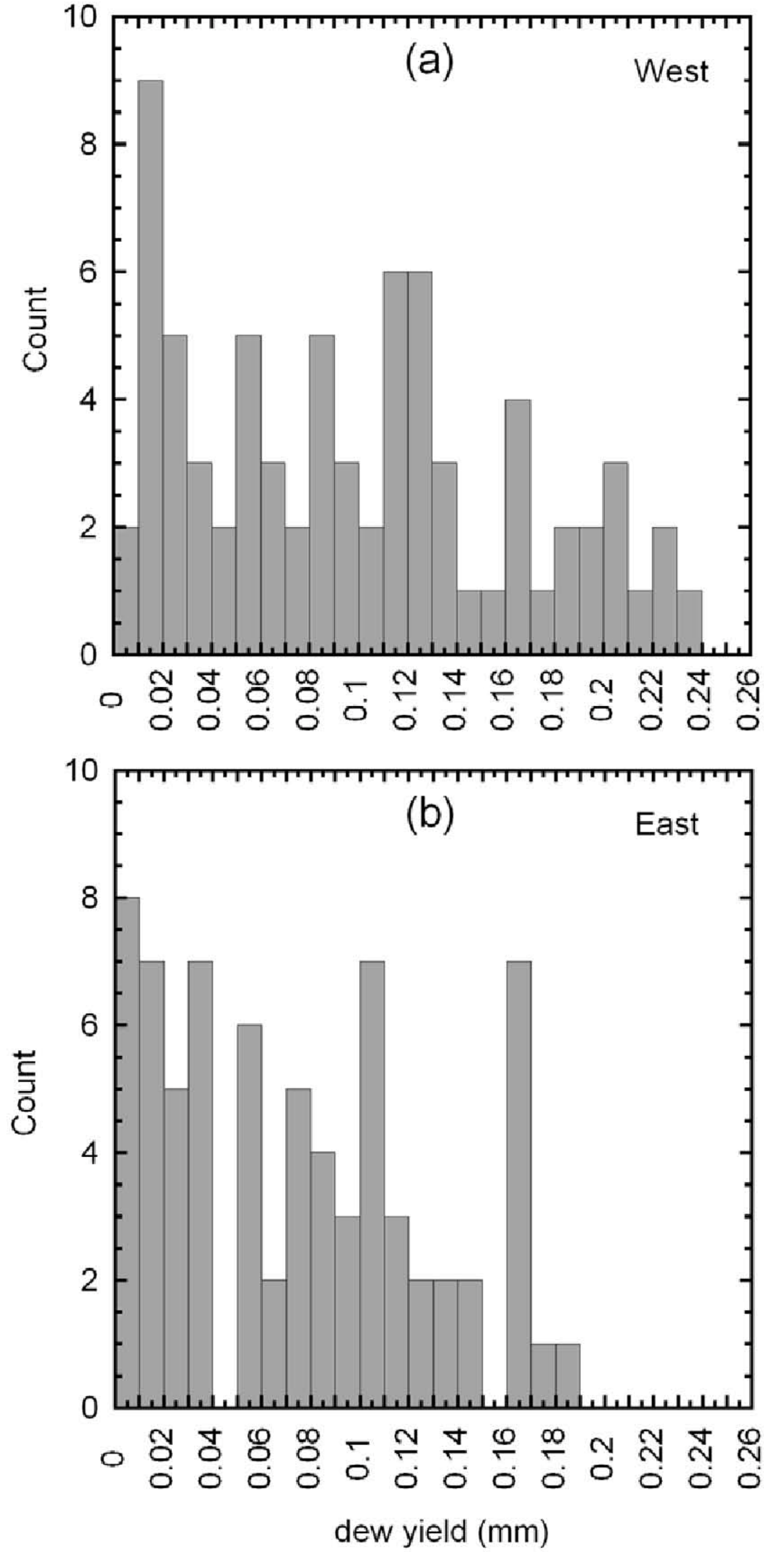

10
8
6
4
2
0
Count
(a)
West
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
(b)
East
dew yield (mm)

Fig. 5

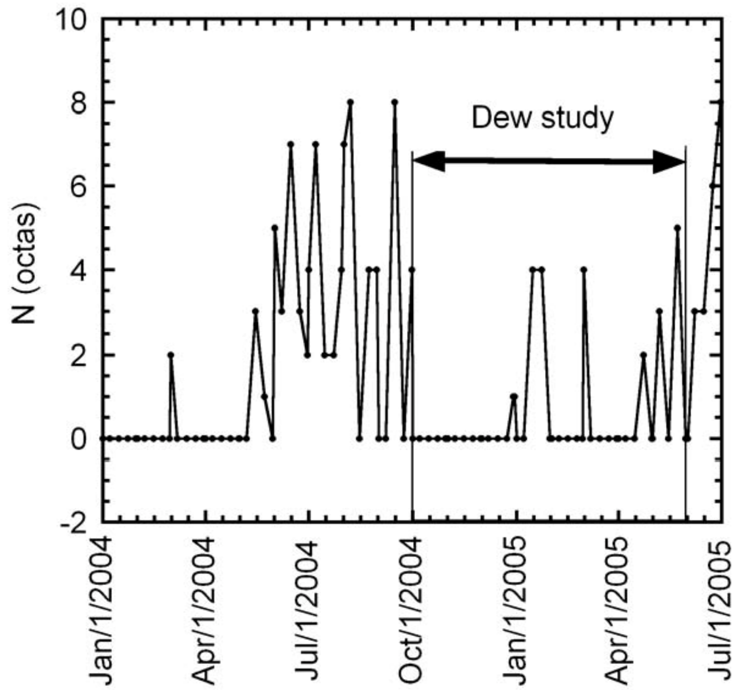

Dew study
N (octas)
10
8
6
4
2
0
-2
Jan/1/2004
Apr/1/2004
Jul/1/2004
Oct/1/2004
Jan/1/2005
Apr/1/2005
Jul/1/2005

Fig. 6.

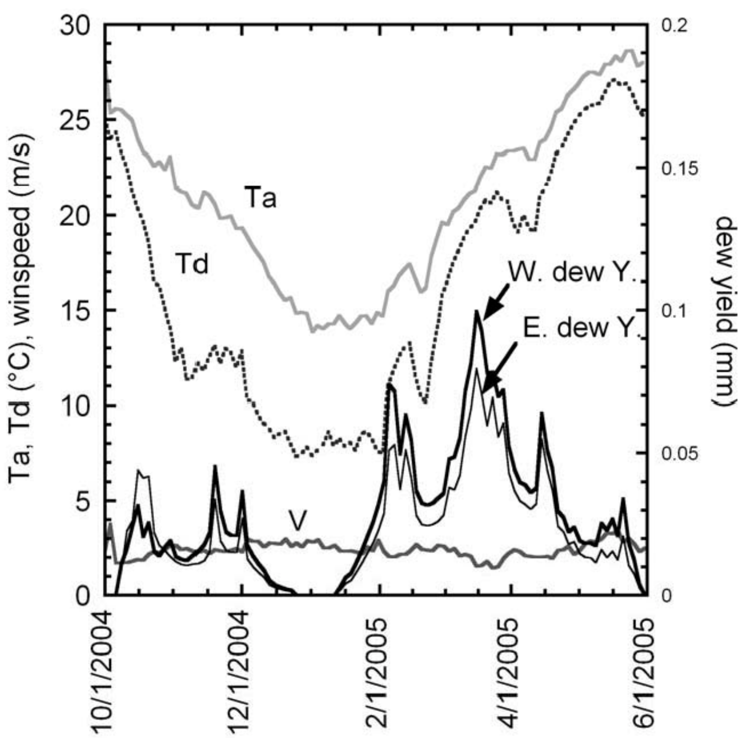
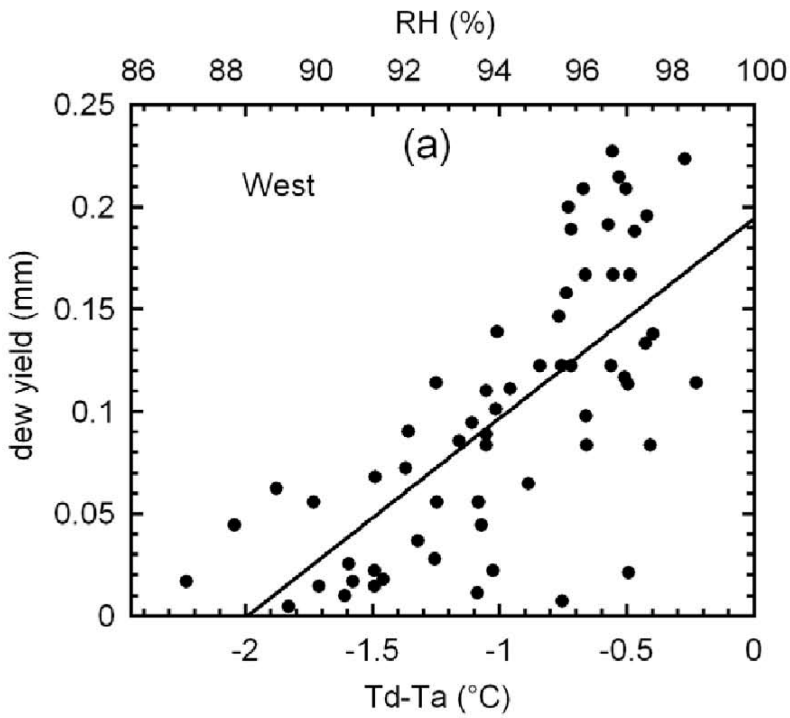

Ta, Td (°C), winspeed (m/s)
dew yield (mm)
Ta
Td
W. dew Y.
E. dew Y.
V
30
25
20
15
10
5
0
0.2
0.15
0.1
0.05
0
10/1/2004
12/1/2004
2/1/2005
4/1/2005
6/1/2005

Fig. 7


RH (%)
86
88
90
92
94
96
98
100
0.25
0.2
0.15
0.1
0.05
0
(a)
West
dew yield (mm)
-2
-1.5
-1
-0.5
0
Td-Ta (°C)

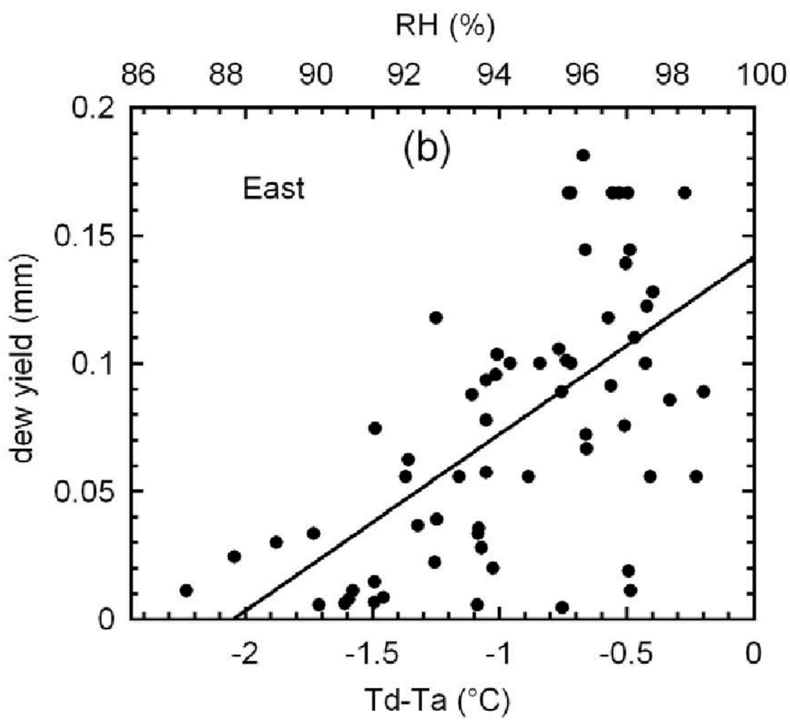

RH (%)
86
88
90
92
94
96
98
100
0.2
0.15
0.1
0.05
0
(b)
East
dew yield (mm)
-2
-1.5
-1
-0.5
0
Td-Ta (°C)

Fig. 8

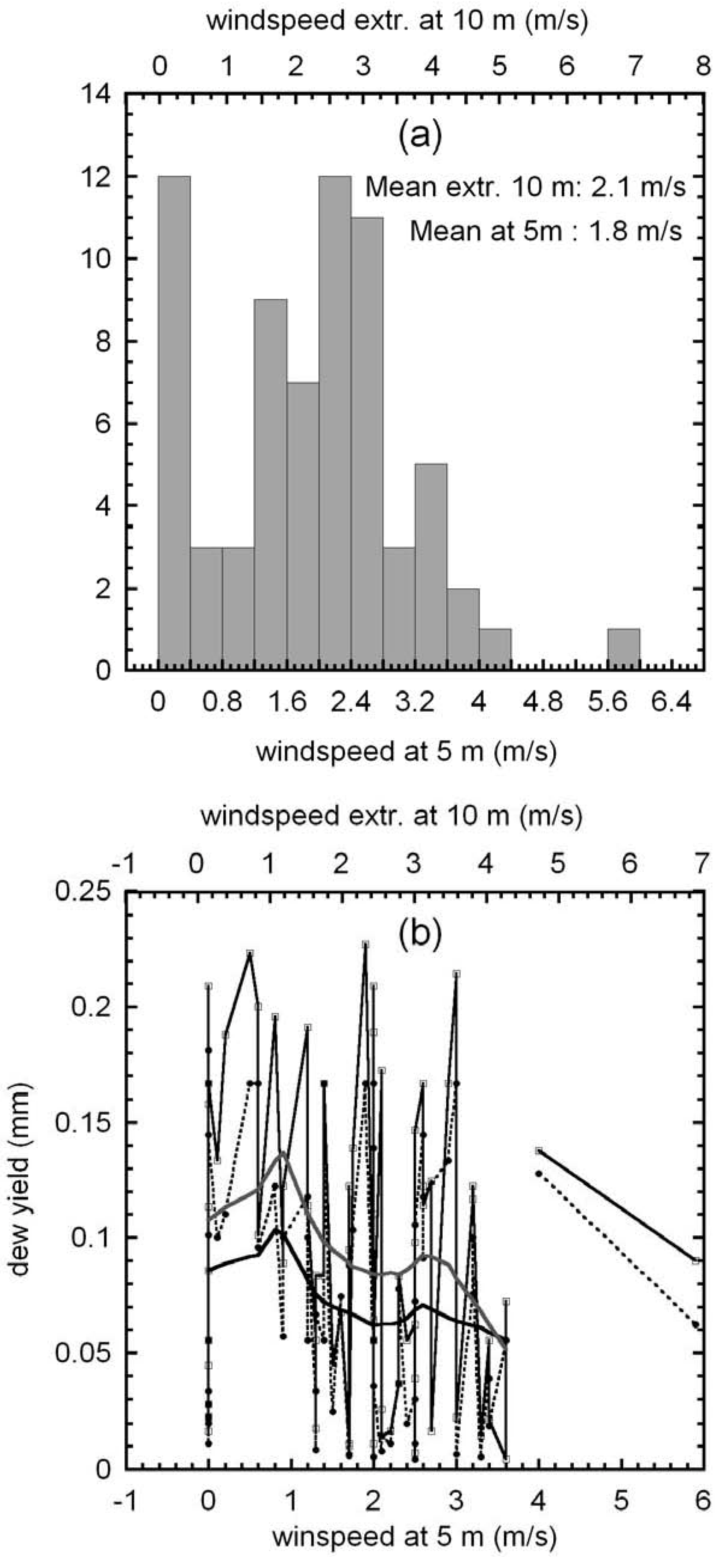

windspeed extr. at 10 m (m/s)
0 1 2 3 4 5 6 7 8
14 12 10 8 6 4 2 0
(a)
Mean extr. 10 m: 2.1 m/s
Mean at 5m : 1.8 m/s
0 0.8 1.6 2.4 3.2 4 4.8 5.6 6.4
windspeed at 5 m (m/s)
windspeed extr. at 10 m (m/s)
-1 0 1 2 3 4 5 6 7
0.25 0.2 0.15 0.1 0.05 0
(b)
dew yield (mm)
-1 0 1 2 3 4 5 6
winspeed at 5 m (m/s)

Fig. 9

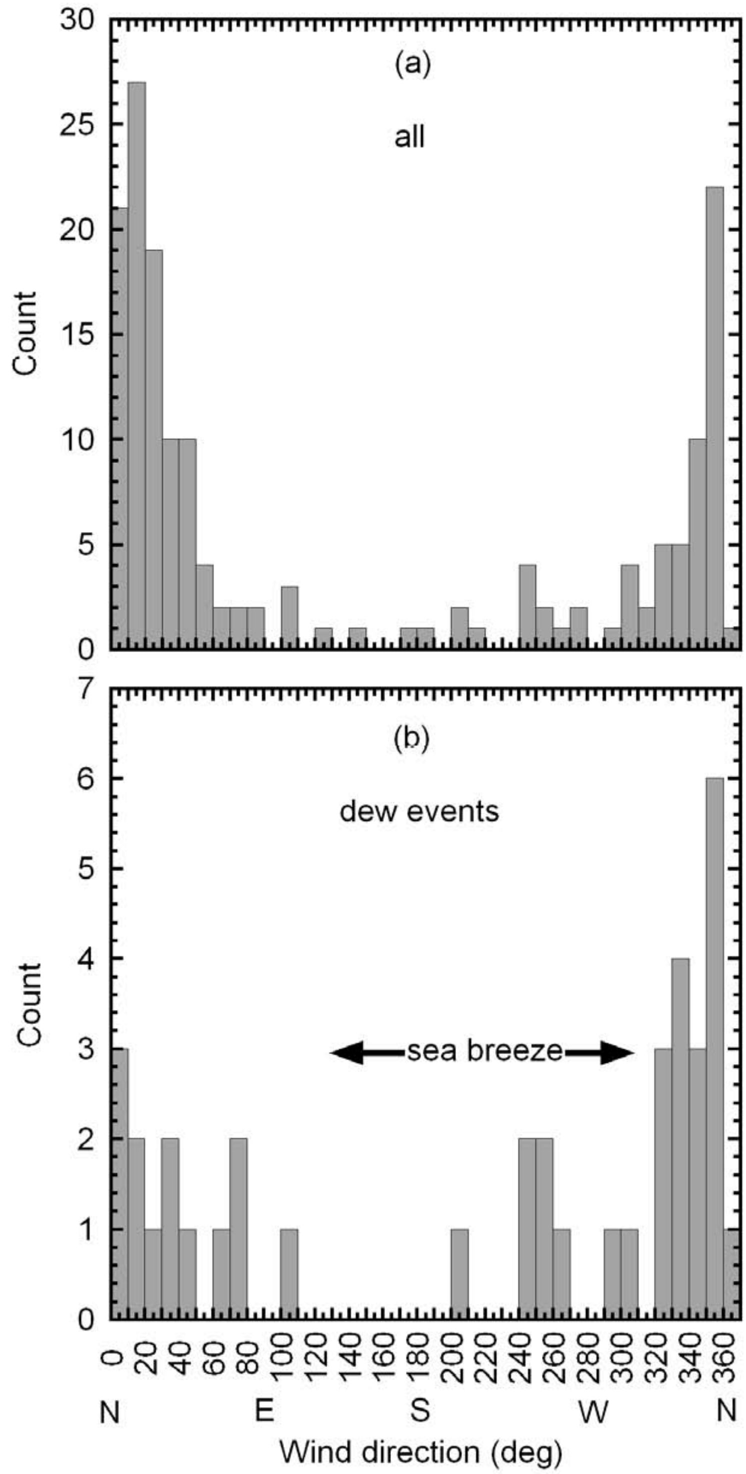

(a)
all
Count
(b)
dew events
sea breeze
Count
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360
N
E
S
W
N
Wind direction (deg)

Fig. 10

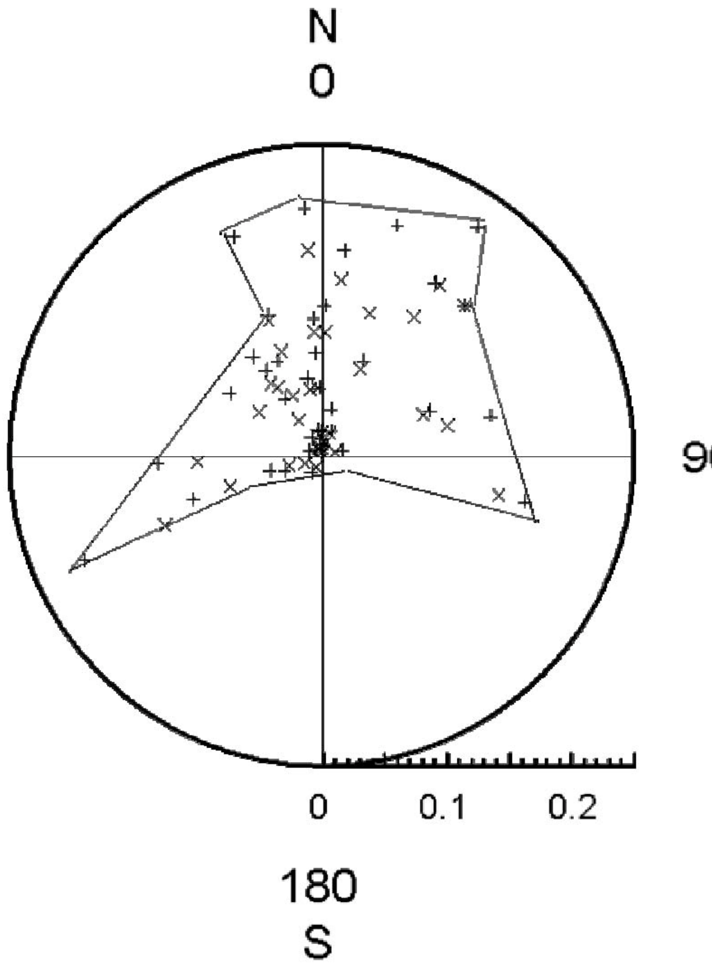
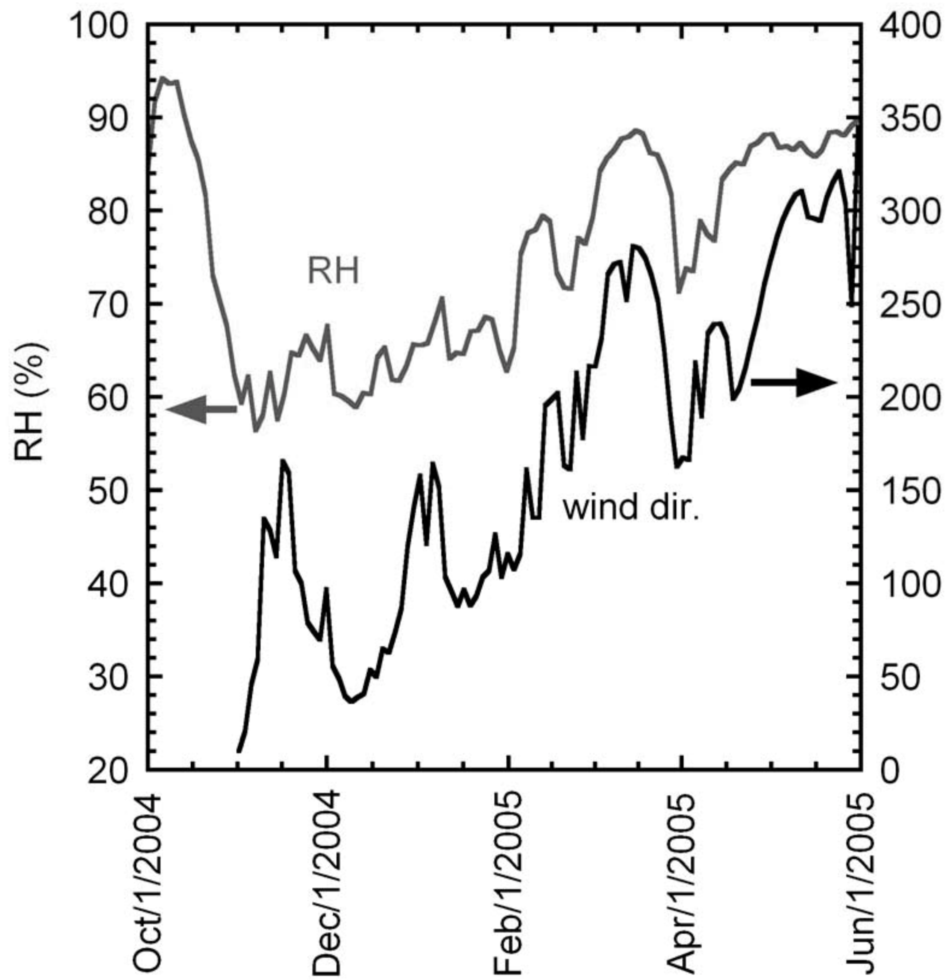


Fig. 11


100
90
80
70
60
50
40
30
20
RH (%)
RH
wind dir.
400
350
300
250
200
150
100
50
0
Wind direction (deg)
Oct/1/2004
Dec/1/2004
Feb/1/2005
Apr/1/2005
Jun/1/2005