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Meteorological conditions at a coastal fog collection site in Peru

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RESUMEN

Durante el periodo junio a noviembre de 1990 se hicieron mediciones meteorológicas en un lugar ubicado a 35 km al norte del centro de Lima, Perú. Estas se enmarcaron dentro de un proyecto para evaluar los volúmenes de agua de niebla que pueden ser colectados. El sitio está a una altitud de 430 m, en la cima de una montaña a 3.5 km de la costa. El promedio mensual de la velocidad del viento en dicho sitio varió de 4.1 m s^{-1} en julio a 5.4 m s^{-1} en octubre. Las velocidades horarias mayores y el más alto pico instantáneo fue de 15.2 m s^{-1} y 16.6 m s^{-1}, respectivamente, y ambos ocurrieron en octubre. El promedio mensual de la dirección del viento fue casi constante a 197°T. La temperatura media mensual subió de 13.1°C en julio a 15.5°C en noviembre y, cuando se comparan estos valores con los registrados en el aeropuerto de Lima (altitud 11 m), implica una tasa de descenso de 0.5°C/100 m en los primeros 400 m de la atmósfera. La humedad relativa promedio estuvo cercana a la saturación desde julio hasta octubre y sólo bajó levemente en noviembre, cuando llegaron las condiciones de mayor sequedad, propias de fines de primavera. Las precipitaciones medidas fueron mínimas, 10.5 mm, aunque significan un incremento sobre el valor climático de 5.9 mm para esos meses registrados como promedio en el aeropuerto de Lima. Estos datos proveen la primera descripción en forma comprensiva de las condiciones en una loma (cerro con vegetación estacional) en la costa de Perú. Ello es importante para la comprensión de cómo esta agua atmosférica se pone a disposición de las plantas y será de gran aporte al diseño y localización de colectores de agua de niebla, los cuales pueden producir agua para forestación en las resecas serranías.

ABSTRACT

Meteorological measurements were made from July through November 1990, at a field site 35 km north of the center of Lima, Peru, during a study designed to assess the quantity of fog water that could be collected. The site was at an altitude of 430 m, on the summit of a low, flat topped, mountain 3.5 km from the coast. The mean monthly wind speed at the site varied from 4.1 m s^{-1} in July to 5.4 m s^{-1} in October. The highest hourly and peak instantaneous wind speeds were 15.2 m s^{-1} and 16.6 m s^{-1}, respectively and they occurred in October. The monthly average wind direction was almost constant at 197°T. The mean monthly temperature increased from 13.1°C in July to 15.5°C in November and, when compared to the climatological values from the Lima airport (altitude 11 m), implied a lapse rate of 0.5°C/100 m in the lower 400 m of the atmosphere. The mean relative humidity was near saturation from July through October and only dropped slightly in November with the coming of drier conditions in late spring. Measured precipitation was a minimal 10.5 mm yet this represented an increase over the climatological value of 5.9 mm for the same months at the Lima airport. These data provide the first comprehensive description of the meteorological conditions on a loma (hill with seasonal vegetation) on the coast of Peru. They further our understanding of how atmospheric water is made available to the plants and will be of great assistance in the designing and locating of large fog collectors, which can produce water for the afforestation and reforestation of the desert hills.

1. Introduction

The west coast of South America, from northern Peru to central Chile, is extremely arid. Lima (12°S) has approximately 10 mm a year of precipitation. This drops markedly as one moves south into northern Chile, where annual precipitation near Arica (18°S) averages < 1 mm. The precipitation then slowly increases until by 30°S at La Serena annual averages are about 70 mm. The aridity results from a combination of subsidence generated by a permanent high pressure area over the Pacific Ocean and the atmospheric stability induced by the cold northward flowing Humboldt Current. These same conditions lead to low cloud decks over the ocean and frequent fogs on the coastal mountains (Prohaska, 1973; Pinche, 1986; Schemenauer *et al.*, 1988). These high elevation coastal fogs are not predictable by conventional meteorological observations of fog occurrence (Cereceda and Schemenauer, 1991) since the observing stations are typically near sea level and several hundreds of meters below cloud base. The primary manifestation of the stability factors noted above is a well developed trade wind inversion that persists throughout much of the year. It inhibits the convective growth of clouds and thus the development of precipitation.

Associated with the low precipitation values is a terrain characterized by sand, rock and minimal vegetation. The exceptions are valleys with small rivers carrying water from the Andes to the sea. The populations of necessity congregate in the valleys, with the intervening areas normally containing only small villages supported by fishing, goats or mining. In such an environment, inadequate fresh water supplies severely constrain the standard of living and the health of the people. This has led to the serious investigation of the high elevation coastal fogs as a water resource in Chile, Peru and elsewhere (Cereceda *et al.*, 1990; Schemenauer and Cereceda, 1991a; Schemenauer and Cereceda, 1992a,b).

In Peru the fog on the coastal mountains is frequently accompanied by drizzle and this combination supports a wet season vegetation on the lomas. The distribution of these lomas and the vegetation types have been studied (e.g., Oka and Ogawa, 1984). Oka and Ogawa remark on the difficulty of obtaining meteorological data from the high elevation coastal areas where fog is frequent. This paper presents the results of a study undertaken in 1990 to document the meteorological conditions on a loma near the north edge of Lima. A subsequent paper will present the results of the concurrent fog collection studies.

2. Field site and instrumentation

The main field site at Cerro Orara was chosen according to established criteria (Schemenauer and Cereceda, 1991b) for fog water collection. Cerro Orara (11°49'S, 77°09'W) is a low, flat-topped mountain 35 km north of the center of Lima. It is only 1.5 km from an area of poor settlements that has a population of 6000 and an extremely limited water supply. It is 3.5 km from the coast, has a maximum altitude of 438 m and a site altitude of 430 m on the northeast end of the ridge (Fig. 1). This was near what was perceived as the daytime cloud base height and probably above the nighttime cloud base. Prohaska (1973) examined the Lima radiosonde data for 1967 and found that from May to November the trade wind inversion was very persistent. The inversion base, which limits the tops of the cloud decks, fluctuated between 300 and 1400 m, with the most frequent occurrences between 600 and 800 m. The base of the cloud decks varied from 150 to 300 m in 1967.

The main field site for this study contained a Campbell Scientific Inc. portable meteorological station, with continuous measurements of temperature (T), relative humidity (RH), wind speed (w_s), wind direction (w_d), solar radiation (R) and pressure (p) being recorded on a data logger. The data were collected from 1 July to 30 November 1990 during the most intense part of the fog season. Data were collected each 5 s, stored as 15 min averages, and combined to form hourly averages. The highest of the 5 s wind speed values was stored as an instantaneous peak value. The site also contained a raingauge, and six fog collectors (Schemenauer and Cereceda, 1991a). Five of the collectors were of standard 1 m^2 size with a base 2 m above the ground. One collector had an area of 0.25 m^2, with a base 2 m above ground. All collectors were vertical surfaces and 5 faced fixed directions. One (omnidirectional) was mounted on a bearing and had a vane to orient it into the wind. One was roofed to shield it to a large extent from drizzle and rain.

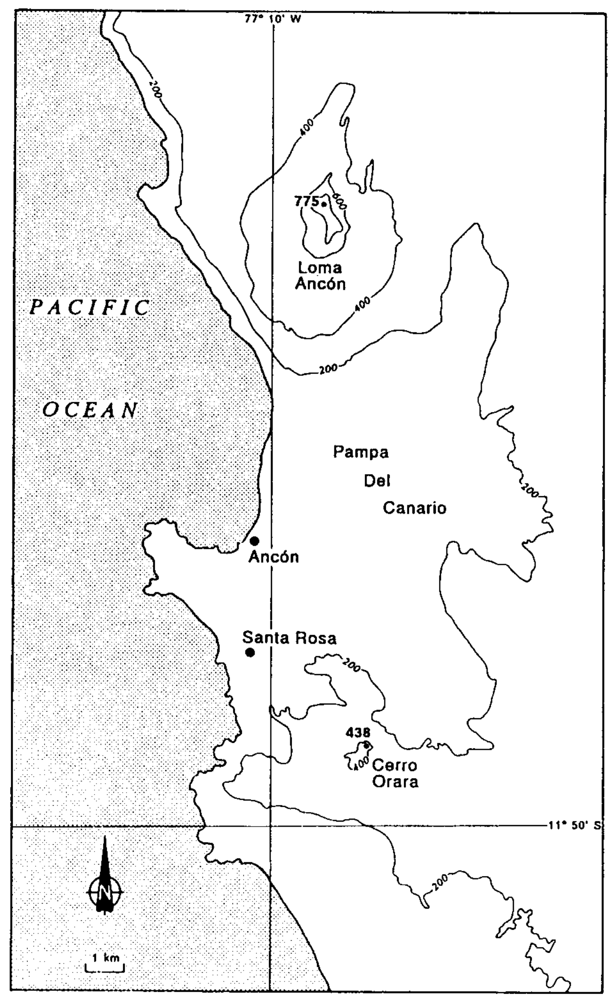

Fig. 1. Map showing the location of the Cerro Orara field site on the coast of Peru, 35 km north of Lima.

3. Meteorological data

Table 1 gives the monthly average w_s, w_d, T, RH, p and R values during the winter to spring transition from July to November 1990. The table also gives the maximum hourly average w_s values and the highest instantaneous (peak) w_s values for each month.

Table 1. Monthly averages of the meteorological parameters at the Cerro Orara, Peru site (elevation 430 m). The maximum 15 minute and peak instantaneous wind speeds for the month are also given.

Month	w_s (m s^{-1})	w_d (°)	T (°C)	RH (%)	p (mb)	R (W m^{-2})	Max w_s (m s^{-1})	Peak w_s (m s^{-1})
July	4.07	199	13.1	95.2	965	97	12.3	13.9
August	4.14	197	12.6	95.1	965	116	11.9	13.9
Sept.	4.36	199	13.5	95.0	965	155	15.0	16.4
Oct.	5.37	196	14.2	94.4	965	167	15.2	16.6
Nov.	4.46	192	15.5	93.5	963	192	13.9	15.0

The average w_s at the site is in the range of 4 to 5 m s^{-1} with a gradual increase from July to October and then a decrease in November. The maximum hourly and peak values follow a similar trend. The average w_s for the entire period was 4.6 m s^{-1}. The maximum hourly average w_s was in October and had a value of 15.2 m s^{-1}. The highest instantaneous value was also in October, 16.6 m s^{-1}. This means that fog collectors put in place, at a site such as Cerro Orara, must be capable of withstanding persistent winds in the 10 to 15 m s^{-1} range, with short term w_s of up to about 20 m s^{-1}. Figure 2 is a plot of the frequency distribution for w_s at the site. The most frequent wind speeds are from 2 to 4 m s^{-1}. They occur 32% of the time. The next most frequent are winds from 4 to 6 m s^{-1} occurring 26% of the time. Only 5% of the hourly average wind speeds had values greater than 10 m s^{-1}. All of the monthly maximum wind speeds occurred between 1445 and 1715 local standard time (LST), with three of the five between 1645 and 1715. One interesting aspect of the wind speed data is that, for high wind situations, the peak instantaneous wind gust in a 15 min period normally only exceeded the mean 15 min wind speed by 10%. The high winds are thus very constant in speed.

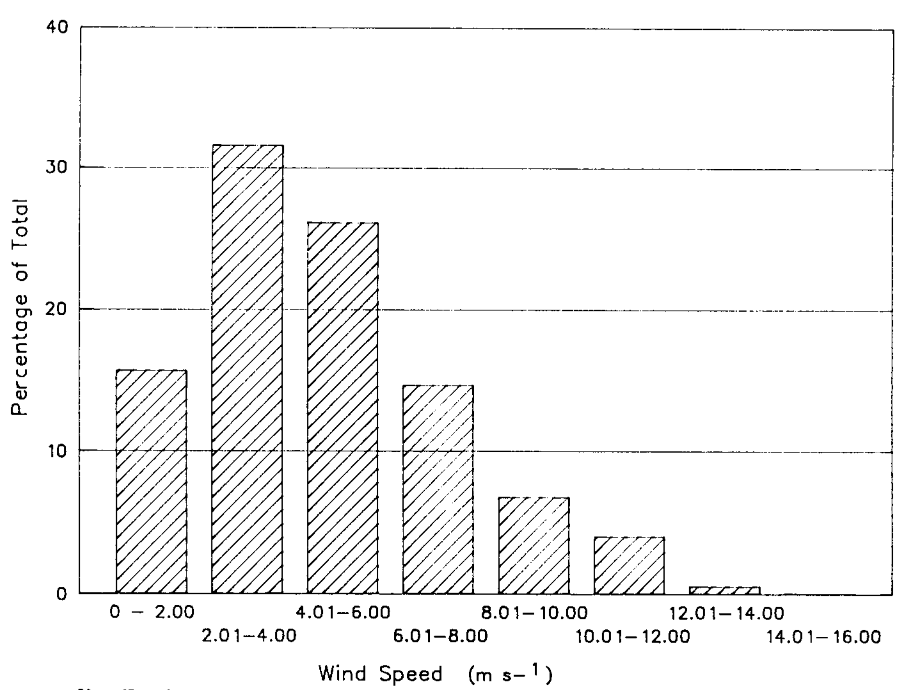

Fig. 2. The frequency distribution of wind speed at the Cerro Orara, Peru fog collection site (11°49'S, 77°09'W; elevation 430 m) for the period July through November, 1990.

Figure 3 shows the average variation of wind speed with time of day for the July to November period in 1990. Wind speeds are relatively constant between 3 and 4 m s^{-1} from midnight to 0900 LST. The minimum hourly wind speed of 3.0 m s^{-1} occurs at 0700 LST. The wind speed increases linearly with time from 0900 to 1700 LST and then decreases in a similar fashion to 2400 LST. The maximum hourly average windspeed of 7.6 m s^{-1} occurs at 1700 LST.

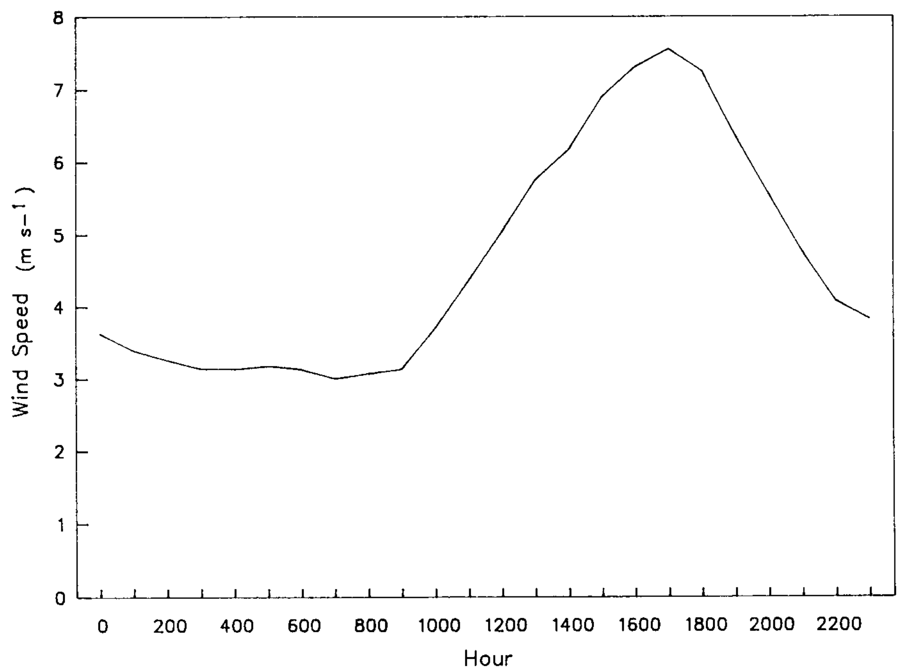

Fig. 3. The diurnal cycle of wind speed at the Cerro Orara, Peru fog collection site (11°49'S, 77°09'W; elevation 430 m), for the period July through November, 1990.

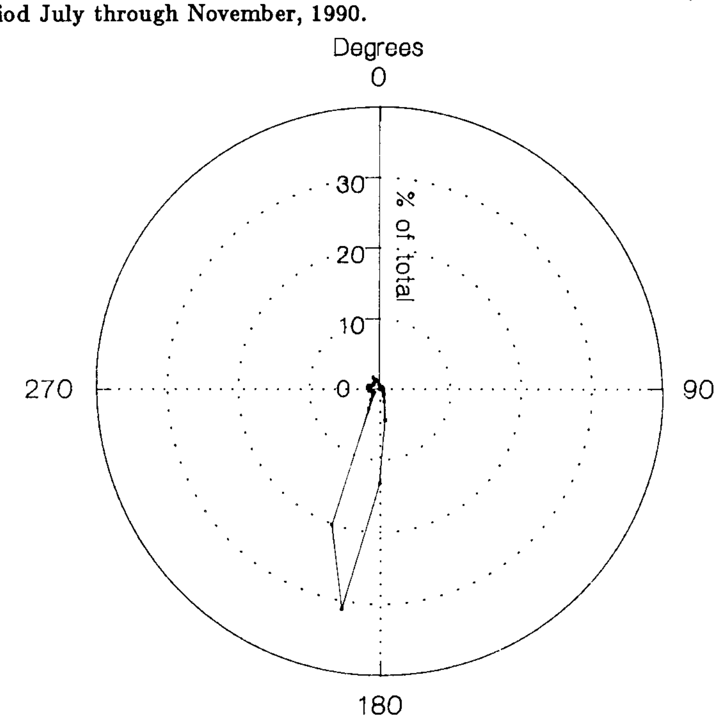

Fig. 4. The frequency distribution for wind direction at the Cerro Orara, Peru fog collection site (11°49'S, 77°09'W; elevation 430 m), for the period July through November, 1990.

The monthly average w_d (Table 1) during the 5 month period was 197°T (degrees true). It was almost constant, varying only from 192 to 199°T. Figure 4 is a plot of the frequency distribution of w_d in 10° steps. It shows there is very little variation at the site; 13% of the occurrences are from 180°; 31% from 190°; and 20% from 200°. The implication is that fixed fog collectors facing SSW will be oriented into the wind under most circumstances. An examination of the data for a single month such as September (not shown) reveals a nearly identical pattern. The average hourly variation in wind direction for the July to November, 1990 period is shown in Figure 5. The persistence of SSW winds throughout the day and the absence of a landbreeze in the evening is clear.

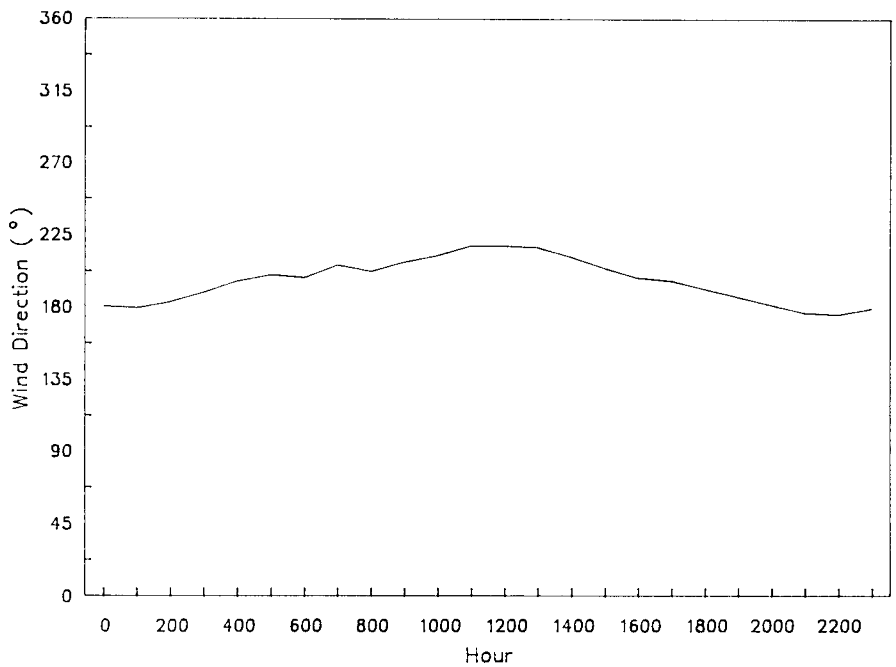

Fig. 5. The diurnal variation in wind direction at the Cerro Orara, Peru fog collection site (11°49'S, 77°09'W; elevation 430 m), for the period July through November, 1990.

The monthly average temperature (Table 1) increases from 13.1°C in July to 15.5°C in November at the site. The minimum temperature measured at the site was 10.7°C at 0800 LST on 24 July. The maximum temperature observed at the site was 21.8°C on 14 November at 1215 LST. The site is very humid at all times with monthly average RH values only slightly under saturation. There is a tendency for the late spring to show slightly drier conditions. The error in an individual RH measurement is about ± 7% at values near 100% and ± 3% at lower values. The monthly means of 720 hourly values should have a precision of approximately $7/\sqrt{N}$ or ± 0.3%. The monthly average pressure at the site was essentially contant at 965 mb.

The monthly average global solar radiation values are given in Table 1 in the conventional manner, i.e. means of all hours including nighttime values. The monthly average values double from July to November. Table 2 gives the maximum hourly solar radiation value for each day with data during the 5 month period. There is considerable variability introduced by the presence of fog at the site and the occasional presence of high cloud. The monthly mean of the maximum daily hourly values increases progressively from July (450 W m^{-2}) to November (805 W m^{-2}). The maximum hourly value increased from July (830 W m^{-2}) to October (995 W m^{-2}) and then dropped slightly in November. The minimum values of the daily maxima increased rapidly from 135 W m^{-2} in July to 305 W m^{-2} in November. The ratio of the minimum to maximum value at the time of peak solar radiation was 0.16 in July and 0.31 in November. This is a considerable change and shows that the reduction of light intensity by the daytime fog is greater in the winter than in the spring. This means that on the foggiest mid-afternoon in July only 16% of the solar radiation passes through the fog, while in November 31% penetrated the fog. These values not only provide information on the optical thickness of the fog, but on the light availability for photosynthesis in foggy coastal environments. There is no comparable low elevation data base on solar radiation published for Peru. Therefore, one cannot know for certain if the maximum values in Table 2 reperesent clear sky values.

Table 2. Daily maximum hourly solar radiation, Cerro Orara, Peru.

Day	July	August	Sept. ($W\ m^{-2}$)	Oct.	Nov.
1	351	445	237	845	-
2	304	833	939	854	-
3	785	506	824	958	-
4	565	494	274	951	-
5	-	506	897	341	-
6	253	776	775	516	671
7	696	245	712	572	962
8	616	611	750	880	725
9	738	830	553	939	973
10	579	839	399	922	923
11	767	621	932	712	839
12	-	-	939	917	923
13	562	-	487	676	716
14	328	182	646	941	960
15	248	710	935	728	434
16	761	892	945	531	860
17	389	858	578	938	930
18	267	148	361	792	303
19	138	273	960	624	817
20	205	341	929	967	903
21	214	232	497	824	595
22	181	386	497	993	915
23	136	199	234	727	502
24	333	-	336	970	833
25	710	-	885	848	920
26	830	-	964	558	927
27	237	-	248	865	907
28	474	-	318	242	929
29	192	-	992	933	715
30	399	-	979	907	938
31	761	478	-	717	-
Average	449	518	667	780	805
Maximum	830	892	992	993	973
Minimum	136	148	234	242	303
Min/Max	0.16	0.17	0.24	0.24	0.31

4. Discussion

In Table 3 the monthly average Lima airport (12°00' S, 77°07' W) meteorological data for the period 1961 to 1970 (Schwerdtfeger, 1976) are given. The airport is at an elevation of 11 m as compared to the Cerro Orara elevation of 430 m. In comparing the data for the months of July to November with Table 1, one sees that the mean pressure at the mountain site is about 50 mb lower and both sites show a slight decrease in pressure from July to December. The monthly mean temperatures are about 2°C lower on the mountain and both sites show an increase in temperature of 2.4°C from July to November. A representative temperature lapse rate in the lower 400 m would therefore be 0.5°C per 100 m. In general, the agreement between the mountain data and the climatological values are excellent when one allows for the changes that would be expected with a 419 m increase in altitude. The air temperature below the inversion base is a function of the sea surface temperature in the wintertime. As long as the extensive cloud cover persists below the inversion base, the direct effect of incoming solar radiation on surface temperatures is small. In 1967, Prohaska (1973) found, from radiosonde observations, an average lapse rate in the marine boundary layer of 0.67°C per 100 m, somewhat higher than in this study.

Table 3. Climatic data for Lima airport, Peru, (12°00'S, 77°07'W; elevation 11 m).

Month	Mean sta. press. (mb)	Temperature (°C) mean			extreme		Mean relat. humid. (%)	Precipitation				Wind	
		max.	min.	daily[2]	max.	min.		mean (mm)	max. (mm)	min. (mm)	max. in 24h (mm)	aver. speed (m s^{-1})[1]	preval. direct.
Jan	1011.5	26	19	21.5	31	15	83	1.2	10.5	-	8.2	3.6	S
Feb	1011.0	26	19	22.3	30	15	83	0.4	2.4	-	1.2	3.1	S
Mar	1011.2	26	19	21.9	29	15	84	0.6	3.4	-	1.9	3.1	S
Apr	1012.1	24	17	20.1	28	11	85	0.1	0.5	-	0.5	3.1	S
May	1013.2	22	16	17.8	27	10	86	0.5	1.7	-	0.9	2.6	S
Jun	1014.4	19	15	16.0	25	8	85	0.8	3.0	-	1.3	2.1	S
Jul	1014.5	18	14	15.3	23	9	85	2.0	8.1	-	5.0	2.6	S
Aug	1014.5	18	14	15.1	23	10	87	2.3	9.6	0.9	3.3	3.1	S
Sep	1014.2	19	14	15.4	22	12	87	1.2	3.7	-	0.7	3.1	S
Oct	1014.0	20	15	16.3	23	13	85	0.4	1.4	-	0.9	3.1	S
Nov	1013.8	22	16	17.7	27	10	83	0.1	0.3	-	0.1	3.6	S
Dec	1012.5	24	17	19.4	28	13	83	0.4	1.5	-	1.5	3.6	S
Annual	1013.1	22	16	18.2	31	8	85	10.0	20.4	3.0	8.2	3.1	S
Rec.[1](yrs.)	10	10	10	30	10	10	10	10	10	10	10	10	10

[1] 1961-1970
[2] 1931-1960

Source: Schwerdtfeger (1976)

The Cerro Orara site had higher relative humidities than the Lima airport averages for the July to November period. The monthly average values at the mountain site were 94 to 95% while the airport values ranged from 83 to 87%. The marine boundary layer is thus very humid throughout it's depth as a result of the persistence of the onshore trade wind flow.

The monthly average wind speeds at Cerro Orara were from 0.9 to 2.3 m s^{-1} higher than at the Lima airport. The range of the mean monthly values at the airport was 2.6 to 3.6 m s^{-1} and on the mountain from 4.1 to 5.4 m s^{-1}. The winds on Cerro Orara show a strong maximum in the late afternoon with the highest average hourly value (7.6 m s^{-1}) occurring at 1700. Hsu (1973) used a simple sea breeze model to estimate the mean speed of the local wind systems in summertime along the major part of the west coast of South America but had little field data to verify the model calculations. The calculations are not directly applicable to the winter and spring data in this study but there is general agreement. The prediction is for daytime values near Lima of 9.8 m s^{-1} and nighttime values of less than 4 m s^{-1}. These are somewhat higher than the measured values shown in Figure 3. It is interesting to note that Hsu (1973) predicts much lower seabreeze speeds of 6 m s^{-1} at latitudes (30°S) comparable to that of the fog collection field site at El Tofo, Chile. Minimum speeds (4.8 m s^{-1}) are predicted for latitudes (18°S) near Arica in the extreme north of Chile.

The trend towards an afternoon peak in wind speed, as is shown in Figure 3, was also found at the El Tofo coastal fog collection site in Chile (Fuenzalida *et al.*, 1989) but the peak hourly value was somewhat lower in Chile, falling between 5 and 6 m s^{-1}, as compared to 7.6 m s^{-1} at the Cerro Orara site in Peru. The Chilean site at 780 m was also different in that it frequently experienced calm winds in the late evening and early morning associated with a shift in wind direction from the daytime seabreeze to the nighttime landbreeze. At the Cerro Orara site in

Peru, the seabreeze persisted throughout the evening and had a minimum average hourly value of 3 m s^{-1}.

The comparison between the meteorological conditions at the fog collection sites in Chile and Peru is important to make since the meteorology controls the rate at which water can be collected. Fuenzalida *et al.* (1989) note that at the El Tofo fog collection site in Chile, the maximum observed solar radiation (with the same sensor) is 1140 W m^{-2} in December. This is a similar value to that observed at the Peruvian site. The more southerly latitude (30°S) in Chile is presumably compensated for by the higher elevation (780 m) of the Chilean site. Table 4 is a brief summary of the meteorological conditions at the Chilean fog collection site for two weeks in November 1988. A comparison to the November data for the Cerro Orara site in Peru (Table 1) shows that the wind speeds are twice as high in Peru (4.5 m s^{-1}) than in Chile (2.1 m s^{-1}), the Peruvian site is warmer at 15.5°C than the Chilean site at 14.1°C, the Peruvian site is more humid at 94% versus 87% in Chile, and the mean pressure is higher in Peru (963 mb) than in Chile (924 mb) reflecting a lower altitude. The highest instantaneous wind speed in Chile during the period was 9.4 m s^{-1}, which is considerably lower than the 15.0 m s^{-1} peak gust recorded in Peru. The maximum hourly solar radiation value was similar at the two sites, 1050 W m^{-2} in Peru and 1070 W m^{-2} in Chile.

Table 4. A summary of the meteorological conditions at the El Tofo, Chile fog collection site (29°26'S, 71°15'W; elevation 780 m) for the period 1 to 13 November, 1988. The maximum and minimum hourly values and the peak instantaneous wind speeds for the period are also shown.

Parameter	w_s (m s^{-1})	T (°C)	RH (%)	p (mb)	R (W m^{-2})	Peak w_s (m s^{-1})
Average	2.1	14.1	87	924	225	2.8
Maximum	6.0	20.5	100	928	1070	9.4
Minimum	-	9.4	48	921	-	-

The prevailing wind direction was listed as south at the Lima airport in each month, while on the mountain it varied slightly from 192 to 199°T. The mean direction for the five months of study was 197°T (SSW). Historical wind data for an earlier period (1957-1962), quoted by Prohaska (1973), also show a small onshore component to the wind at the Lima airport, which is enhanced slightly in the afternoon. Prohaska states that 74% of the winds at the airport were from the south and southeast, which is basically along the coast (Figure 6) with a small onshore component. Oka and Ogawa (1984) inferred the prevailing wind direction during the winter fog season at Loma Ancón from the vegetation pattern on the hillside (the loma is just north of the city of Ancón, Figure 1). They found the vegetation was on the southwest side of Loma Ancón in both 1961 and 1980, indicating the wind was from that direction. This is in good agreement with the measured wind in this study at Cerro Orara 10 km to the south. Oka and Ogawa also plot wind roses for the Campo de Marte station in Lima for July 1971 and July 1980. This station shows that southwest winds dominate at all hours of the day.

Figure 6 shows a section of the coastline of Peru near the Cerro Orara site. A wind vector at 197°T has been drawn on the figure. It clearly shows the onshore nature of the mean wind at the site. The wind passes over La Isla San Lorenzo (35 km upstream of the site) and over approximately 5 km of shoreline before arriving at the site. During a period with a more southerly flow, the wind will pass over the Lima urban–industrial complex as well as the PetroPeru refinery before reaching the site. The chemistry of fog water collected at this location should be examined carefully before being used as a domestic water supply, though initial indications (Schemenauer and Cereceda, 1991c) are that the water collected in an operational program could meet drinking water standards.

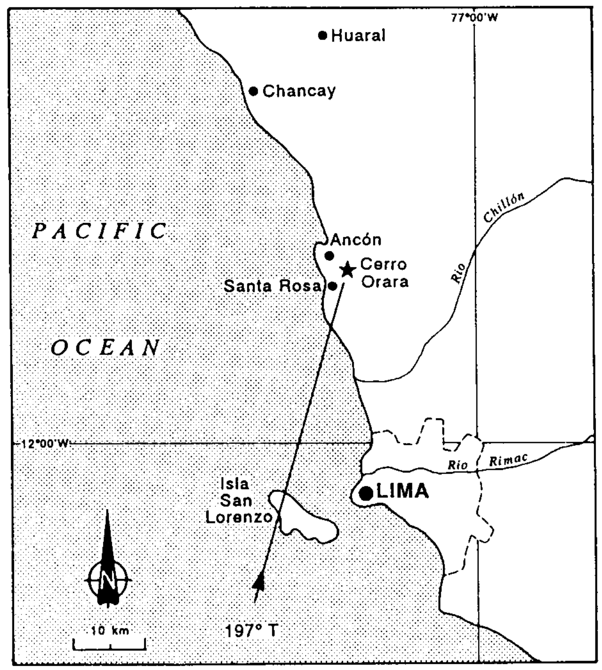

Fig. 6. The coast of Peru south of the Cerro Orara field site showing the direction of the mean wind, 197°T.

According to the climate data (Table 3), total precipitation for the July to October period averages 5.9 mm at the Lima airport, while at Cerro Orara itself a value of 10.5 mm was measured in 1991. One might expect higher precipitation values on the mountain, since in the fall to lower elevations some precipitation would be lost to evaporation, but such a brief data set cannot confirm this for coastal Peru. Prohaska (1973) quotes Roessl (1967) as having determined that the lomas receive 100 to 200 mm of drizzle (garúa) during the winter season. The present study does not support such a high precipitation value for the coastal hills. There may, however be a downward trend in annual precipitation that influences such comparisons. Oka and Ogawa (1984) show a clear decrease in the annual and winter precipitation for the period 1951 to 1980 at the Campo de Marte site in Lima.

A study of coastal fog frequencies in Chile (Cereceda and Schemenauer, 1991) has shown conclusively that one cannot predict fog frequencies on the coastal mountains using observations of fog occurrence at low elevation meteorological stations. In Chile, specialized observations near 28°S have documented that fog is present on about 50% of the days in the year at altitudes of 700 m. In addition, there is patchy fog present on another 25% of the days. Similar observations were not available for the Cerro Orara site in Peru but the actual collection of fog water by the 1 m^2 collectors was recorded. When fog water is collected, the visibility is normally less than 100 m, there are moderate winds and moderate liquid water contents in the fog.

Details of the measured fog frequencies and amounts are given in subsequent publication. Fog was collected from the omnidirectional collector on 91% of the days from 2 August to 15 December, 1990, with half of the days without fog occurring in the last three weeks of measurements. Quantitative data are missing for the early part of the winter (June and July) but it is expected that the fog frequencies would be as high or higher. Prohaska's (1973) data for the winter (June through September) of 1967 show that Lima had overcast skies on 90% of the days. This low overcast would produce fog on the coastal hills.

5. Conclusions

The meteorological data presented here have led to a better understanding of how atmospheric water is delivered to the coastal hills of Peru. The lomas near Lima experience almost daily fogs from June through December. These fogs, and the garúa (drizzle) that sometimes accompanies them, support a seasonal vegetation cover. During the dry season, the vegetation dies off, or enters into dormancy, and the herbaceous plant matter largely disappears leaving only a darkening on the hillside. The fog droplet sizes and fog liquid water contents were not measured at the Peruvian site but data collected at sites in Chile (Schemenauer and Joe, 1989) and Mexico (García–García and Montañez, 1991) may provide some indication of the conditions to be expected.

Even though the garúa may only amount to a few mm of precipitation in the lomas, it is sufficient to wet the ground and to accumulate in low lying areas. This most likely leads to the initiation of the plant growth. Once the plants are growing, they can acquire additional water by collecting the small droplets of water in the fogs, which impact on the vegetative surfaces. The measured mean wind speed at the Cerro Orara site of 4.5 m s^{-1}, and an assumed fog liquid water content of 0.2 g m^{-3}, would mean that there is about 1 g of water in the form of droplets moving through each m^2 of space above the lomas per second during the June through December period. The collection of this water, plus conditions of near 100% humidity, support plant growth into the spring even after the garúa stops. As one progresses into spring, the fogs become less thick and less frequent, and plant growth eventually stops. On the foggiest day in July only 16% of the maximum possible solar radiation was reaching the ground. On the foggiest day in November 31% was reaching the ground. This progressive increase in solar radiation results in higher temperatures and lower humidities and ultimately to conditions that will not support the vegetation.

This work has application both in the understanding of the lomas, which extend more than 1000 km along the coast of Peru, and in the development of arrays of artificial fog collectors to provide water in this arid region. This water can be used for afforestation, agriculture or domestic purposes. The applications for fog collection technology also extend far beyond the borders of Peru. As Schemenauer and Cereceda (1991a) have shown, the conditions may be suitable for its use in such far flung locations as California, the Canary Islands, Chile, Mexico, Namibia and the Sultanate of Oman.

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