Relative humidity patterns and fog water precipitation in the Atacama Desert and biological implications

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[1] Fog is the most important source of water for native plants and biological soil crusts in the Atacama Desert. Since fog depends upon available moisture, an understanding of climatic patterns is essential to interpret its present-day occurrence and distribution. In this work, temperature and humidity of ambient air and collected fog water in selected sites were studied across a transect from the coast to inland of the Atacama Desert, by using automated outdoor sensors for temperature and relative humidity, and also fog collectors equipped with automated rain gauges to measure collected fog water flow rates. Field measurements were organized to determine fog and collected fog water patterns at three selected sites, namely, Coloso, Inacesa and Yungay in addition to the relative humidity and temperature variation with altitude at Coloso Mountain located within Coloso site. The results show a decreasing trend in the collected fog water flow rates from the coast toward inland locations. Daily thermal oscillations at each site are closely related to fog water collection. At Coloso Mountain, an adiabatic cooling-like effect of the wind ascending its slope was observed preferentially during nighttime. At daytime, occasional distortions observed in the temperature profiles are probably produced by a thermal driven-air convection process along the Coloso Mountain slope heated by solar radiation. The reduction in available water from fog from the coast to the inland site is consistent with the reduction in colonization rate for hypolithic cyanobacteria along this same transect.

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1. Introduction

[2] In most areas of the Atacama Desert fog that takes place regularly provides the main source of water for the endemic life forms dwelling on the soil surface. In contrast, rain contribution in this area is reduced to very short measured quantities not exceeding 1.5 mm per year in the cities of Arica, Iquique and Antofagasta. Heavy rainfall is a very rare event. Between 1916 and 1999, Antofagasta was affected by alluvial events in seven opportunities, the most important being in 1940 and 1991. In all cases, the rains occurred during the winter period of the development phase of El Niño events [*Vargas et al.*, 2000]. There is some evidence that El Niño events that bring rain to the coast do not reach inland sites [*McKay et al.*, 2003].

[3] In various coastal locations where isolated mountains or steep coastal slopes intercept the clouds, a fog-zone develops. This moisture allows the development of plant communities termed lomas formations and biological soil crusts [*Rundel et al.*, 1991; *Moore*, 1998]. Since fog is dependent upon available moisture, an understanding of climatic patterns of temperature and humidity is essential to interpret its present-day occurrence and distribution.

[4] The decreasing native and biological soil crust [*Moore*, 1998] density from the coast toward the inland Atacama desert is associated to the decreasing occurrence of humidity in the air giving rise to places with extreme aridity conditions which are of considerable interest as an analog to the Martian surface [*McKay et al.*, 2003; *Navarro-Gonzalez et al.*, 2003]. Throughout the Atacama Desert in Chile north of about 26°S rain is negligible in terms of biological processes and the distribution of soil microorganisms is defined by the occurrence of fog. The "Mars-like" soils [*Navarro-Gonzalez et al.*, 2003] occur in locations where high coastal mountains block the penetration of the marine fog. *Rech et al.* [2003] have confirmed the lack of penetration of marine fog in these areas based on sulfur isotopes. Thus the extent of zone of "fog shadows" of the coastal range is of interest in studies of the response of microbial life to extreme dryness.

[5] In the absence of precipitation, different strategies to collect water from humid air are exhibited by organisms

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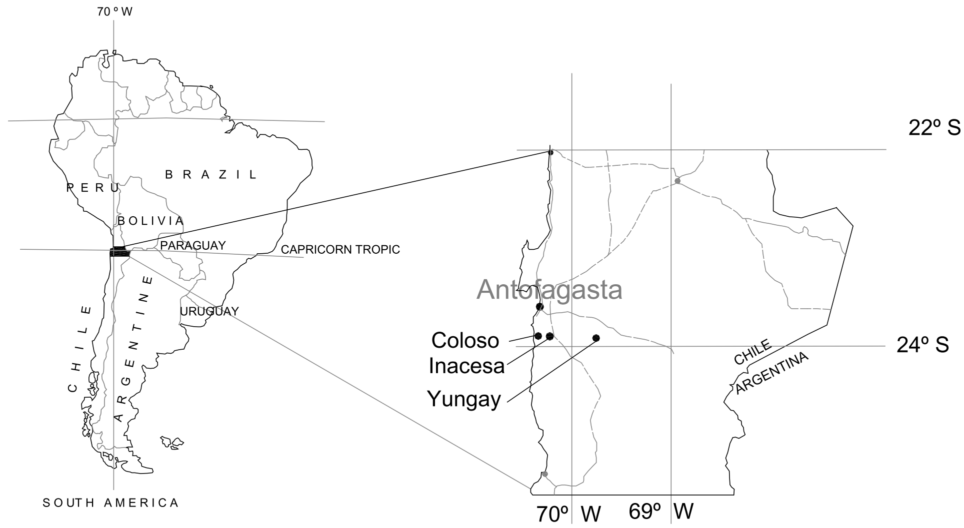

Figure 1. Experimental site locations at northern Chile. Coloso a coastal site 15 km south from Antofagasta city. Inacesa and Yungay located at 8 and 45 km from the coast, respectively. All locations lie alongside 24°S parallel approximately.

existing in desert areas [*Le Houérou*, 1998]. Some isolated stands of trees in desert regions, such as Chile's Fray Jorge National Forest have been sustained for millennia by fog-derived water [*Canto*, 1998]. Because of their dense small leaves forming spatial geometry with a high specific area, some plant and trees species are very efficient at collecting fog water droplets. In the Yungay station located in the extreme arid core of the Atacama Desert, Tamarix (*Tamarix Gallica*) trees, exhibits a remarkable efficiency in collecting fog water. A group of 25 trees planted in 1990 and irrigated only during the first 2 years, were able to survive until now only by fog water intercepted by its dense foliage (Indes, 2002). Movement of water from the groundwater table situated at 20 m deep by upward diffusion is precluded by several layers of alternate impervious clay in the Yungay soil profile. The diurnal temperature oscillation is the cause of fog in this inland location [*McKay et al.*, 2003].

[6] In 1938 first studies about artificial water collection on metal surfaces, begun in Kent Island, Canada [*Cunningham*, 1998]. Later, in 1951 the standard design of fog water collector in current use was developed from studies on fog water collection in Antofagasta, Chile [*Garró*, 2006]. The original idea was to induce water droplet collection and/or precipitation on solid obstacles of different configurations placed in the stream path of air containing water-fog at selected coastal locations. These obstacles referred as 'fog collectors' evolved to a current design consisting in plastic nets or threads fixed in rigid frames positioned to face into the predominant winds. Nowadays, fog collectors are widely used around the world [*Olivier*, 2004; *Schemenauer and Cereceda*, 1992, 1994].

[7] The potential for extracting water from fog is a function of the amount of water it contains, how often it occurs; and wind speeds. Its frequency of occurrence depends on regional atmospheric circulation, the temperature of the ocean water and the stability and intensity of the thermal inversion processes. If the climatic phenomenon that produces fog is stable, fog will form regularly. In the northern coast of Chile, the conditions that produce fog occur throughout the year, although they are more intense during the winter and spring months and less during summer and autumn [*Cereceda et al.*, 2002].

[8] All the research activity and projects on fog water collection in northern Chile has been focused on specific coastal locations at altitudes between 600 and 1200 m a.s.l. where the presence of fog is more intense and durable. In these locations the averages of the reported water range between 1 and 15 L m^{-2} day^{-1}. A comprehensive description on fog research in northern Chile has been provided by *Larrain et al.* [2002]. One of the largest fog collection projects has provided, since March 1992, an average of 11 m^3 day^{-1} of potable water to a village of 330 people in the northern coast of Chile [*Schemenauer and Cereceda*, 1994].

Table 1. Geographical Location in UTM Coordinates (Datum PSAD-56, South America) of the Selected Experimental Sites

SITE	UTM COORDINATES (ZONE 19)		ALTITUDE, M	SITE AND TYPE OF EXPERIMENTS
1	348020 E	7364448 N	202	Coloso, Temp and RH patterns
2	348303 E	7364504 N	320	Coloso, Temp and RH patterns
3	348722 E	7364657 N	490	Coloso, Temp and RH patterns
4	348183 E	7366386 N	976	Coloso, Temp and RH patterns
5	348696 E	7363958 N	500	Coloso, Fog water collection
6	359016 E	7362105 N	560	Inacesa, Fog water collection.
7	397952 E	7334009 N	1050	Yungay, Fog water collection

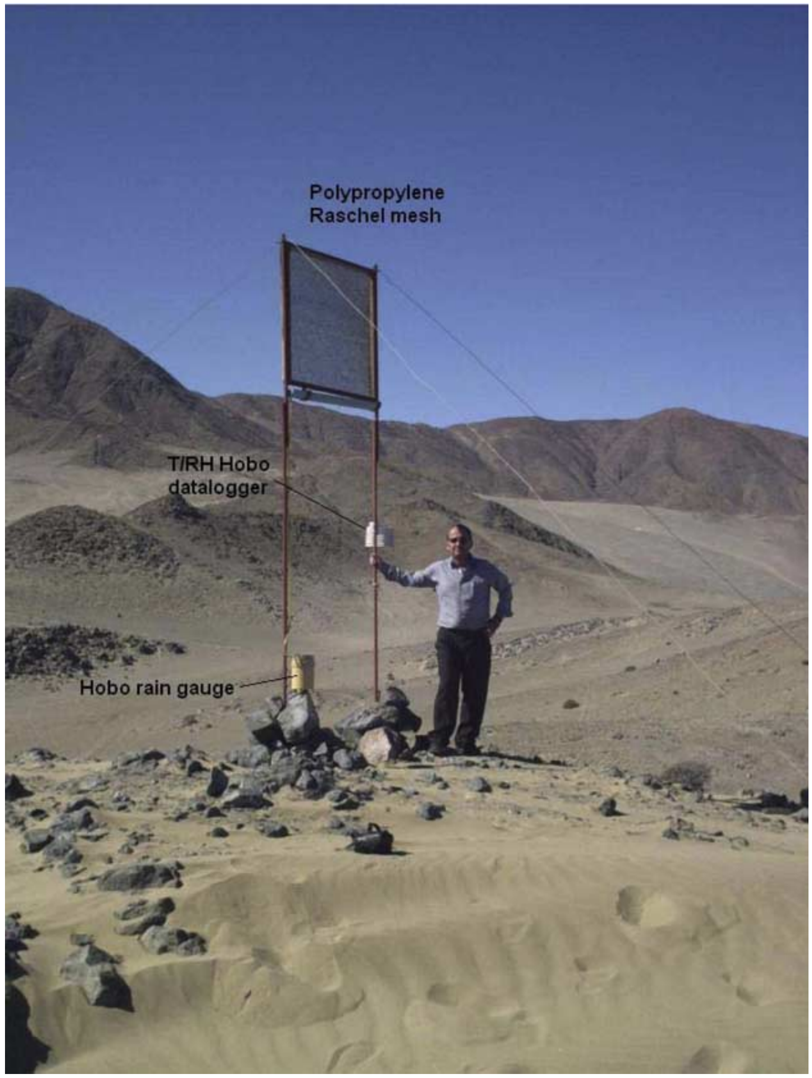

Figure 2. Fog water collector apparatus consisting of a frame to secure a standard polypropylene mesh mounted in a vertical 4 m high posts and sensors for collected water, temperature and relative humidity measurements with time.

[9] In this work, relative humidity, temperature, and collected fog water were studied along a transect extending from the coast to an inland hyperarid location in the Atacama Desert. Using these data the temporal as well as the topographical influence on the atmospheric water content was examined. We compare the decrease in water available from fog from the coast to inland sites with the reported decrease in availability of hypolithic cyanobacteria along this same transect.

2. Experiment

2.1. Research Sites

[10] The surface of the Atacama Desert is characterized by a paucity of bare rock outcrops, an abundance of rock of

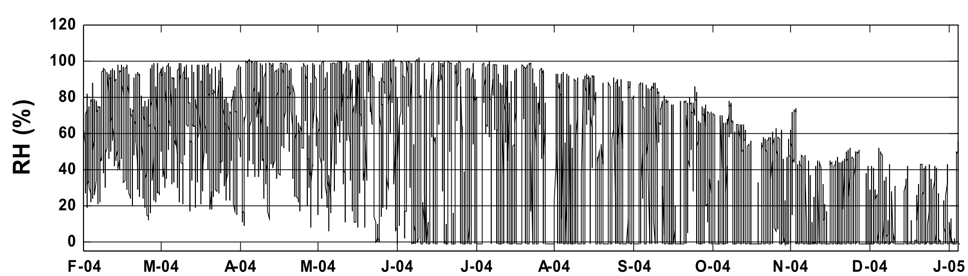

Figure 3. Typical decreasing trend of RH values produced by a faulty RH Hobo sensor placed at Coloso's site.

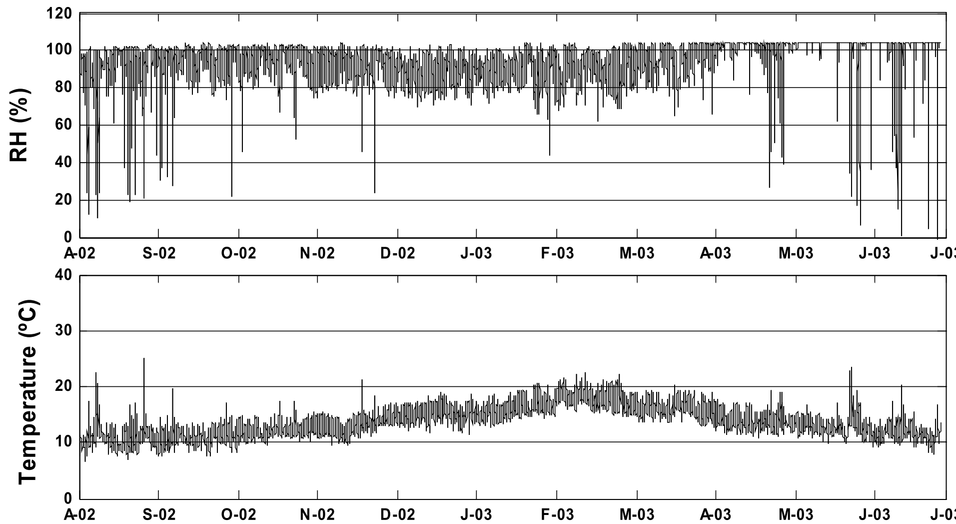

Figure 4. Temperature and RH values at Coloso site.

varied sizes, and smaller-sized material forming a lag over a highly saline regolith. Saline minerals unevenly dispersed are abundant and include halides, iodates, borates, sulfates and most significantly, substantial amounts of sodium nitrate (caliche). In particular, patches of highly eroded crusts known as 'chuzca' composed by fine particles are susceptible to dispersion in the air under mechanical perturbation of soil imposed by wind, traffic, and industrial activities.

[11] In most of the drill cores extracted during routine search campaigns for specific minerals or groundwater in Atacama Desert, it is common to observe a distinctive vertical soil profile composed of broad alternate layers of sandy soil and impervious clay. These profiles can also be seen in old unlined abandoned wells. These clay layers prevent water diffusion from groundwater to the surface. Moisture data at subsurface soil level obtained after a short rain event at Yungay site by *McKay et al.* [2003] suggest moisture flow from the surface downward and then back up to the surface with no evidence of exchange with the deep groundwater.

[12] For this study, three field sites namely, Coloso, Inacesa and Yungay, located across a coast-inland transect (latitude 23°49′S) were selected (Figure 1). These sites were chosen to be spatially representative with free exposure to all wind directions and provided with accessible roads.

[13] Coloso, the selected area in the coast at 14 km south of Antofagasta is characterized by a series of steep hills, cliffs and plains from the shore up to an intermediate plateau at 490 m above sea level (a.s.l.), where a coastal road passes through. Within this area, Coloso Mountain has an altitude of 970 m a.s.l. Predominant winds coming from the Pacific Ocean penetrate the interior after ascending this terrain forming localized fog at specific times of the day. The selected site for fog water collection tests on this area (site 5, Table 1) was in the top of a small sandy hill. Sites 1–4 were along the slope of Coloso Mountain.

[14] Inacesa, the intermediate site situated 8 km from the coast is characterized by an uneven terrain with abundant

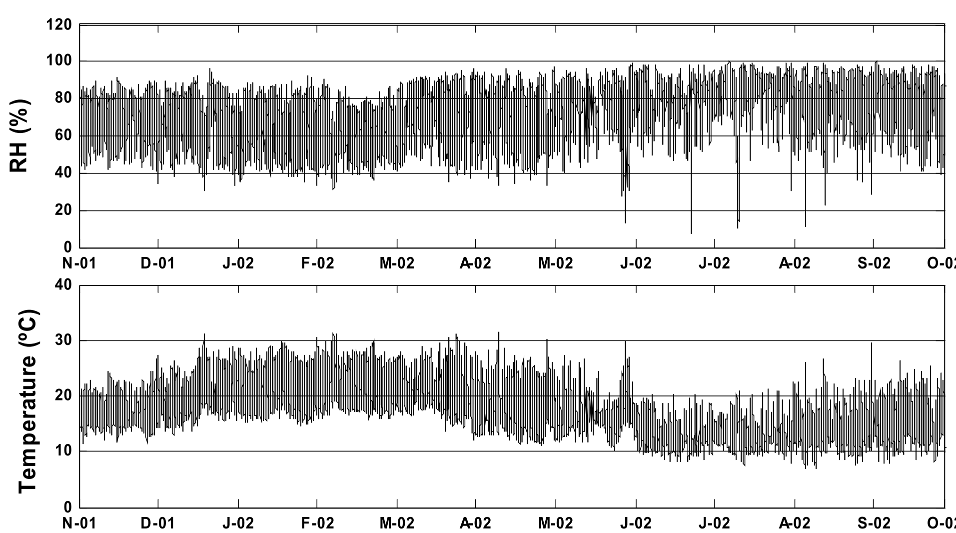

Figure 5. Temperature and RH values at Inacesa site.

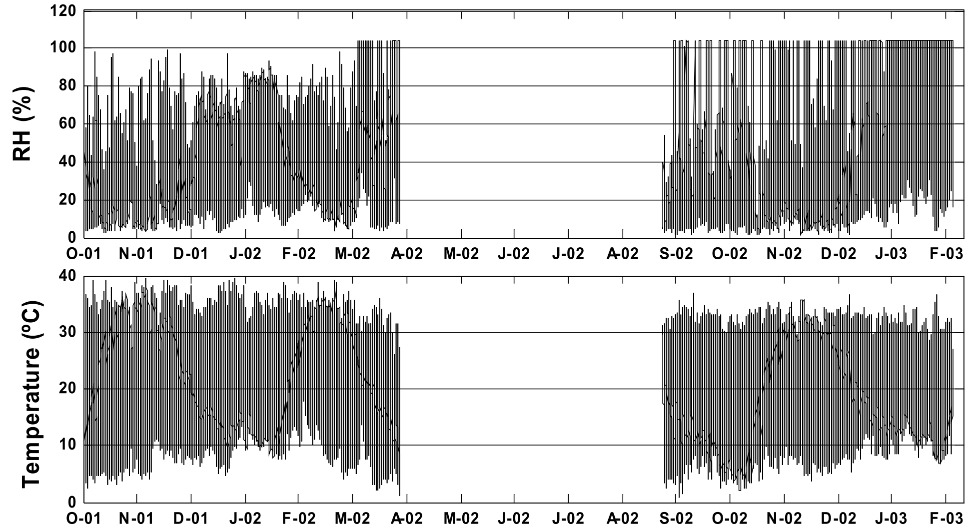

Figure 6. Temperature and RH values at Yungay site.

rocks and small hills and coastal mountains at the distance. Yungay, the farther east inland location, is 45 km from the coast and is characterized by a smooth terrain and dispersed hills of varied sizes at the distance.

2.2. Methodology

[15] Air humidity and collected fog water patterns studies were organized to determine fog patterns and fog collected water variation along the transect from the Coloso to Yungay sites, and also the relative humidity and temperature variation with altitude in the Coloso coastal site.

[16] For a continuous temperature and relative humidity collection data, Hobo (Onset Computer Corporation, Pocasset, MA) H8 Pro Series data loggers designed for outdoor operation were used. This device has a temperature sensor that is encased in a sealed compartment, and a relative humidity sensor that is partially exposed to the ambient air. Sensors were set to record data at 30 min intervals and installed inside a radiation shield to minimize the influence of direct and diffuse solar radiation, and ambient dust while keeping an efficient contact with ambient air. Data were periodically downloaded from the sensor via a HOBO shuttle.

[17] A schematic diagram of the apparatus to collect water from fog is shown in Figure 2. Its design was according to a standard collector model [*Garró*, 2006]. A 1.0 m × 1.0 m rigid metal frame securing a fog collector consisting of a 35% shade coefficient polypropylene Raschel mesh was mounted in two vertical 4 m high posts held in place by 3 equally spaced high-strength wires as lateral supports. The frame was oriented along the E-W axis, the prevailing direction of the wind. Below the frame there is an inclined trough secured for fog-water collection with an opening in the lower part to conduct the water to an automatic rain gauge. Fog collected water was automatically recorded using a tipping recorded bucket type rain gauge (Hobo Onset logging rain gauge model RG2-M). A time and date stamp is stored for each 0.2 mm tip event for detailed analysis. A temperature/RH Hobo sensor was placed at the side of the fog water collector.

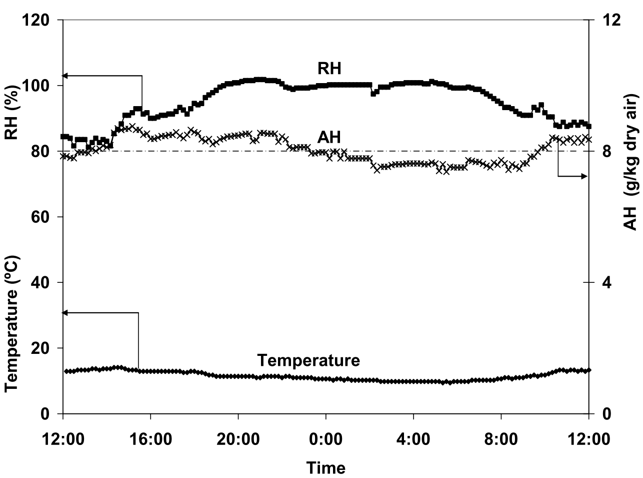

Figure 7. Temperature, RH and AH daily profiles on 29 September 2002 at Coloso site. Corresponding axes are indicating by arrow connectors.

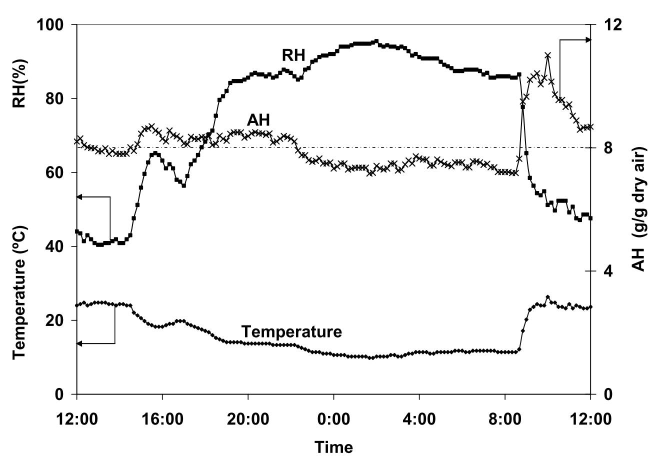

Figure 8. Temperature, RH and AH daily profiles on 29 September 2002 at Inacesa site. Corresponding axes are indicating by arrow connectors.

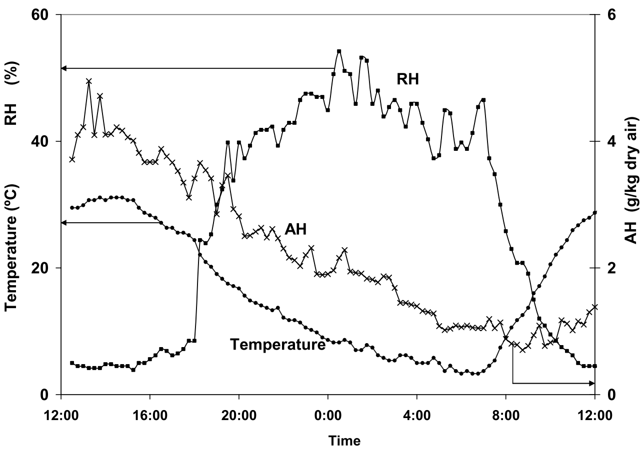

Figure 9. Temperature, RH and AH daily profiles on 29 September 2002 at Yungay site. Corresponding axes are indicating by arrows connectors.

[18] For RH and temperature patterns studies at Coloso Mountain, 4 Hobo sensors were placed at different altitudes of 202, 320, 490 and 976 m a.s.l., respectively. The exact geographical locations are given in Table 1. Given the difficult accessibility to the 202 and 976 m a.s.l. sites, HOBO sensor data were downloaded once a year. For fog water collection studies, the water collector apparatus was installed at site N°5 at 500 m a.s.l. The other inland locations, Inacesa and Yungay having altitudes of 560 and 1050 m a.s.l. are situated at 8 and 45 km from the coast respectively, both in a plain area with no visible obstacles for the wind.

[19] On each field trip to download stored information from field sensors, a single RH data taken from a portable HOBO sensor were used as standard control. Absolute humidity (AH) values were calculated from experimental RH and temperature data using a relationship taken from the literature [*Treybal*, 1980].

3. Results and Discussion

3.1. Sensor Performance on Field Conditions

[20] Throughout all measuring campaign all Hobo data logger temperature sensors exhibited a uniform performance. In contrast, humidity sensors showed breakdown after one or two years of continuous operation in the field. This malfunction was manifested as an anomalous decreasing tendency of RH values over time as shown in Figure 3. Standard data taken from portable Hobo data logger helped to identify and confirm a faulty operation. Anomalous data were discarded and defective Hobo sensors replaced. Thus periods of time with missing data were unavoidable unless sensors were frequently replaced. Our results are consistent with data recorded in this area using other sensors and logging equipment [e.g., *McKay et al.*, 2003].

[21] Abnormal high RH data values up to a maximum of 104 % were sometimes originated during periods of intense fog accompanied with condensing water droplets on solid surfaces. According to sensor specifications intermittent condensation is permitted only when temperatures are less than 30°C and errors of ±4 % are expected. Therefore such abnormal lectures are associated to a response under a water film deposited on the RH sensor during over saturation periods.

[22] RH sensor has an active surface designed to interact with air humidity. A repeated exposure to condensing water, dissolved gases and/or dust is recognized as a potential hazard for these sensors. In all experimental sites of the present research, the use of radiation shields and screens was no solution to prevent dust contamination. In fact, the presence of dust in all internal parts of every radiation shield and sensor was evident after several months of its installation in the field. A particular form of acid attack triggered by dust and moisture that takes place in Atacama Desert [*Quinn et al.*, 2005; *Navarro-Gonzalez et al.*, 2003] could be the main detrimental factor affecting sensor performance.

[23] Rain gauges were affected in a different form by external contamination. Dust deposited in its internal parts affected the life of the battery and electric contacts. A frequent on-site maintenance and battery replacement was effective to extend its operating life.

[24] In general the above described problems were more intense at the Yungay site where higher wind speeds and greater oscillations in daily RH values take place.

3.2. Temperature and RH Variation Along a Transect

[25] Temperature, RH and AH data for Coloso, Inacesa and Yungay sites during a time span of 15 months are presented in Figures 4–6, respectively. A continuous increase in temperature and a decrease in RH values are observed from coastal to inland sites. However, AH data present a particular behavior; for Coloso and Inacesa sites, AH values are quite similar in a range between 7 to 12 g/kg dry air. In contrast, Yungay shows significant lower values between 1 to 6 g/kg dry air. We can assume from these data, that between Coloso and Inacesa sites the coastal wind is adiabatically heated and moisture removed.

[26] Occasional air warming events provoking a sharp decrease in relative humidity was observed at the Coloso site. Thermal driven air convection process along the Coloso Mountain slope heated by solar radiation may explain this effect.

[27] In the absence of any net flux of water into the soil fog deposition, dew formation and water adsorption [*Agam and Berliner*, 2006] should balance water evaporation from the soil during daytime. Therefore, averaged over a day, the water flux between Atacama soils and the atmosphere

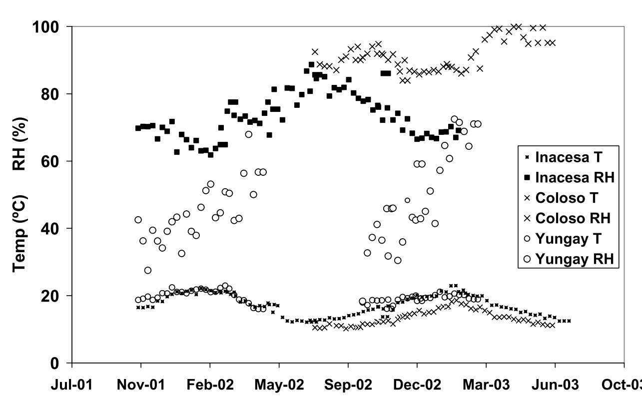

Figure 10. Weekly average temperature and relative humidity values for the experimental sites over 2 years.

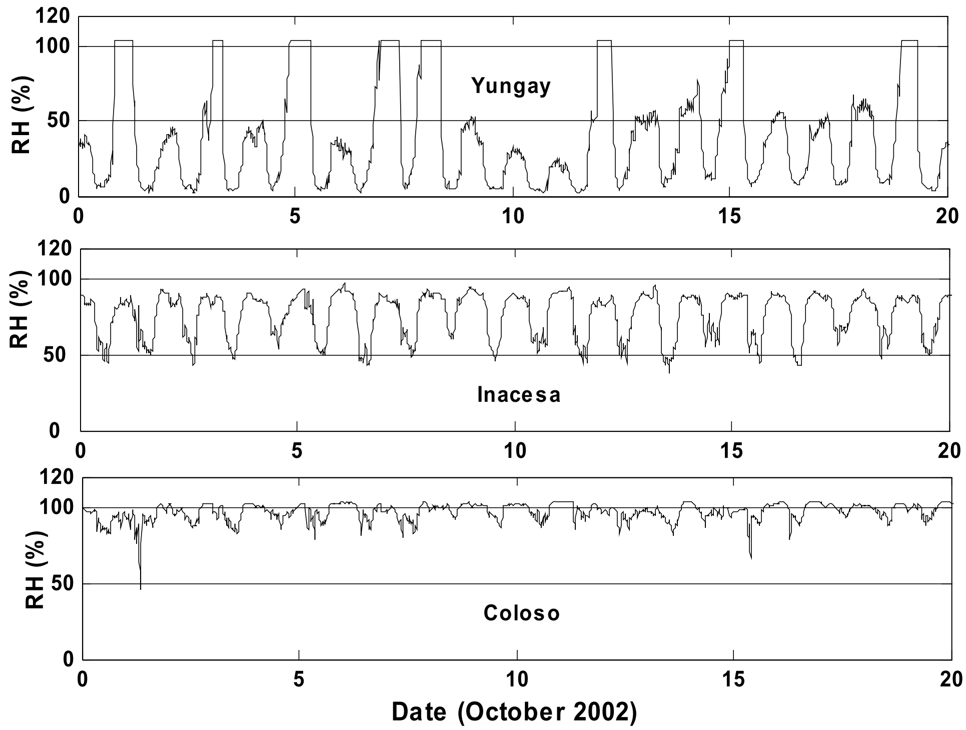

Figure 11. Relative humidity variation between 1 and 20 October 2002 at different experimental sites.

should not play any significant role in the observed humidity variation in the ambient air. The effect on the daily cycle of atmospheric humidity is expected to be maximum just after sunrise when dew or water absorbed into the ground is returned to the atmosphere.

[28] Given the geographical conditions by which Atacama Desert is bordered by the Pacific Ocean and the coastal range on the west and the Andes on the east, three distinctive wind sources are expected: (a) wind coming from the east which is desiccated at low temperature in high altitudes and gradually heated as flows down to the desert providing a source of very low RH air, (b) humid wind coming from the west because of the Pacific Ocean influence, and (c) down slope winds coming from the coastal mountains desiccated at high altitudes and heated as flow down. Evidence provided by *McKay et al.* [2003] indicates a significant contribution of the coastal winds. This is based in the observation that warm dry air at Yungay site, is correlated with high speed winds coming from the west. According to our historical data, wind speed and direction patterns are quite similar in coastal and inland locations. They differ only in the higher peak values taking place during afternoon hours at inland locations.

[29] Relative humidity depends on the temperature and absolute water vapor concentration. If absolute water concentration in the air (expressed as kg water vapor/kg dry air) in a particular location remains constant, then the RH and temperature values should be interdependent in a way equivalent to a line traced on a psychometric chart at constant absolute humidity [*Treybal*, 1980]. In Figures 7, 8, and 9, temperature, RH, and AH values registered on 24 June 2002 are plotted for Coloso, Inacesa, and Yungay sites, respectively. The amount of total water in the air expressed as AH values at Yungay site ranges between 1 and 5 g/kg dry air. These values are significantly lower than the corresponding ones registered at Coloso and Inacesa sites, ranging between 7 to 10 g/kg dry air. It was found that the simultaneous period of high temperature and AH values occurring simultaneously at Yungay, coincides with a fixed west to east wind direction. In contrast at lower AH, wind direction is shifted to different directions.

[30] The adiabatic heating for transition wind between Coloso and Inacesa observed from global data over a 15-month period, is reaffirmed on daily basis data registered on 24 June 2002 (Figures 7 and 8).

[31] Temperature and RH values from Figures 4–6 are presented as weekly average values in Figure 10. It is interesting to note that the average temperature values for Yungay and Inacesa sites present similar seasonal values and trends. The same trend is shown by Coloso data but with slightly lower values. In contrast, the RH trend although well defined, shows a significant scattering, which is largest for the Yungay data (Figure 10). As shown in Figures 4, 5, and 6, this scattering is directly related to the amplitude of the diurnal RH variation profile. This can be explained in terms of the predominant advective mechanism for RH saturation at temperatures regulated by the presence of the Pacific Ocean in the coast which gradually shifts to radiatively driven saturation at inland locations [*Cereceda et al.*, 2002] as diurnal thermal oscillations increase. As a consequence, a continuous decrease in the dew point, reflecting reduced absolute humidity, should be produced at increasing distances from the coast.

[32] The RH data over 20 consecutive days (October 2002, Figure 11) shows a permanent adiabatic heating for air stream flowing from Coloso to Inacesa site, and large RH oscillations reaching air saturation at the Yungay site.

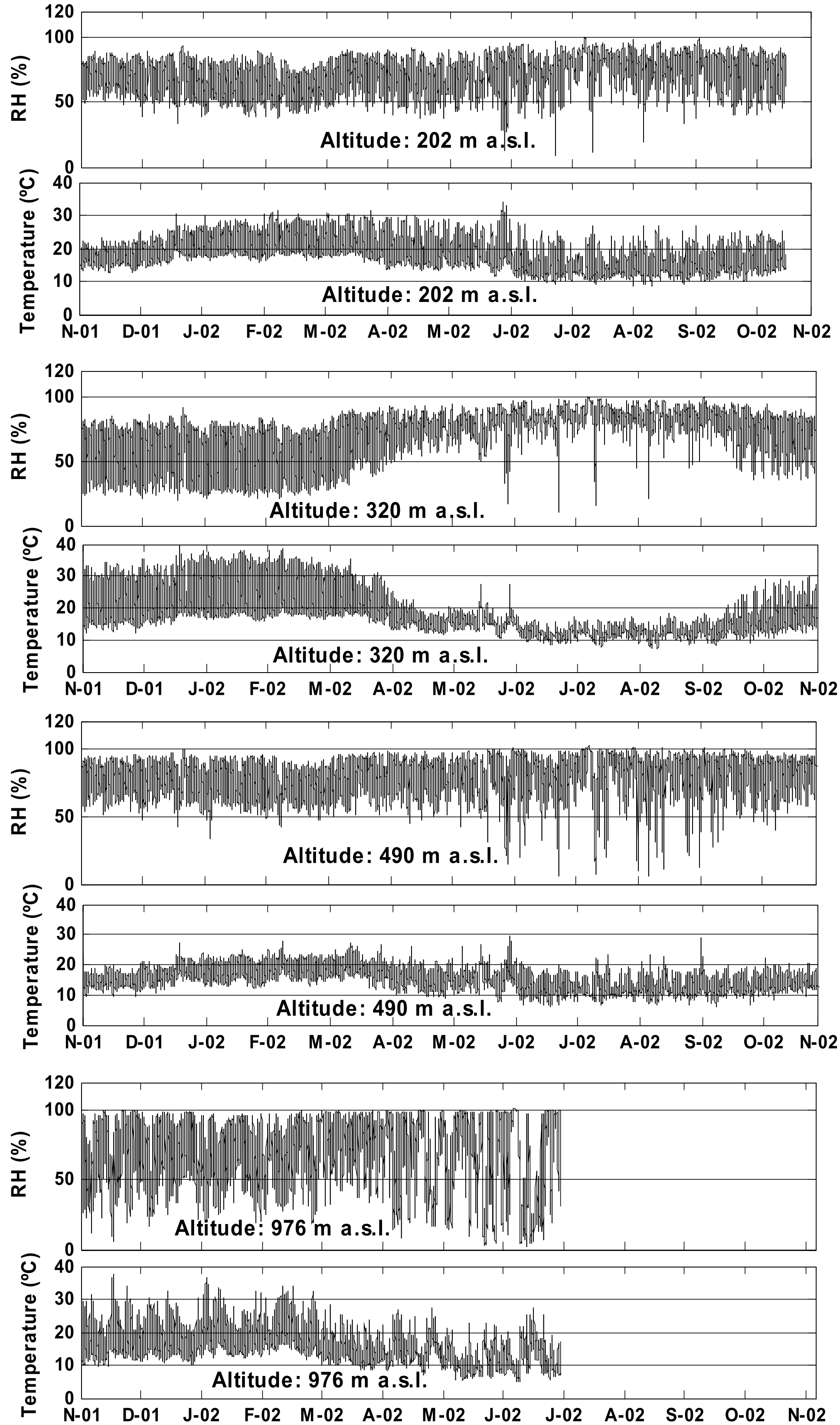

Figure 12. Temperature and RH data at different altitudes of Coloso site.

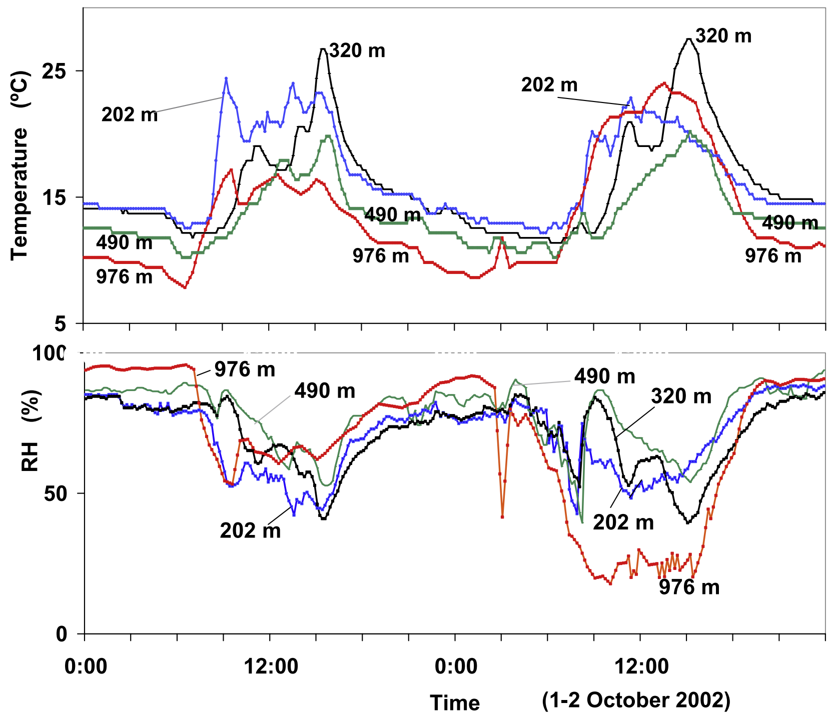

Figure 13. Daily air temperature and relative humidity profiles at different altitudes of Coloso site.

3.3. RH and Temperature Variations With Altitude at Coloso's Site

[33] Very often a thick blanket of fog is seen covering the top of Coloso Mountain. This fog is formed when the ascending wind from the Pacific Ocean up to the top of Coloso Mountain is cooled adiabaticaly. Temperature and RH profiles at different altitudes shown in Figure 12 provides a demonstration of such effect. As expected, the maximum RH values, approaching saturation preferentially at night times, are seen at the top in addition to wider daily oscillations. Analysis of data over two consecutive days (Figure 13) show a clear adiabatic cooling with altitude only at nighttime; at midday hours this effect is uncertain and at times seems to be inverted. This may be a result of wind direction changes and/or convection induced by solar radiation. The very low RH values shown at 976 m during midday 2 October 2002 (Figure 13) suggests occasional wind intrusion from the inland desert. It is very interesting to note that air at site 5 (Table 1) exhibits higher RH values in comparison with site 3 even though both are at almost at the same altitude. Topographical considerations are probably responsible for this result.

3.4. Water Collected From Fog

[34] Fog occurs if the water vapor concentration in the atmosphere reaches a saturation condition expressed as 100% relative humidity. However, the presence of some contaminants (soluble trace gases, hygroscopic matter and weakly soluble or insoluble core) may give rise to stable fog, even though the ambient relative humidity never reaches this limiting condition [*Kulmala et al.*, 1997; *Charlson et al.*, 2001]. When fog is formed, suspended

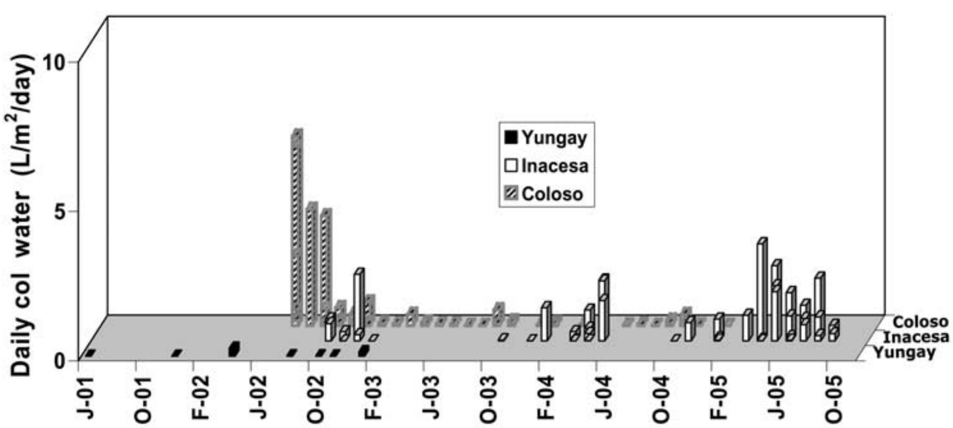

Figure 14. Daily collected water distribution at different sites. Data after February 2003 and December 2005 are not available for Yungay and Coloso, respectively.

water droplets from fog are trapped in the mesh screen of a fog water collector. As water accumulates on the fog collector screen dispersed droplets on the strings grow large enough to drip in the trough that conducts water into the automatic rain gauge. After two years of continuous operation, all metal parts of the collecting system were affected by a generalized corrosion that was more severe at the coastal Coloso site. This hazardous effect is due to the continuous exposure of metal surfaces (screen supports, posts and fittings) to wet-dry cycles in the presence of saline dust drawn by predominant winds. In particular the presence of chloride ions in the fog collected water [*Cáceres et al.*, 2004; *Jacob et al.*, 1985] greatly exacerbates corrosion rates of exposed iron surfaces [*Corvo et al.*, 1995]. During the time interval of this research fog collection by itself was not affected by these corrosion problems. However, this is an important consideration for long run fog water collection projects.

[35] The measured flow rate of collected fog water, during fog events was irregular and characterized by alternated periods of small and large flow rate values. The fog water collection process is probably formed by alternated periods of water accumulation and sudden detachment from the net. The maximum flow rate value of fog water collected ever detected in a time interval of 2 minutes was 152 ml m^{-2} min^{-1} at 17:35 of 15 July 2002 on the Coloso site. In the same site the maximum daily flow was 6.3 L m^{-2} day^{-1}. This value is in agreement with those reported in other locations of northern Chile [*Larrain et al.*, 2002]. Daily fog water collected shown in Figure 14 indicates the largest and lowest amounts of collected water at the Coloso and Yungay sites, respectively. Because of sensor breakdown fog water collected data after February 2003 and December 2005 at Yungay and Coloso, respectively, are not available. This also happened in Inacesa in several months of 2003. Although the presence of fog is a necessary condition, it is not sufficient for water collection. This is especially true in Yungay, where despite the frequency of fog periods, the amount of collected fog water was significantly lower than other sites (Figures 6 and 14). In this location, fog takes place under low air water concentration, therefore the potential for extracting water from it is also low. The direction and intensity of wind should be an important complementary condition to achieve high collection efficiencies [*Cereceda et al.*, 2002]. This has important implications for the role of fog as a source of moisture for soil bacteria and hypolithic algae [*McKay et al.*, 2003; *Warren-Rhodes et al.*, 2006].

[36] Fog water collection under saturation and constant temperature of the air is a condition strictly observed at the Coloso and Yungay sites. However, data from the Inacesa site seems puzzling, as they occasionally indicate water collection during periods of RH values slightly lower than 100 %. Faulty operation of Hobo sensor is unlikely, since their performance were periodically verified. Solar heating from large nearby rocks dispersed around this site could affect local air. The extent to which a dense fog formed in the coast maintains its stability after being transported by wind from the coast to the Inacesa site is unknown. No information concerning fog dissipation rates were found in the literature. This observation is kept as an open problem for which no definite explanation can be given at this time.

[37] *Warren-Rhodes et al.* [2006] reported on the distribution of hypolithic cyanobacteria in the Atacama Desert. They found that virtually zero colonization rate in the Yungay area with concomitant decreases in species diversity and carbon turnover rate compared to other sites in the Atacama. Similar decreases are observed from the coast inland at the latitude of Antofagasta. Because all of these sites experience negligible rain, the explanation for these ecological variations has long be thought to be due to variations in fog water. Our results provide a quantitative base for accepting this hypothesis. *Warren-Rhodes et al.* [2007] have further shown the importance of fog as a source of moisture and the role of large stones acting as natural fog collectors. The artificial fog collectors used in this study provide models for quantitative calculations for the collection of water from these stones.

4. Conclusions

[38] Detailed measurements of temperature and relative humidity in air in addition to fog water collected over a 4 year period in selected sites of the Atacama Desert, partly disclosed the influence of topography and ambient factors on the potential for fog water recovery. At the coastal Coloso site an adiabatic cooling affecting the air as it ascends to 970 m takes place preferentially at night producing an increase in relative humidity at higher altitudes. Absolute humidity and flow rates of flow water collected presented similar values between Coloso and Inacesa. A significant drier condition presented at Yungay site severely limits water collection potential. The need to extend this research to elucidate the exact role of air circulation on humidity patterns, kinetics aspects of fog dissipation and stability is derived from the present results. Our results suggest that while fog is observed in inland sites, such as Yungay, the amount of water represented by this fog is lower than fog that occurs at coastal sites. Thus biological systems such as soil bacteria, hypolithic cyanobacteria, lichens and even cacti that rely on fog moisture will be more abundant along the coast. In extreme areas like the Yungay site where the coastal mountains effectively block the incursion of the marine fog very little life survives.

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