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Fog measurements at the site "Falda Verde" north of Chañaral compared with other fog stations of Chile

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Abstract

Fog collection data registered through a Standard Fog Collector (SFC) installed by a local fishermen's association at a height of 600 m at the "Falda Verde" site, north of the Chilean harbor Chañaral (26°17′S/70°36′W), from November 1998 to November 2000, are analyzed. Trying to give new lights on the dynamics of fog along the Chilean northern coast, this article compares, for the first time, the data obtained at Falda Verde with those obtained at five other Chilean fog stations. The total time period runs from 1987 to 2001. A mean of 1.46 l/m^2/day was registered at the Falda Verde site after 2 years of measurements, one of the lowest yields along the north Chilean coast. After a brief historical recapitulation of fog researches in the study area, geographical explanations of the water yields obtained in different sites are discussed. The annual mean collection from Cerro Moreno and Paposo shows a clearly different behavior from all other sites, showing a greater stability throughout the year. Other stations have a marked difference between extreme seasons. Alto Patache yields, if not the best in Chile, are very high and offer unexpected possibilities for future applications in the coast. Stations located away from the seashore (Cerro Guatalaya) are clearly less productive. Ocean proximity, altitude, south and southwest orientations of the coastal ranges and local relief explain some of the differences noted.

Keywords: Fog; Fog oasis; Water collection; Coastal desert; Atacama desert; Coastal communities; Water use

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1. Introduction

The initiative of installing a Standard Fog Collector (SFC) at "Falda Verde" was undertaken in 1998 by a local association of fishermen who wished to diversify their economic resources (traditionally based on offshore fishing) and complement them with new agricultural exploitations at the piedmont, near the sea. Knowing what has been recently done in terms of water collection elsewhere in Chile (Cereceda et al., 1997; Cereceda and Schemenauer, 1998; Espejo, 2000, 2001; Larrain et al., 2001; Osses et al., 1998; Velásquez, 1995), we were asked to study the feasibility of water collection at the site. Following the suggestions that resulted out of our first visit (April 1998), a small project was launched with the support of local funds. Fog collection measurements were made and installed by trained local fishermen and registered in-visits were programmed every 2 weeks for the next 2 years. These measurements provided new information about the behavior of fog at the arid north of Chilean coast from a different and a much lower altitude. In September 2001, a 5000-l tank was installed at the foot of the mountain, which is fed by a 432-m^2 catching mesh. Nine 48 m^2 fog collecting devices, set on wooden poles, have been erected in the upper section of the coastal plain (between 550 and 600 m high). Fishermen hope to stock enough water for small agricultural exploitations.

2. The study area

The area is located at the coast of the Atacama desert, in the first three northern regions of Chile. Fig. 1 shows the geographical location of the six fog sites where SFCs have been installed.

Fig. 2 shows the area of Falda Verde, about 800 km south of Alto Patache fog oasis (20°49′ S). It lies 600 m high on top of a small coastal range, leaning from NW to SE, a few kilometers north of harbor Chañaral (26°17′N and 70°36′W). No higher elevations were found in the vicinity for future agricultural parcels near the sea. The Bay of Chañaral makes a huge half circle (open to the sea) so that the area of Falda Verde receives the predominant trade winds directly from the south, which normally flow into this area from 180° to 185°. This prevailing wind direction throughout the year corresponds with the one registered at Alto Patache, lying further north, and appears to be caused by local relief, which modifies the dominant SW winds into South winds. The site of Falda Verde is a small mountain range that runs close to the sea at the northern margin of Salado Valley, one of the few intermittent desert rivers that cross the territory. Predominant wind direction comes from 260° at Paposo and 270° at Cerro Moreno. Wind direction at Cerro Guatalaya comes from 225° at Alto Patache; however, winds come directly from the south (180°).

3. Objectives and methodology

Three main objectives are discussed in this paper:

1) To process information received from a new fog site in coastal northern Chile (Falda Verde, Chañaral).

Fig. 1. Geographical location of the six fog stations in Northern Chile.

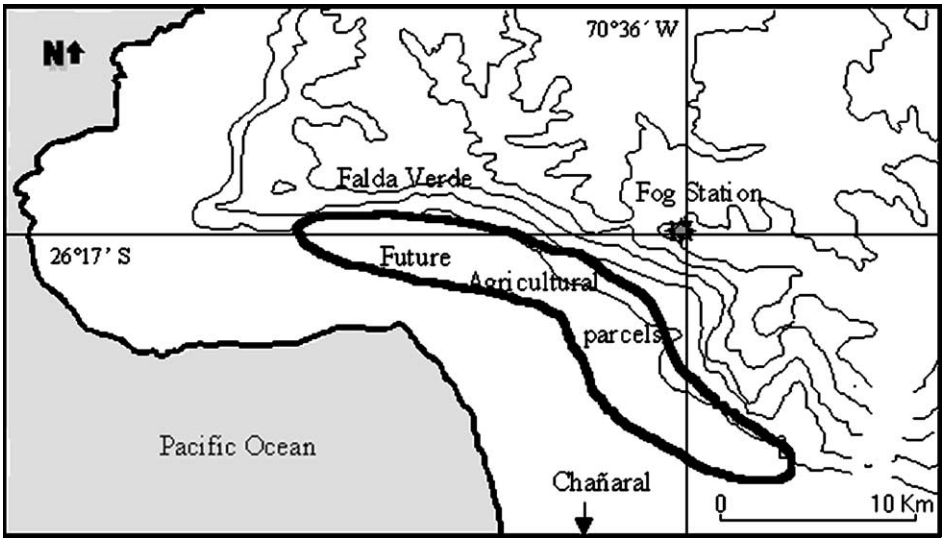

Fig. 2. Study area at Falda Verde, Chañaral.

2) To compare the records of water collected at all known places in northern Chile, where fog studies have been carried out during the last 2 decades, for at least the whole year. The six fog sites (Fig. 1) lie between two fog collection stations: Cerro Guatalaya (20°15′S) and El Tofo (29°17′S).

3) To point out possible explanations about the collection yields observed at different latitudes and altitudes, which give new insights on the behavior of fog along the Chilean arid coast, under the influence of the Humboldt Oceanic Current.

In November 1998, local Falda Verde fishermen installed a fog collection structure (SFC) at the coastal range (600 m), according to the type proposed by Cereceda and Schemenauer (1993). Measurements were made every 2 weeks by trained local personnel.

By comparison, measurements at Alto Patache and Cerro Guatalaya (near Iquique) were made from July 1997 to September 2001. Measurements at Paposo, collected by R. Espejo, started from May 1999 up to the present, and at Cerro Moreno from end of September 1999 up to the present. Collection data from El Tofo Station were recorded by CONAF Station personnel.

4. Climatology

The west coast of South America, from northern Peru to Central Chile, is extremely arid (Fuenzalida Villegas, 1950). Lima (12°S) has approximately 10 mm/year of precipitation. This drops markedly as one moves south into the northern Chile where annual precipitation near Arica (18°S) averages <1 mm (Weischet, 1966, 1975). The precipitation then slowly builds up until 30°S at El Tofo; annual averages are about 70 mm. 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 conditions lead to low cloud decks over the ocean and frequent fogs on the coastal mountains. The primary manifestation of the stability factors noted above is a well-developed trade wind inversion that persists throughout the year. It inhibits the convective growth of clouds and thus, the development of precipitation (Schemenauer and Cereceda, 1993). In the study area, the precipitation averages are: Iquique (Patache) 0.6; Antofagasta (Cerro Moreno-Paposo) 9 mm; Chañaral (Falda Verde) 30 mm; La Serena (El Tofo) 70 mm. Temperature at the coastal locations are characterized by low variation between summer and winter and day and night. Annual temperature averages are as follows: Iquique 17 °C; Antofagasta 16.5 °C; for Chañaral 16 °C; La Serena 14 °C. Relative humidity is similar along the area and is approximately 75%.

El Niño Southern Oscillation (ENSO) is a very important phenomenon that has influenced the precipitation annual yields; for example, in Iquique the total precipitation was 7.3 and 11 mm in 1983 and 1992, respectively (Cereceda et al., 2000).

5. Historical research of fog in northern Chile

One of the first scientists who gave special attention to fog studies in Chile was the German climatologist, Walter Knoche. Leaning mainly on data published from coastal meteorological stations and with scarce direct field knowledge of the northern coastal areas, he expressed the opinion that the northern section of the country (der "Grosse Norden" and "Kleine Norden") was rather poor in the presence of "Camanchaca" (fog). He wrote that the mist in the north of Chile touches the continent at very few points with the exception of "very local conditions like river valleys…". He significantly pointed out that "the most common appearance of this condensation is only limited to a narrow, moreover, very narrow coastal fringe". Knoche based his statements on the sightings made by ship observers who travelled along the coast from Valparaíso to Callao. In acute contrast with our present knowledge of the fog phenomenon, he even dared to say that "the Great North and a section of the transition region of the Small North have to be described as poor in fog (nebelarm)". (Knoche, 1931, p. 84). Our knowledge, which is obtained directly from the field, at the top of the coastal mountain chain looking at the sea at about 800–900 m high, strongly contradicts his pronouncements. In 1952, Kummerov studied the relict of rain forest of Fray Jorge, Province of Coquimbo (30°30′ S). Using a Grunow instrument, he showed that "fog precipitation was up to 10 times greater than that of rain". He added, significantly for our purpose, that "the total precipitation is sufficient to allow growth of newly planted trees provided that a catching frame of adequate size exists nearby" (Kummerov, 1952, 1966). After him, in 1963, the German botanist, Gerhard Follmann, spoke of the "nordchilenischen Nebeloasen", giving particular attention to the fog oasis in Paposo and Cerro Moreno. Following Kummerov's observations, he realized that the plants themselves, in such foggy areas, created their own "rain climate" (in his words "ihreigenes Niederschlagklima"; see Follmann, 1963, p. 104). Shortly before 1958, fog research in Northern Chile, specifically in the Antofagasta area, was undertaken by pioneer members of the recently created Universidad del Norte. Small cylinders with thousands of vertical nylon threads were used at the beginning. Soon,

Carlos Espinosa and other scientists at the local university made collections in various nearby places with different kinds of devices (see Espinosa, 1961, 1967, 1977, 1978; Gischler, 1991, pp. 5–15). The first instruments made in Antofagasta used nylon threads, mosquito net, saran mesh, and finally burlap as collection devices. Different structures like cylinders, paralelepid, or macrodiamant types held the catchers. (Gischler, 1991). The first collections made by Antofagasta scientists were gathered at mountainous elevations located not far from the town (Cerro Mirador, Cerro Miramar, or Mina Andrómeda).

This paper constitutes the first known comparative study presenting collection data from the six fog stations, offering reliable data for coastal Northern Chile and running at least for the whole year. These stations are located from 20°15′S to 29°17′S. The area covers nine geographical degrees along coastal South America (see Fig. 1).

6. Results and discussion

Table 1 gives the data of the six studied locations, their geographical setting, and period of measurements.

In order to foresee future possible applications, Table 2 presents water collecting estimates in each stations according to their yield and number of collectors to be used.

Water potential at different sites is estimated here. We can easily distinguish among the stations those that show a very high water potential (Alto Patache and Cerro Moreno) and those with a much lower production (Falda Verde and Cerro Guatalaya). For instance, by installing 100 fog collectors (40 m^2) at Falda Verde, it would be possible to collect in a year a total amount of 2,087,800 l. Even if water potential at this site seems, at first, very low, fishermen at Chañaral, using adequate technology, could practice small horticulture to satisfy their basic needs. The Alto Patache station provides in a year 5.46 times more water than Falda Verde, totalling in an annual yield of 11,402,600 l. Evidently, this amount would permit multiple applications. Alto Patache (in contrast with Cerro Moreno fog site) offers good access possibilities by land.

Tables 1 and 2 present water collection averages obtained at six different fog stations in Northern Chile during different periods. As it becomes evident, Cerro Moreno shows the best catching yields, followed closely by Alto Patache. Cerro Guatalaya, in contrast, offers the lowest amount because it is located farther from the seashore (12 km).

Table 1
Geographical characteristics and period of measurement at the fog sites in Northern Chile

Site	Location	Altitude	Years studied	Total period (months)	Collection (l/m^2/day)
Alto Patache	20°49′S/70°09′W	850	1997–2001	49	7.81
Cerro Guatalaya	20°12′S/70°00′W	1050	1997–2001	49	0.93
Cerro Moreno	23°51′S/70°26′W	1150	1999–2001	21	8.26
Paposo	24°59′S/70°26′W	750	1999–2001	25	3.36
Falda Verde	26°17′S/70°36′W	600	1998–2000	23	1.43
El Tofo	29°27′S/71°18′W	760	1987–1995	83	2.98

Table 2
Estimated collection data according to yields obtained at the six fog stations in Northern Chile

Daily presumed collection data according to Fog collector number using 40 m^2 collection net (l)					
Site	SFC	1 Collector	20 Collectors	50 Collectors	100 Collectors
Alto Patache	7.81	312.4	6248	15,620	31,240
Cerro Guatalaya	0.93	37.2	744	1860	3720
Cerro Moreno	8.26	330.4	6608	16,520	33,040
Paposo	3.36	134.4	2688	6720	13,440
Falda Verde	1.43	57.2	1144	2860	5720
El Tofo	2.98	119.2	2384	5960	11,920

Fig. 3 presents a double entrance graphic showing a surprising curve obtained after exactly 2 years of water collection at both stations (Falda Verde and Alto Patache). The time period involved is also exactly the same (Nov. 1998–Nov. 2000). The observed trend is almost identical although the water amounts collected are quite different. In order to get valid conclusions concerning general trends of fog presence and productivity through time in northern Chile, we need to compare many other new coastal registers (not just the six included in this study), measured during exactly the same period of time. This will be a subject of future study.

In June, the graphic shows, in the two stations, a high correspondence in the 2-year study with exactly the same peak. Although the two coastal stations are located about 800 km apart, it means that the atmospheric circulation and wind activity in both places may be similar. Local conditions, such as altitude and relief, explain the differences in the amount of fog. In both cases, moreover, the best collecting period occurred between June–July and November 1999, which was much more stable than 2000.

As shown in Figs. 4 and 5, we can distinguish three types of response of fog behavior during the year according to the stations: (a) those stations presenting very low values from December to May (Alto Patache, Falda Verde and Cerro Guatalaya); (b) those that show a rather homogeneous behavior throughout the year (Paposo and Cerro Moreno;

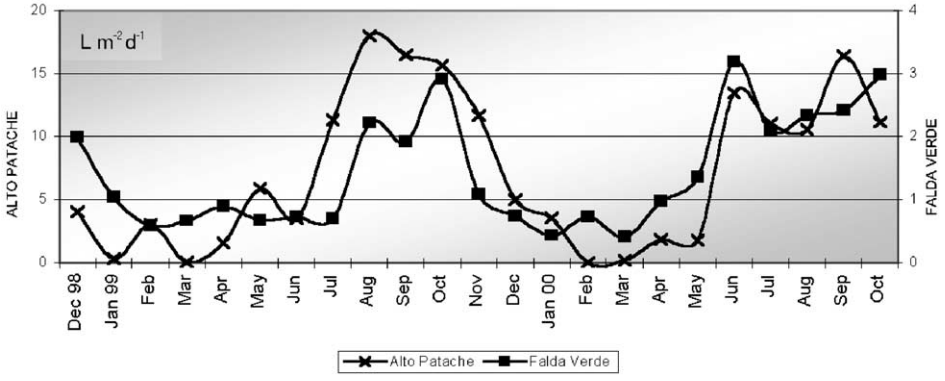

Fig. 3. Two years of comparative fog collection at Falda Verde and Alto Patache in 1998–2000 (monthly behavior).

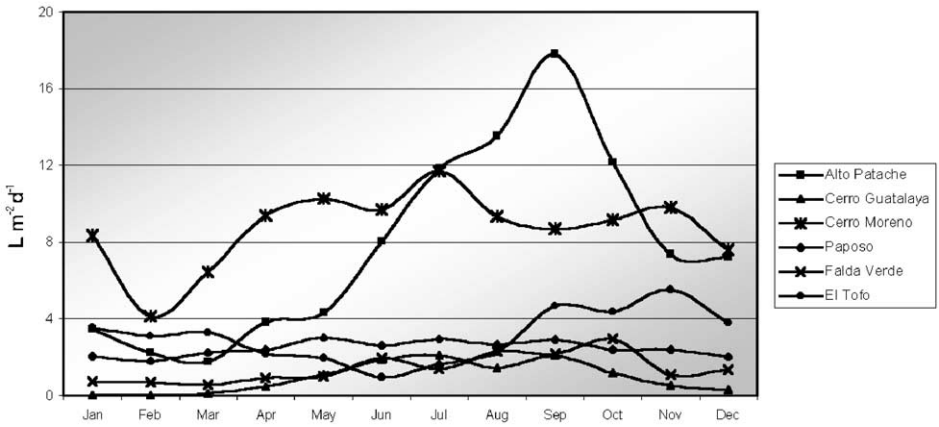

Fig. 4. Comparative monthly daily means at six fog stations.

even though Cerro Moreno shows a sudden drop in February); and finally (c) those that register their lowest values from April to August (El Tofo). Collection figures for June is very low in El Tofo, whereas in other stations, this month appears as highly productive.

In general, Fig. 6 shows a consistent collection rate in all stations from 1998 to 2001, except for Alto Patache in 1997. Year 1997 (the last "El Niño" year) was exceptionally rich in water collection in Alto Patache. It coincides with "heavy" rains that fell in that area (August 1997). From 1999 to 2000, at the sites of Falda Verde and Cerro Moreno, we noted a small rise in collecting values. Even though 4 years represent too short a period for observation, we can say that the general trend to world desertification process (visible in plant extinction and death at Alto Patache) and increasing global warming has not yet been reflected in this short-term analysis.

Cerro Moreno shows the best results in water collecting in northern Chile so far. However, the measuring period involved is still too short for full conclusions. It is a very peculiar geographical setting—in the hilltops of the largest peninsula in continental Chile may explain, at least partially, this climatological singularity. The Mejillones peninsula—in older geological times, a good-sized island—in fact, constitutes today a topographical rarity in the rather continuous Chilean coastal conformation. This strange geological and

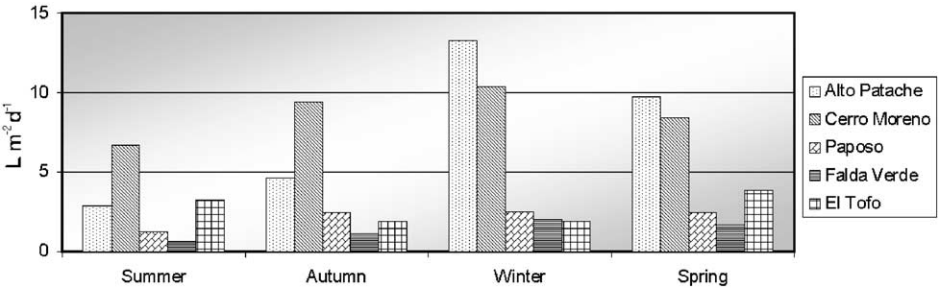

Fig. 5. Comparative seasonal daily averages between five fog stations.

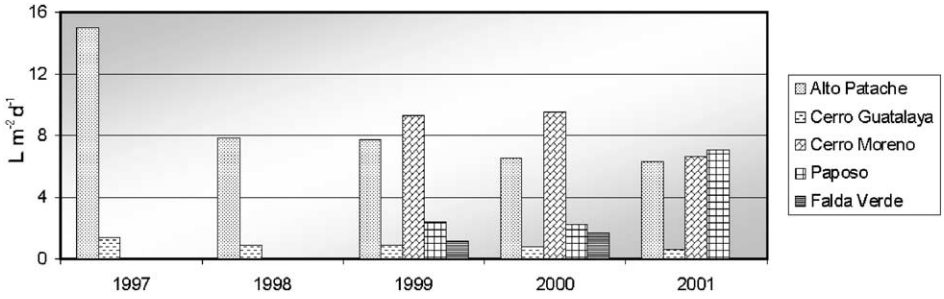

Fig. 6. Total yields averages in five fog stations (1997–2001).

geomorphological relief feature greatly favors the southern and southwestern exposition of its mountain tops and slopes, reaching altitudes of up to 1350 m, being one of the important peaks in the Northern Coastal Cordillera. Cerro Moreno flanks go down very abruptly to the southwest and south (with a very small coastal terrace), facing directly the trade winds (180–185°) with no interference from land obstacles. As biogeographers and oceanographers maintain, oceanic upwelling have been detected at its base, strongly favoring evaporation of water at oceanic surface and marine life (Cañón and Morales, 1985). Some of the authors of this article (who have lived for years in the city of Antofagasta which lies south of Cerro Moreno) testify to the presence of an impressive cloudy mass that always crowns Cerro Moreno's summit, visible from far away. On rare occasions, when northeastern winds blow, this cloud dissipates or disappears. This huge, ever-present fog mass permits the existence of a very significant fog oasis along Cerro Moreno's highest slopes (700–950 m), containing thousands of cacti and several other plant and animal species. The mere existence and area development of this fog oasis is, in itself, a proof of the strong water potential of the site.

Collection data gathered at Alto Patache seem to be very promising along the northern Chilean Coast. The uninterrupted 4-year research[1] in the area offers a solid basis for potential future applications because the period studied (1997–2001) covered "El Niño Southern Oscillation" (ENSO) and "La Niña" periods—the two most significant and contrasting climate events that visit this area (Cereceda et al., 2000). Even if some important differences in water collecting can be observed during these years (some years being clearly wetter than others), the presence of rain during the ENSO event of 1997–1998 did not significantly influence the mean data obtained so far (7.81 l/m^2/day). Although the presence of rains seem to be indispensable in terms of plant growth and development, creating every 5–7 years the so-called "flowering desert" in those areas (Pinto, 2001), fog certainly does not depend on rain. Both phenomena seem to be clearly independent although interconnected. Many plants grow each year in the fog oasis just fed with normal winter/spring fog and without any rain event. Recent fog measurements made in the area of Alto Patache (August–September 2001) clearly demonstrate that water contained in normal fog sufficiently penetrates at certain places, reaching plant roots, bulbs, or tubers causing growth of leaves and even flowering processes.

[1] Measurements at Alto Patache and Cerro Guatalaya SFCs have been continued up to the present (2002).

At Paposo and Cerro Moreno stations (see Fig. 6), the yearly curve shows much smaller changes between summer and winter than in other stations studied—giving a clear demonstration of better stability in terms of water production. Although Cerro Moreno shows better water production than Paposo, both sites clearly proved to be apt for practical purposes, especially for delivering cloud water to village communities located at the coastal fringe.

The rather modest water productivity observed at the Paposo site is surprising, given that this fog oasis has been known for centuries for its notable endemic flora and the presence of several coastal springs. Old voyager and colonial descriptions often mention the site as being a typical exception among the hyperarid desert landscapes of coastal Chilean North. This site has been known since the 16th century as a favorite site for Chango fishermen settlements shortly after the first contact with the Spanish. In 1815, French voyager Mellet testified to the presence of Chango Indians at Paposo and described their hunting activities (Mellet, 1954, p. 114, discussed in Larrain, 1977–1978, pp. 66–68; Philippi, 1860, discussed in Larrain, 1974, 1996, 1999).

We expected that its water production would be, by far, the best on the Chilean Coast. So far, it has not proved to be so. Maybe the present location of the SFC is not the most appropriate in terms of altitude (750 m). Paposo shows normal dense fog even at the level of the first coastal terrace lying at 25–30 m, a few meters from the sea shore. They sustain, even now, big cactus groups and extended stocks of plants reaching the seashore.

7. Conclusions

This paper focuses on presenting water collection results a new fog collection site in Northern Chile, Falda Verde (Chañaral). At the same time, it compares these modest results with reliable records obtained from the five other fog stations in Northern Chile. Thus, a new insight on the behavior of fog along the Chilean Northern coast can be reached. Possible explanations of the differences noted between fog sites are presented in this work in terms of their relationship with altitude, ocean proximity, orientation, and relief characteristics.

There is a striking resemblance in the graphic curve presenting water production at two sites—Falda Verde and Alto Patache—in the same months, in the 2-year study (1998–1999). Falda Verde yields never reach down to zero, an event that occurs in Alto Patache during middle summer. Falda Verde results during summer are, therefore, interesting and seem to support the fishermen's horticultural plans. Other fog stations behave differently, presenting either collection peaks at different months or different comparative total amounts in the same months.

Falda Verde results are, in fact, very modest in comparison with other Chilean Stations (see Fig. 6), being the weakest in terms of total water collection among sites that lie close to the coast. However, the average amount of l.46 l/m^2/day obtained would permit, by means of appropriate storage systems, to irrigate small agricultural plots. These still modest results are certainly not due to the presence of a weak type of fog at Falda Verde, but rather to the exceedingly low altitudes, where collecting has been practiced so far (only 600 m). Efforts should be made in Falda Verde to find better locations even if the distance to the sea terrace increases.

The results obtained at other fog stations like Cerro Moreno, Alto Patache, and Paposo offer unlimited applications, either at the sites themselves (i.e., for reforestation plans) or at the coastal level, where fishermen, lacking good-quality water, have been living and working for centuries.

As a general comment, we have observed that all the years that we have studied are different and unique; most of the stations do not follow exactly identical patterns, often manifesting strong differences. All the hypothesis tested (latitude, altitude, topography, wind exposition, etc.) appear to account for the differences, but observation and research, especially on General Atmospheric Circulation, should be undertaken in order to have access to a better understanding of the general patterns of fog behavior on the North Chilean coast.

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