Measurements of Fog Water Deposition and Their Relationships to Terrain Features

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1. Introduction

Measurements of cloud liquid water content (LWC) have had a long and somewhat tortuous development. Most efforts have concentrated on making absolute LWC measurements from aircraft, initially with passive impactor-type devices and later with aircraft-powered systems providing analog or digital outputs. A hot wire, constant-current probe (J-W LWC meter) manufactured by Johnson-Williams Ltd. of Palo Alto, California has been used now for almost 30 years. Strapp and Schemenauer (1982) have discussed the problems associated with using this instrument. Of all of the LWC measuring devices proposed in the last few years, the design proposed by King et al. (1978) has met with the most acceptance. Its calibration and operation has been discussed by King et al. (1985). Particle Measuring Systems also makes a Forward Scattering Spectrometer probe that has been widely used for producing LWC measurements from an integrated droplet spectrum (Knollenberg, 1972).

Despite the successful use of these instruments on aircraft, they have not met with similar success for ground-based measurements of cloud LWC. Some of the problems are technical, such as providing an acceptable aspiration system or providing for long periods of unattended operation. Other problems are associated with the representativeness of a measurement of LWC at one point on a mountain. Multiple sampling points are usually precluded by cost ($10 000 or more per instrument), lack of the considerable power the systems require, or the absence of sufficient operators to maintain the systems.

A wide variety of passive cloud water samplers have been developed over the years to provide a measurement of cloud LWC, cloud water flux to the surface or, more recently, cloud water samples for chemical analysis (e.g., Nagel, 1956; Falconer and Falconer, 1980). Devices of this type are relatively inexpensive, require low maintenance and are reasonably robust. They do not, however, normally have a recordable

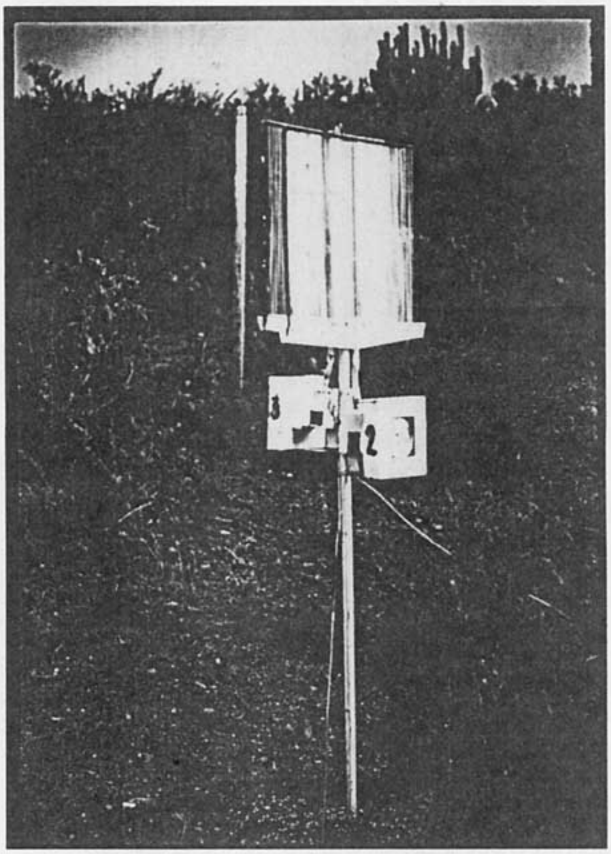

FIG. 1. Neblinómetro mounted at a field site showing the collecting surface (50 cm × 50 cm), the trough for the runoff, the outlet tube and the flow rate indicator. In this case two collectors were mounted together to look crudely at the collection efficiency.

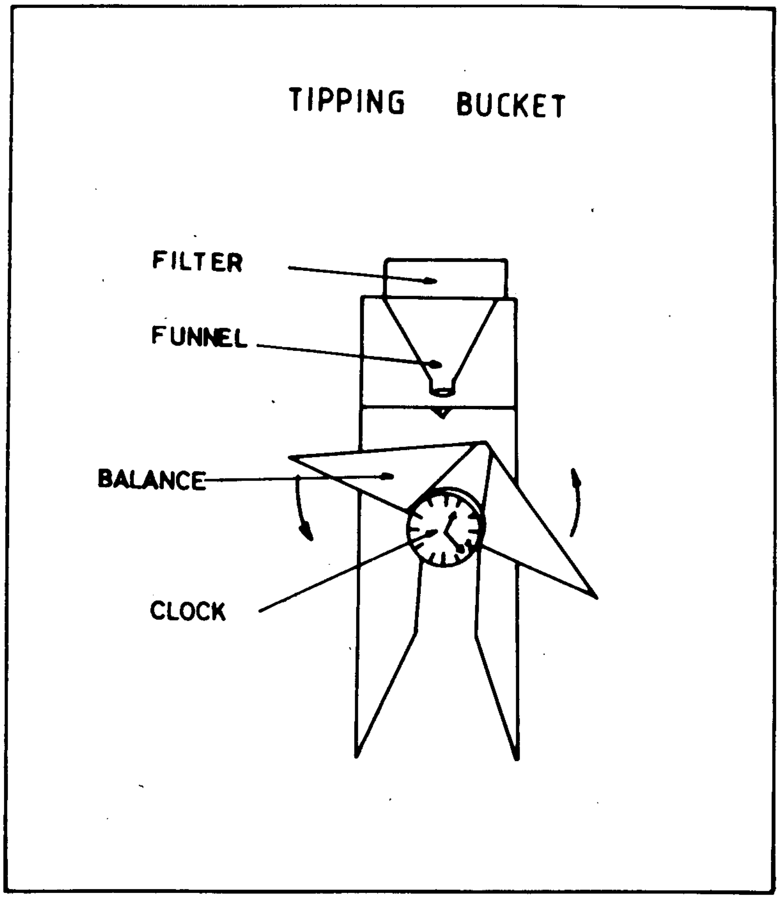

FIG. 2. Mechanism of the neblinómetro "alarm clock" volume rate indicator.

output. This note describes a passive collector that has been extensively field tested in Chile, and which has an innovative, inexpensive volume flow meter. It can provide relative measurements of fog water deposition in mountainous terrain and, with the addition of wind measurements, can provide estimates of fog (cloud-on-the-mountain) LWC. The data from the collectors will be used to determine if useful amounts of water can be removed from the clouds for human consumption and agricultural purposes.

2. Neblinómetro

The passive collector designed and built in Chile (Carvajal, 1982[1]) at the Pontificia Universidad Católica de Chile for a geographical study of fog is called a neblinómetro. The collector is shown in Fig. 1.

The neblinómetro is a device that captures the fog/cloud droplets on nylon filaments that are mounted in an iron frame. The panel size is 0.5 m × 0.5 m with a warp of 180 nylon threads of 0.4 mm diameter. The iron frame is 1 cm in diameter and is supported on a 2 m iron pole. The neblinómetro is commonly used with a device to measure the amount of collected water. It is simply an alarm clock which has had the internal clock mechanism removed (Fig. 2). The hands of the clock are connected via a shaft to a pair of tipping buckets. Water from the collector is fed through a tube to the buckets, which when tripped advance the hands of the clock. The operator only has to read the clock to determine the number of tips of the buckets and thus the amount of water that has been collected. The apparatus is simple, reliable, robust and requires minimal operator training. It can be left in the field for more than a year without operator maintenance or observation. By modifying the materials, it could also provide fog water samples for chemical analysis.

The buckets that receive the water from the collector can be made almost any size, depending on the appli-

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[1] Carvajal, N. H., 1982: *Antecedentes Generales, Observación y Cuantificación de las Neblinas, Sector Temblador, IV Region, Chile.* Memoria para optar al Título de Geógrafo, Pontificia Universidad Católica de Chile, Instituto de Geografía, Santiago, Chile.

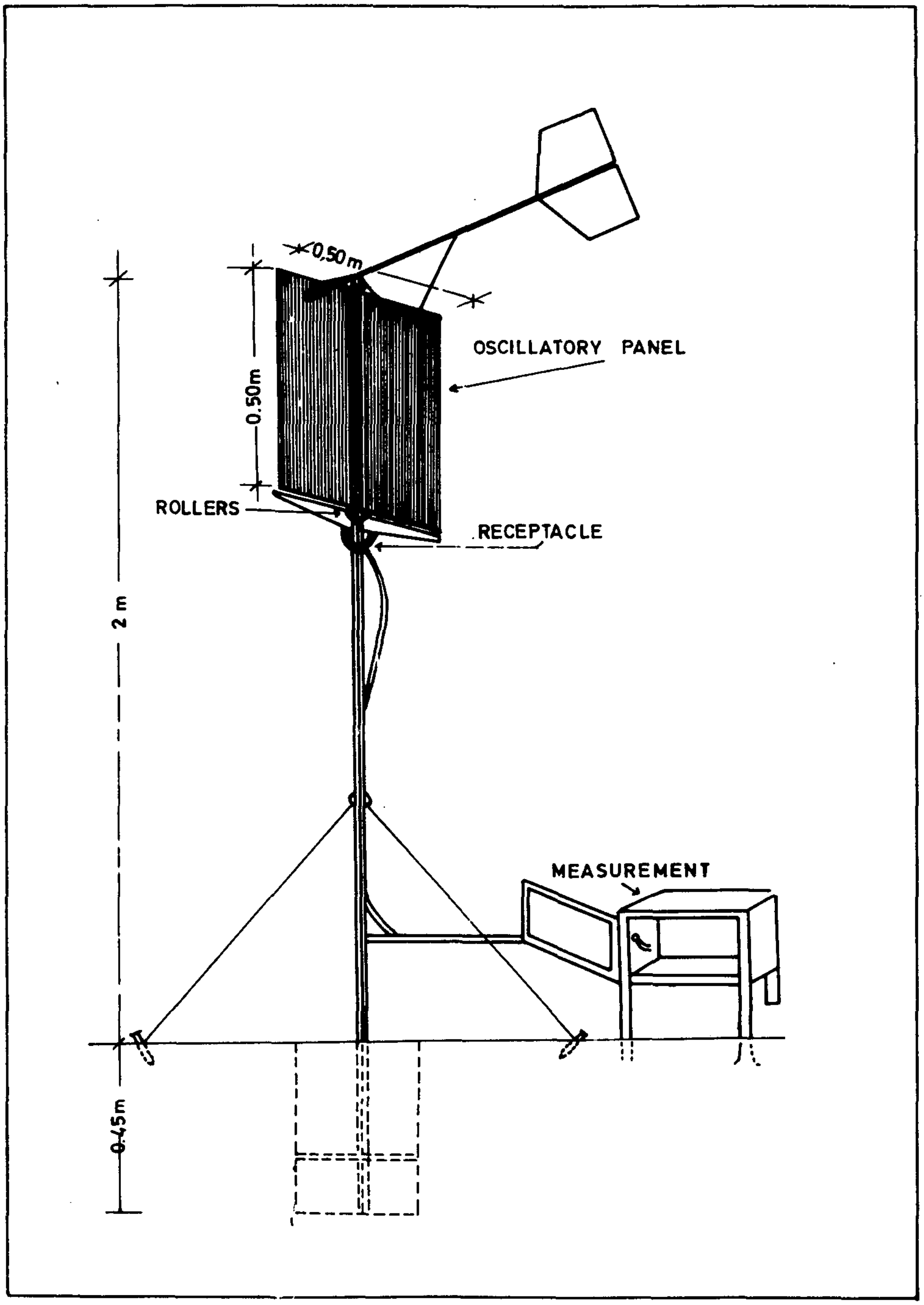

FIG. 3. Neblinómetro modified by the addition of a wind vane to orient the collecting panel normal to the wind. The panel is on rollers and feeds water to a receptacle and then a hose. The alarm clock flow rate meter in this case is in an external housing.

cation. In practice they usually have a volume of about 16 cm^3. Each unit is calibrated individually to allow for manufacturing differences. To move the clock hand 1 sec requires 3.3 tips. This corresponds to a collected volume of 52.8 cm^3 for the typical collector. The total volume collected since the last reading is easily determined even weeks or months later. There is no ambiguity in the readings, since to move 12 h requires

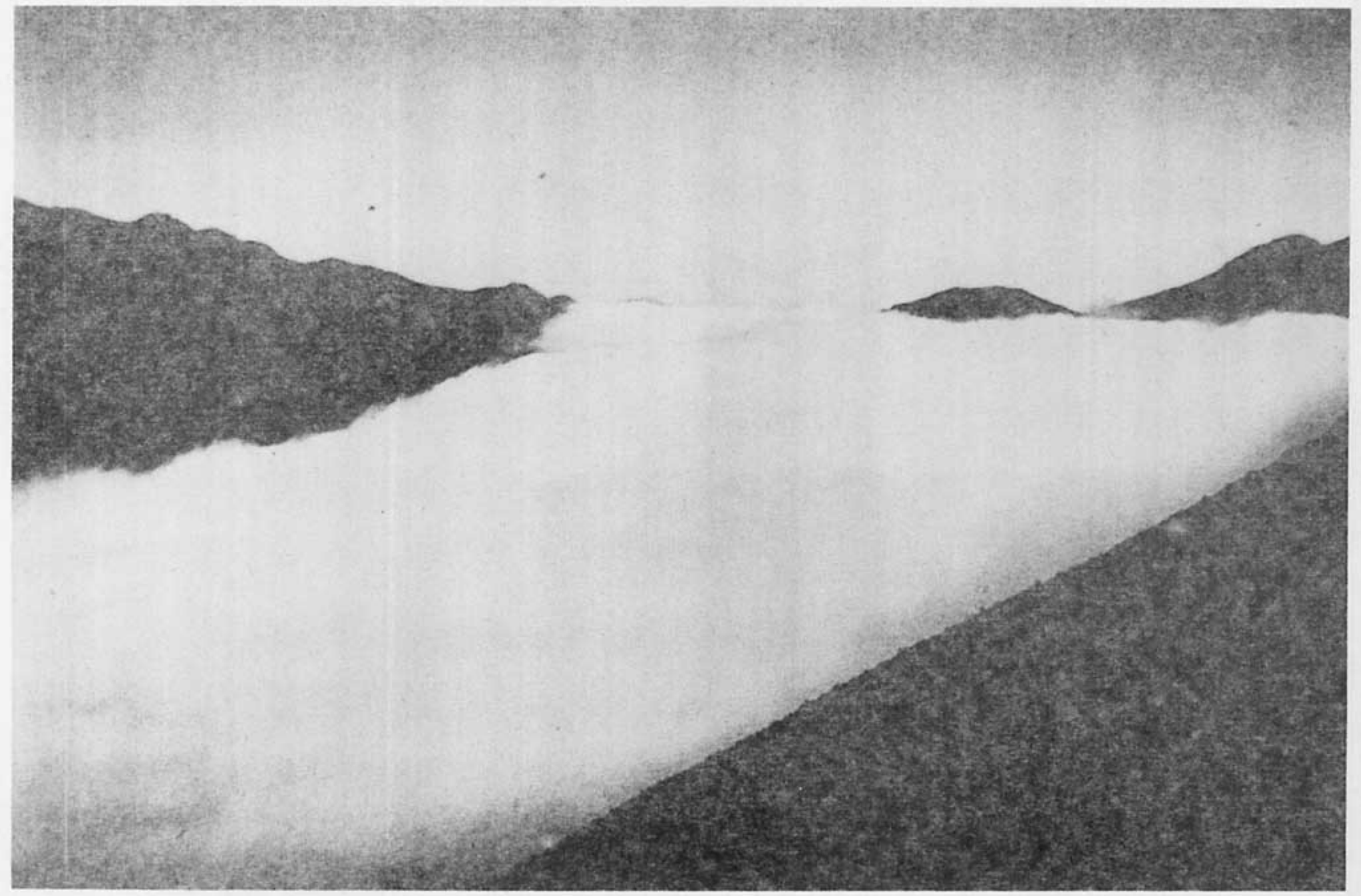

FIG. 4. Photograph of fog passing through the Portezuelo (a minor saddle point) as seen from near the summit of El Tofo.

142 560 tips. An average collection rate at the El Tofo site is 650 cm^3 per day, or 40.6 tips per day. Thus it would take 3511 days or almost 10 yr at this rate for the clock to change by 12 h. Higher collection rates are certainly measured, but the usefulness of the clock still extends for several years. The highest collection rate observed in dense fog on El Tofo corresponded to one tip every 16 sec or about 60 cm^3 per min.

A neblinómetro can be kept facing the wind by the addition of a wind vane (Fig. 3). This entails some minor modifications to the method for removing water from the collector.

The total cost of a neblinómetro (in Chile) is about $55.00 (United States currency). Materials for constructing and mounting the collector cost $5.00, the labor $8.00. Materials for the flow-totalizing mechanism, alarm clock, tipping buckets, etc. are $16.00 and the corresponding skilled labor is $26.00.

The collection efficiency of the neblinómetro for fog water has not been determined. Within the next year, measurements will be made simultaneously with a PMS FSSP and a PMS CSIRO device to look at this problem. If one calculates collection efficiencies as discussed by Langmuir and Blodgett (1961), one obtains for a 0.4-mm wide ribbon and an airspeed of 2 $m\ s^{-1}$ at 1000 mb and 20°C, a total collection efficiency of ~80% for 15-μm diameter droplets, ~65% for 10-μm diameter droplets and ~30% for 5-μm diameter droplets. Without measurements of the droplet-size spectrum, an exact collection efficiency cannot of course be determined; it seems unlikely that the mean volume diameter in these thin clouds is greater than 10 to 15 μm (it may even be lower), and therefore an assumption of collection efficiencies of about 50% for the droplets swept out by the threads does not seem unreasonable. In addition, since there may be some reduction of the ambient wind speed due to the obstruction of the collector and since the collecting surface (threads) makes up only 22% of the total cross-sectional area of the collector, a net collection efficiency almost 80% lower may in fact result, i.e., only 10% of the total fog water that would flow through a similar cross-sectional area

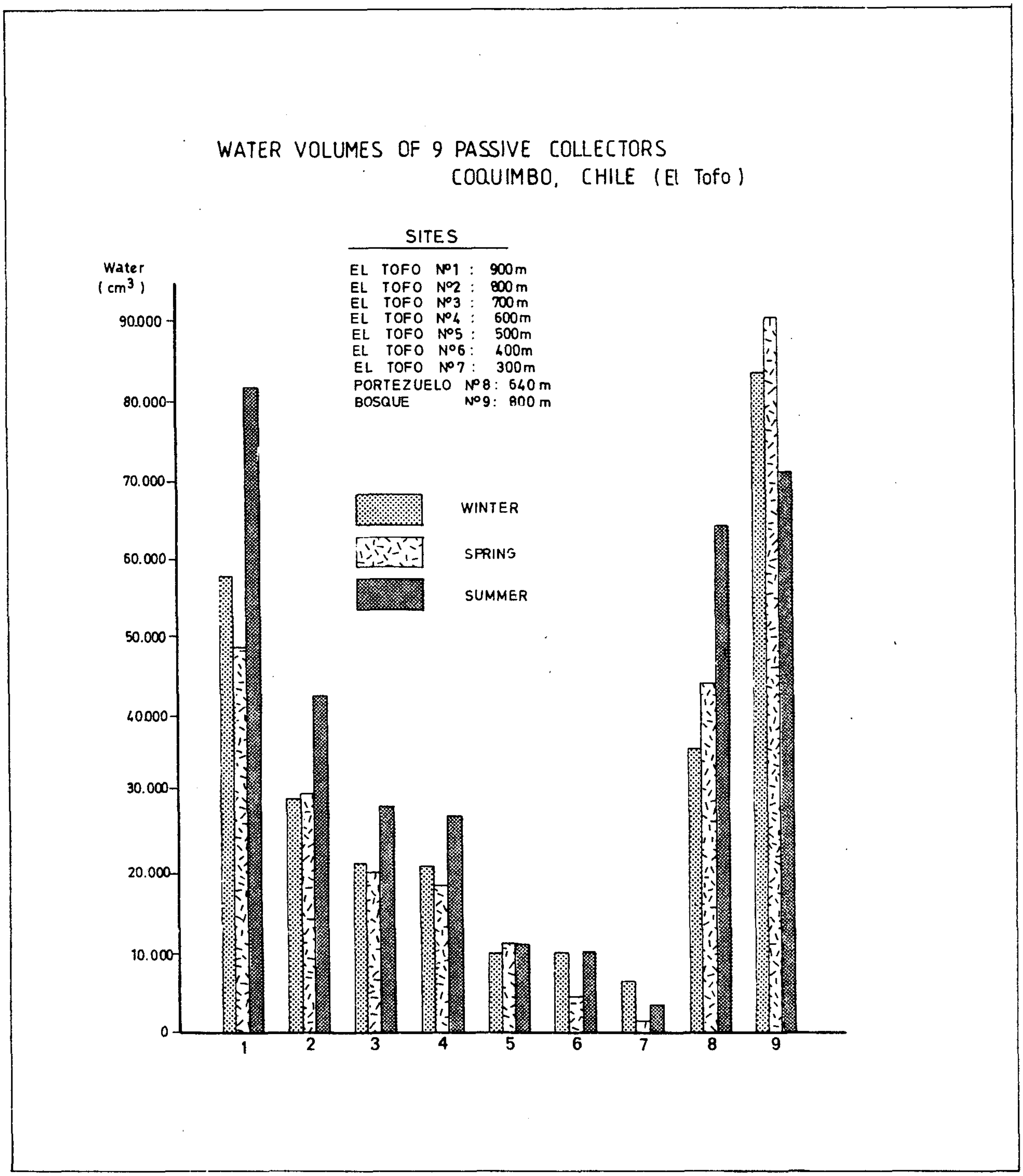

FIG. 5. Amounts of water collected by neblinómetros at nine locations (Fig. 6) from June 1982 to March 1983. The data are divided into amounts by season.

would be collected. Wind speeds higher than 2 m s^{-1} are not common, but when present, would increase collection efficiencies (to 90, 80 and 55% at 5 m s^{-1}, for example). Because of the rarity of these winds, the longer term collection efficiency would remain in the 10% range. For applications in other environments with

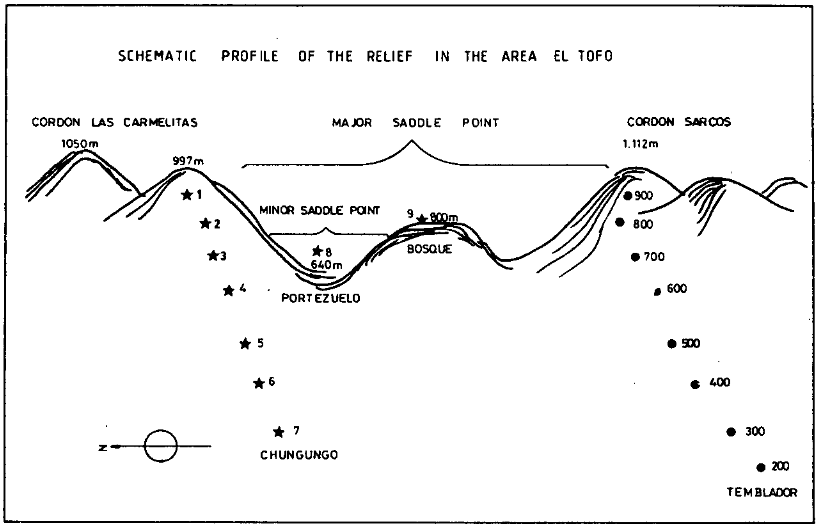

FIG. 6. Sketch of the topography and sampling locations in the vicinity of El Tofo. The sampling locations are marked with a dot on Corden Sarcos and with a star on El Tofo, El Portezuelo and El Bosque.

higher wind speeds, wind tunnel collection efficiency calibrations may be valuable. Operations at temperatures < 0°C could also be examined in a wind tunnel.

3. Field measurements

An interesting meteorological phenomenon in the arid zone of Chile is the almost constant presence of coastal stratocumulus decks that result in persistent fogs in regions of the coastal mountains (Fig. 4). These fogs have been studied for some time with the idea of utilizing the water for reforestation. A few results from a study on and near El Tofo, a coastal mountain in the region of Coquimbo (29°26′S, 76°16′W), are presented to illustrate the use of the neblinómetro. The purpose of the study was to determine the variation in fog water deposition with altitude, and to examine the

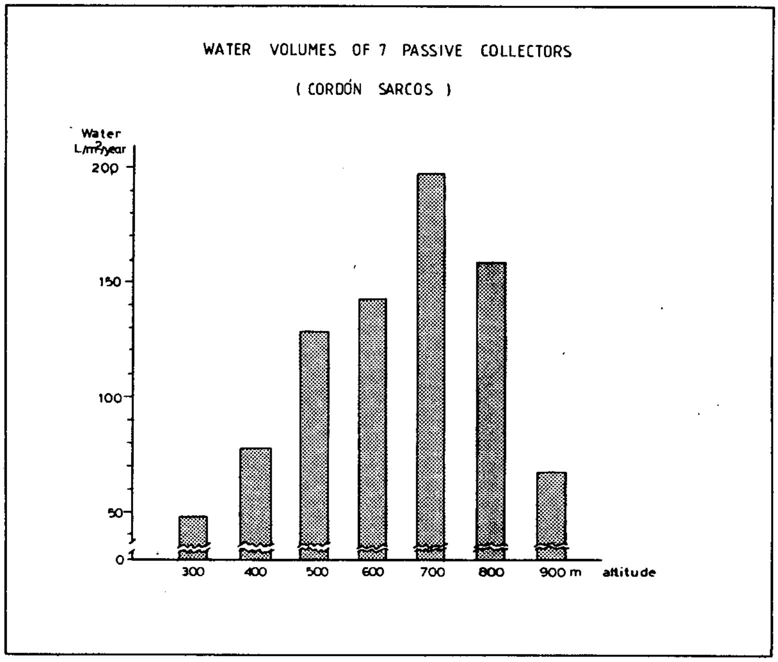

FIG. 7. Normalized fog water collection for seven locations (Fig. 6) on Cordon Sarcos near El Tofo.

effects of topography on the fog water collected (Cereceda, 1983[2]; Larrain and Cereceda, 1982[3], 1983[4]).

A set of seven neblinómetros was installed on a hillside with a southwest exposure at altitudes from 300 to 900 m at intervals of 100 m. The collectors faced the prevailing wind. Two additional collectors were installed on a nearby summit (El Bosque) and saddle point (El Portezuelo). The amounts of water collected by the neblinómetros were measured once a week from June 1982 to March 1983. Figure 5 shows the amounts of water collected at the nine locations as a function of the season. Figure 6 shows the local topography and the sites. The amount of water collected depends, of course, on the number of hours of fog, the fog LWC and the wind speed. These are not yet well defined at these locations. The integrated effect of these factors is, however, well documented by the neblinómetros. The amount of water deposited on the collectors shows a strong increase with altitude at El Tofo. It is also interesting that at 800 m on a minor summit (El Bosque), in the major saddle point, the fog water deposition is much higher in all seasons than at the same altitude on the flanks of El Tofo. Figure 7 shows the normalized (per square meter per year) collection rates at seven locations on the nearby Cordon Sarcos. The peak cloud water collection rates were at 700 m on the Cordon Sarcos, and then dropped off with altitude to 900 m. Maximum amounts were collected in the summer. The collection of fog water on these mountains is a complicated function of both the local topography and the height of the inversion produced by the subtropical anticyclone which caps the cloud deck. Measurements of relative fog water deposition can provide insight into these mechanisms.

4. Conclusions

A device for the collection of fog water and the measurement of fog liquid water deposition has been described. The neblinómetro has the advantages of being low cost, requires low maintenance and is very reliable. It can provide relative values of fog water deposition which are useful in defining the cloud climatology of mountainous regions, and with the addition of wind measurements, can give an estimate of the actual LWC. In late 1987 as many as 40 neblinómetros will be deployed on a mountain in northern Chile. The results will be analyzed in concert with supporting meteorological and cloud physics measurements.

There is an increasing emphasis on mountain cloud chemistry and the desire to measure the deposition of cloud water on forests (e.g., Schemenauer, 1986). Relatively simple measurements as described here can contribute to our understanding of the physical and chemical processes taking place.

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