REMOTE SENSING: METHODS AND TECHNIQUES TO DETERMINE POTENTIAL AREAS FOR FOG WATER COLLECTION*

by

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1. Introduction:

Chile has been a pioneer in the massive use of fog water collected by artificial devices for domestic use, forestry, agriculture and other purposes. After decades of experience, there are some considerations that can be analyzed in order to improve the scientific studies, the technology and the social and economical issues. In this paper, the use of satellite images for the determination of the stratocumulus cloud behavior and the potential areas for fog water collection will be discussed.

In Chile, the studies about fog have been undertaken since the middle of last century. In the sixties, in the northern Atacama desert, the studies began in relation to the possibilities of collecting fog water by artificial means (Espinosa, 1982) and several preliminary investigations were done in order to understand the hydrological potential of the clouds of Antofagasta. The geophysical aspects were also studied at that time, in relation to the origin and displacement of the low stratocumulus deck (Fuenzalida et al., 1988 and 1989), and the importance of the inversion layer in the cloud dynamics (Espejo, 2001). In the 80´s the geographers began to study the behavior of fog in its spatial and temporal dimension (Schemenauer et al., 1994, Osses et al. 1998) . Questions such as what type of relief, altitudes, slopes, and expositions are the most adequate for fog were investigated (Schemenauer et al. 2003).

Actually, there are geographical methods for detecting the best places with high frequency of fog , techniques to study the potential for fog water collection, and large or massive systems for the collection of the water. A project funded by the National Commission of Science and Technology of Chile has studied the possibilities of the GOES satellite images to explore the stratocumulus cloud behavior and the formation of fog.

Choosing places to evaluate fog water collection potential has been made until now in an empirical way, however in the last three years, the research done in the Atacama desert with remote sensing has given good results. Between May 2001 and April 2003, around 11.000 GOES-Imager scenes were stored and part of them has been digitally processed and analyzed. The first tasks were to define adequate algorithms to discriminate stratocumulus from the other elements and to define a methodology for analyzing spatial and temporal behavior of this type of low cloud . It is possible to calculate area and frequency of stratocumulus coverage and define places where fog can be used as an hydrological resource. Investigations have been don to know in what place in a mountain range has more cloud coverage, what season is the best for fog water collection, and what is the diurnal, monthly or annual behavior (Farías, et al, 2002). Also the definition and application of a methodology to test the results of GOES images in real time, from the study area, was done in 2002 (Osses, et al, 2002).

2. Fog studies: background

2.1. Geographical fog surveys by cartographic analysis and field work

Many scientific investigations have been done in order to find places for fog water collection. Some studies in islands have given important clues to understand the coastal fog dynamics. In the Canary Islands, Dr. Marzol has studied in Tenerife, the geographical aspects of fog and has quantified the water collection in several places, and has analyzed its relationship with meteorological parameters and the relief (Marzol, 1994, 1998). Similar studies were done by J. Juvik and Ekern in Hawaii since the decade of 1950; they have worked in several islands and have made relations with vegetation (Juvik and Ekern, 1978; Juvik and Nullet, 1998). In Cape Verde, Goncalves and Cunha have done experiments to use fog water and Sabino (1998, 2001) is doing projects on agriculture and forestry. In Chile, several studies were done in the Robinson Crusoe island in the Juan Fernández archipelago, in order to understand the spatial distribution of rain and fog in relation to the relief, and also about fog water chemistry (Cereceda et al, 1996; Cereceda et al., 1998).

Places, similar as the northern Chilean coast, such as South Africa and Namibia, have also been studied. These countries are located in the western and southern parts of the continents and have similar anticyclone, wind and ocean current patterns. In the first country, Dr. Olivier did an important study of fog distribution using conventional meteorological stations where visibility was reported. She and her scientific team also evaluated several places in mountain ranges and had operational projects (Olivier, 1997, 1998; Van Heerden et al. 1998, Louw et al., 1998). In Namibia, fog has been studied for several years with a Grunow instrument and actually, standard fog collectors (SFC) have been used to study fog distribution and water collection potential (Mtuleni, 1998). The same methodology was used in the Sultanate of Oman (Cereceda et al., 1990) and before, Stanley – Price (1988) had done a survey in the mountains of Salalah.

In the coastal mountains of South America several researches have been done in Ecuador, Perú and Chile. They all have similarities as a mountain range near the sea, trade winds, Humboldt current, Southwest Pacific anticyclone and the presence of deserts and semi deserts (Cereceda et al., 1998). Schemenauer has reported other surveys done in countries of Asia and in Central America (Schemenauer et al., 2003).

What all this studies have in common, is that they have been looking for fog water as an hydrological resource. In almost all this places water is scarce and there is a real need of water for people. However, biologists, ecologists, botanists also study fog in order to understand its role in the ecosystem, either in deserts or in the humid tropics. The studies only cover small areas and the results are referred to the places where the instruments have been placed. Some parameters can be used to extrapolate the results to other areas, but there are many factors that play a role in fog distribution and fog water collection potential. To advance in this issues it would be interesting to have a map of fog distribution at a regional scale, such as what Stone did in the United States in the 30´s with meteorological stations data (Stone, 1936) and the studies of Court and Gerston in 1966 or Peace, in 1969 in the same country. However meteorological standard stations in Chile are not adequate for this type of research, since they are usually located where people live, and foggy environments are not the best sites. Schemenauer and Cereceda (1991) did a study of the occurrence of fog in Chile using the meteorological records (visibility) of standard stations in 24 coastal sites and 18 inland sites of the country and conclude that in the northern desert, they are not located in the fog belt.

2.2. Geographical fog survey by remote sensing analysis

Some studies have been done to study fog distribution with remote sensing; one of the most important was done by Dr. Jörg Bendix from the University of Bonn with other European scientists. They studied fog in the Alpine Region, in the valley of Po river with NOAA-AVHRR. This method is based in a series of calculations of the properties of the fog (albedo and optic depth). The detection of fog was done by the differences of temperature between the mid infrared and thermal bands. The results were verified in standard meteorological stations and with a system of observations and measurements specially prepared in the field. They determined the top and base of the cloud with radiosondes and digital model of elevation, visibility and water content and discrimination between advective and radiation fog (Bendix J. and M. Bachman, 1993); Bendix 1995).

3. The Tarapacá Project: field research and remote sensing

This research, that began in 1997, has the two components above mentioned: field site research and remote sensing. In order to understand the formation of fog in the northern part of Chile it is necessary to study the stratocumulus cloud of the South Pacific and the geographical features of the continent. In this project, the cloud was surveyed with GOES images, penetration corridors to the continent were analyzed using a digital elevation model (DEM) with NOAA-Avhrr images (since they have higher spatial resolution) and fog was studied in a coastal field site with SFCs and sensor for air and soil temperature and relative humidity.

3.1. The South Pacific stratocumulus cloud and the Chilean fog.

In the case of Chile and Perú, advective and orographic fog is typical in the coastal deserts. The stratocumulus cloud located in the Southeastern Pacific is being studied because of its influence in the world climate, due to its persistence in time and the wide surface it occupies. VEPIC (VAMOS East Pacific Investigation of Climate) congregates scientists of all over the world to study this phenomenon in its various perspectives, specially its meteorological properties. An interesting study was done in a transect from the Chilean coastal port of Caldera to Eastern Island in 15 days of October 1999. Measurements of temperature, relative humidity, solar radiation, pressure and winds were done, and radiosondes were used (Garreaud, 2001).

These investigations are very important to advance in the scientific knowledge of cloud and fog. However, for the purposes of fog distribution, it is necessary to study the presence of the cloud, the altitude at which it is located and the relief that will intercept it. If the altitude of the relief features is not enough to intercept it, the cloud will continue its way inland, but if there is a mountain at the correct altitude, then advective fog will be formed (fog is a cloud at land level). Orographic fog is also frequent and it is formed by the arrival of humid air masses from the Pacific into the continent. The cliff and the coastal range oblige the air mass to ascend and a cloud is formed due to the cooling processes. The pattern shown is of spots or strips of cloud/fog in the high mountains. The theoretical background and the field data acquired during 1997-2001 were given in Cereceda et al., 2002 and Larrain et al., 2002.

3.2. The GOES satellite images process

The study area is a wide portion of ocean and land in the north of Chile between 19°48´S - 22°00´S and 69°00´W - 71°00´W, in the Region of Tarapacá. The total area is 57.500 km^2, where 57% is in the continent and 43% is over the ocean. The predominant relief is a coastal mountain range that ends in a huge cliff facing the sea (Fig. 1).

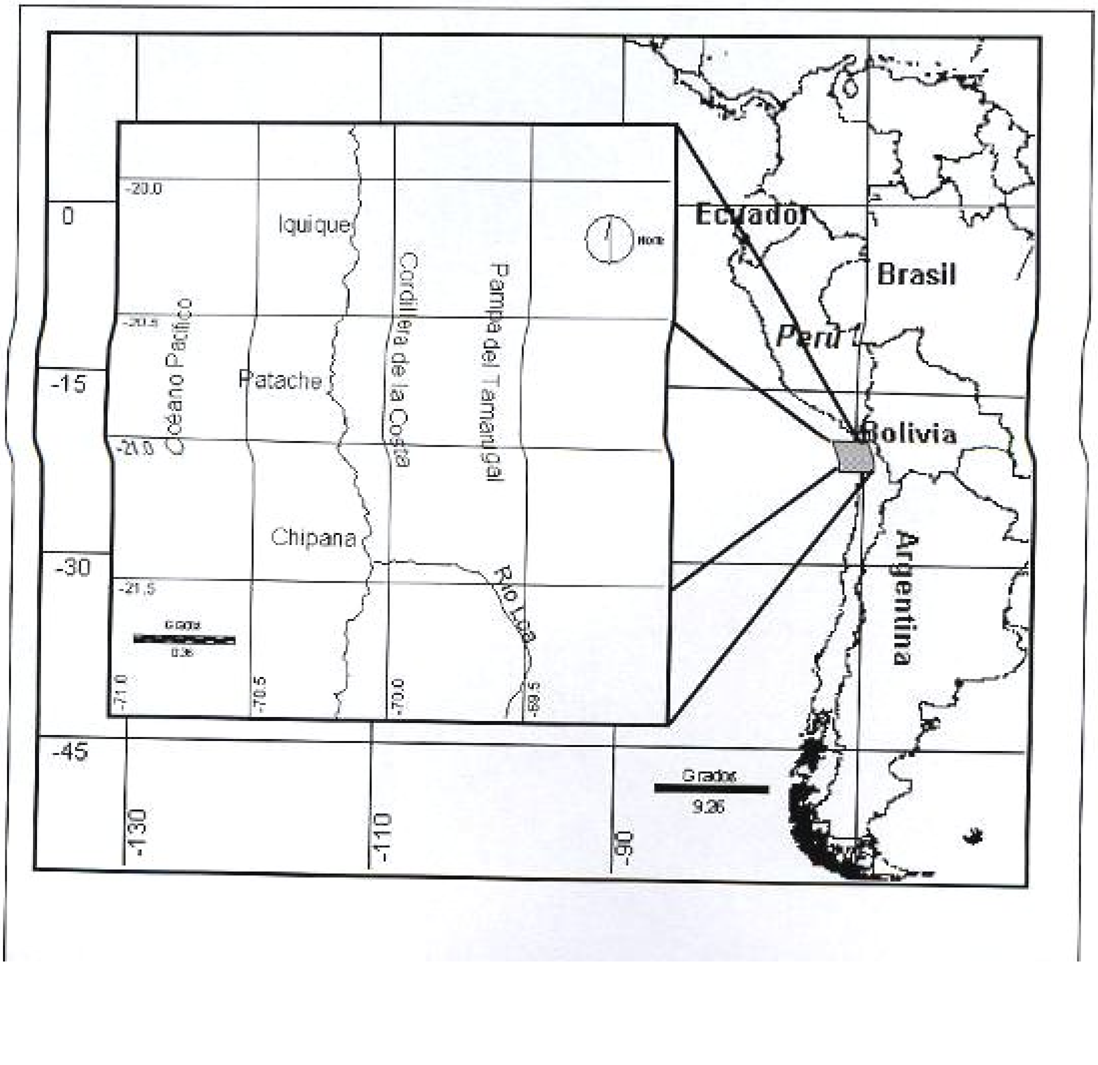
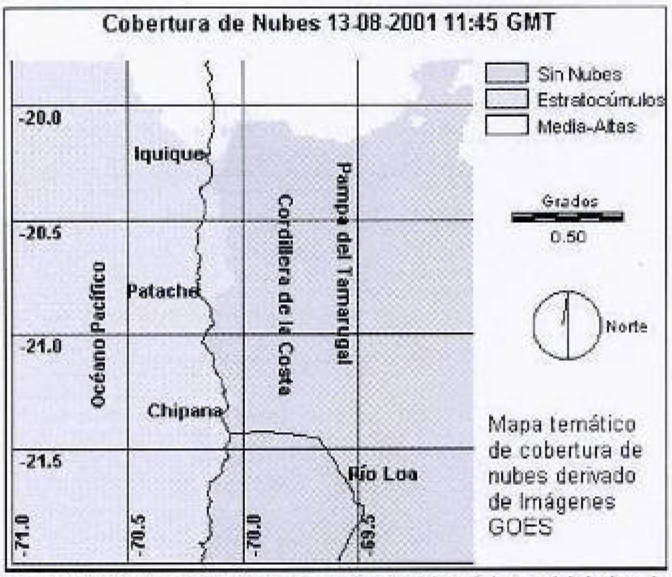


Fig. 1.- The study area.

The methodology of GOES images processing has been discussed in other papers (Farías et al., 2001; Osses et al., 2002). Algorithms were elaborated to discriminate low clouds and its classification of categories are done by spectral thresholds and change detection. As a result of the digital GOES image processing, thematic maps each 90 minutes are obtained with



three categories: without cloud, with low clouds and mid and high clouds (Fig. 2).

Fig 2. Thematic map derived from GOES images.

The spatial and temporal behavior analysis can be done with the results of the thematic maps done by the image process (Farías et al., 2002). The following information can be analyzed by this method: the total cloud coverage in the study area; the cloud coverage in the sea and the cloud coverage in the continent: the daily behavior of cloud coverage detecting maximum and minimum expansion of the cloud; the weekly behavior detecting the areas covered by the cloud; the monthly behavior detecting the areas covered by the cloud; discrimination between advective, orographic and radiation events. Maps of frequency of cloud cover can be done in order to find the places where the presence of it is more permanent. Figure 3 shows the development of an advective event every 3 hours (originally the monitoring is each 90 minutes).

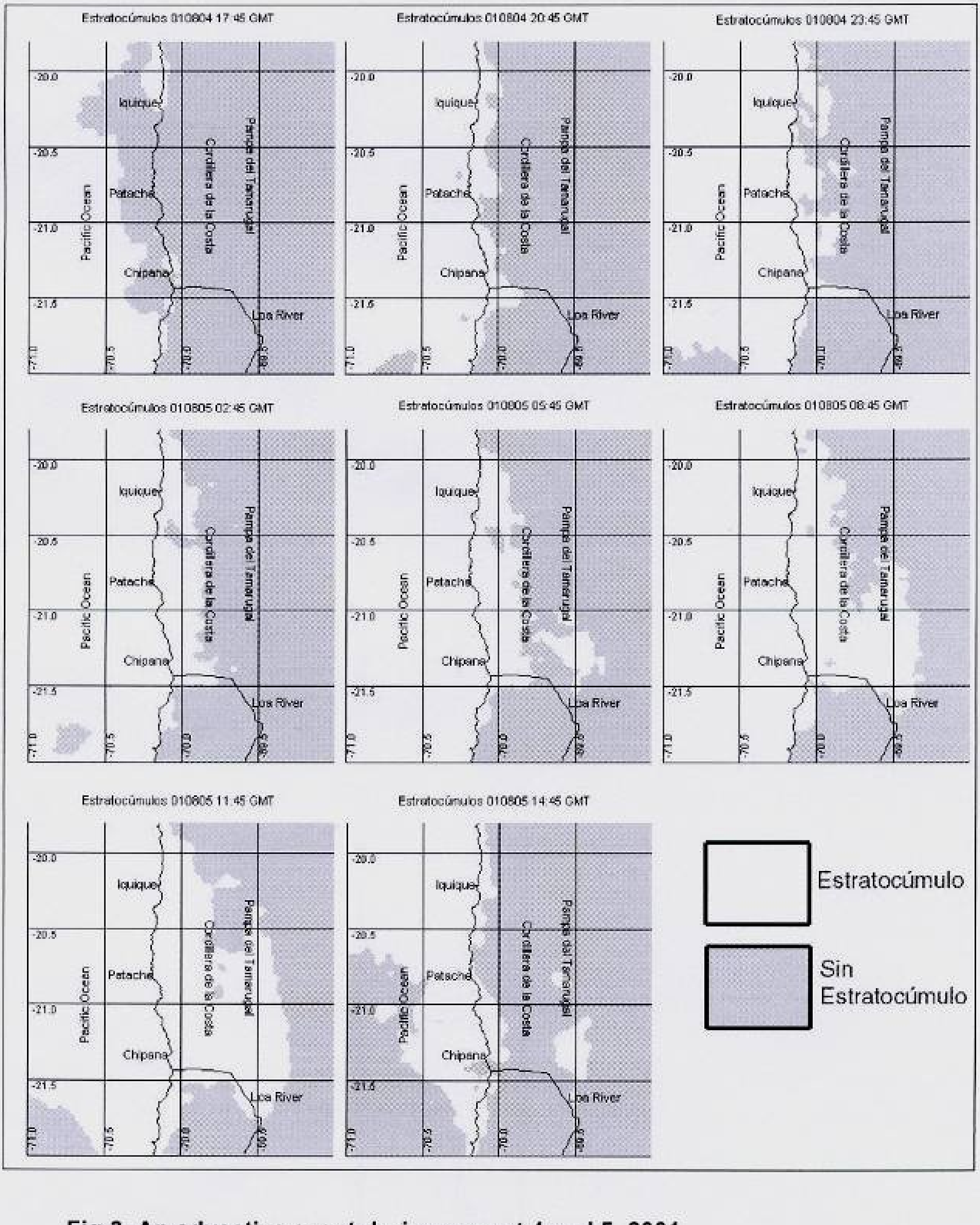


Fig 3. An advective event during august 4 and 5, 2001.

3.3 NOAA images and DEM

The digital elevation model (DEM) show geomorphological features, slopes and exposure and several views are done in two or three dimensions with different orientations to distinguish the relief and its relation to the spatial behavior of the cloud (Fig 4).

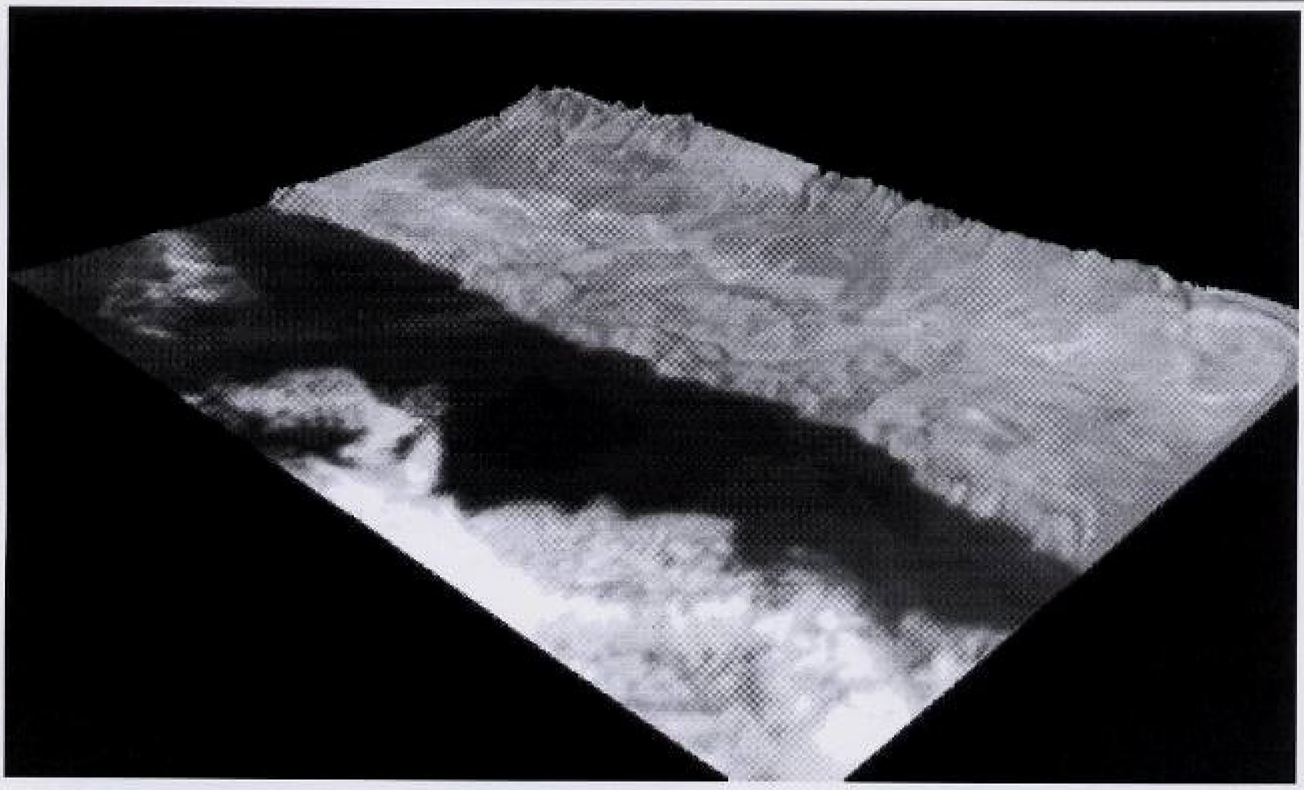


Figure 4: South-west view of the study area using DEM and NOAA Images.

The analysis of the relief in the DEM and the results of cloud cover in the images will give the places where the cloud reaches the terrain. In that case, it is highly probable that fog is present (Fig 5).

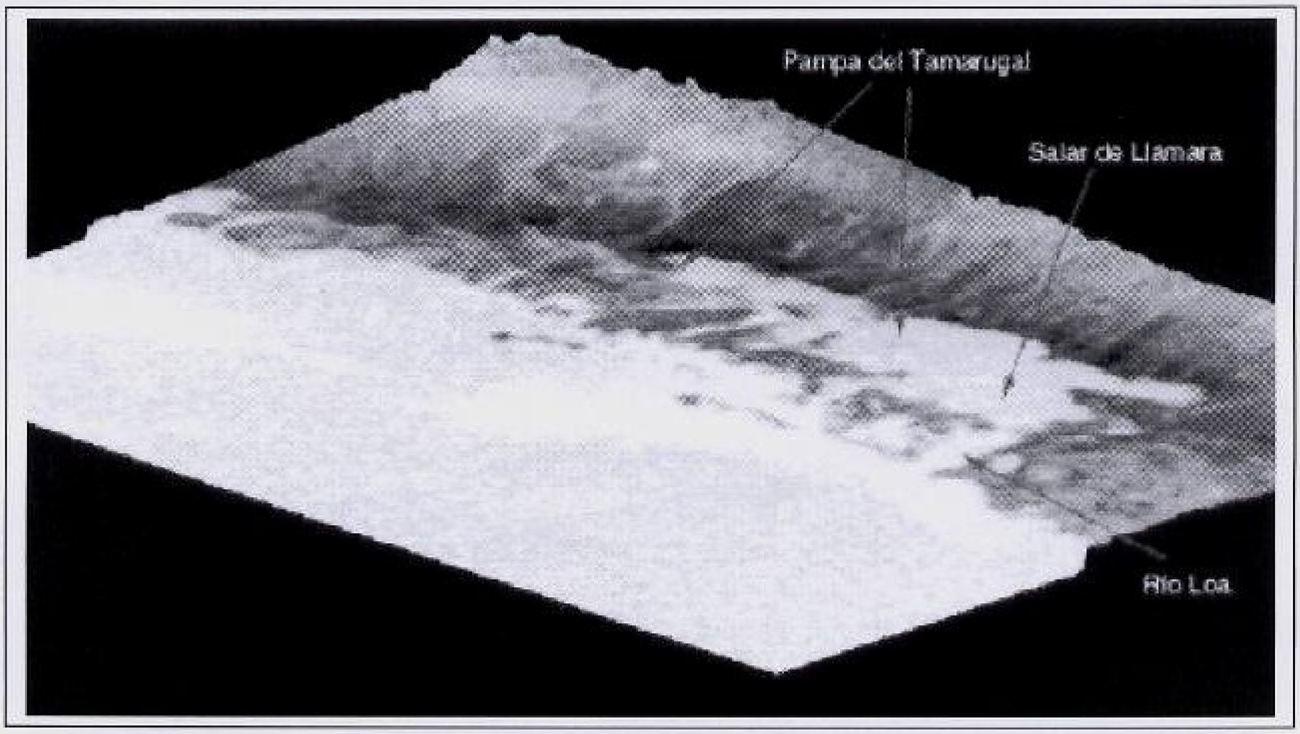


Fig. 5: DEM and NOAA image of the study area with cloud cover

One of the objectives of this study is to detect corridors or path where the cloud penetrates from the ocean into the continent, in Fig. 6, seven corridors were identified and they coincide with low plains or valleys

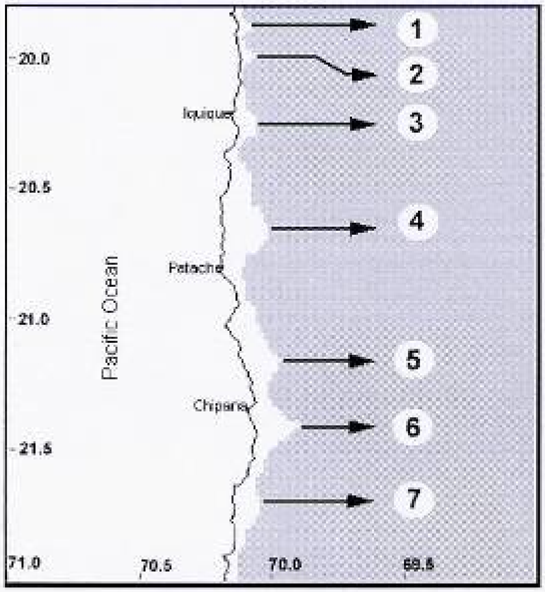


Fig. 6: Cloud penetration corridors in the study area

3.4. Ground truth

The method described show the top of the cloud, but does not prove its contact with the land nor if fog is present in the area. In order to verify the results of cloud cover, an experimental field work was done during 10 days in July 2002.

The way to do this procedure was to find a place high enough to be over the cloud and have visual points (mountain peaks) to observe the cloud top. This was done in Cerro Carrasco of 1.596 m.a.s.l. Another field site of observation was located in the area where usually the cloud intercepts the terrain (frequent fog). This place was Alto Patache at 750 m.a.s.l, where research has been done since 1997. A third group of observers was located under the base of the cloud at 450 m down Alto Patache, where the altitude of the base of the cloud was observed. To do this step a set of SFCs were located each 100 m as mark points. In the three stations, the observers also registered temperature and wind direction and velocity at the same GOES hours (Fig. 7).

The methodology used followed these steps:

a) Process of 10 GOES images each day in laboratory and thematic maps for each situation were elaborated. The hours were chosen having in mind the most representative times of fog presence; they were 03:09, 04:45, 07:45, 09:09, 13:45, 15:09, 16:45, 18:09, 19:45, 21:09 Local Time.

b) In Cerro Carrasco, visual analysis was done of the cloud cover and 100 thematic maps were drawn at the same hours that the GOES images were processed. The period chosen was with full moon in order to have night observations (Figs. 8 and 9).

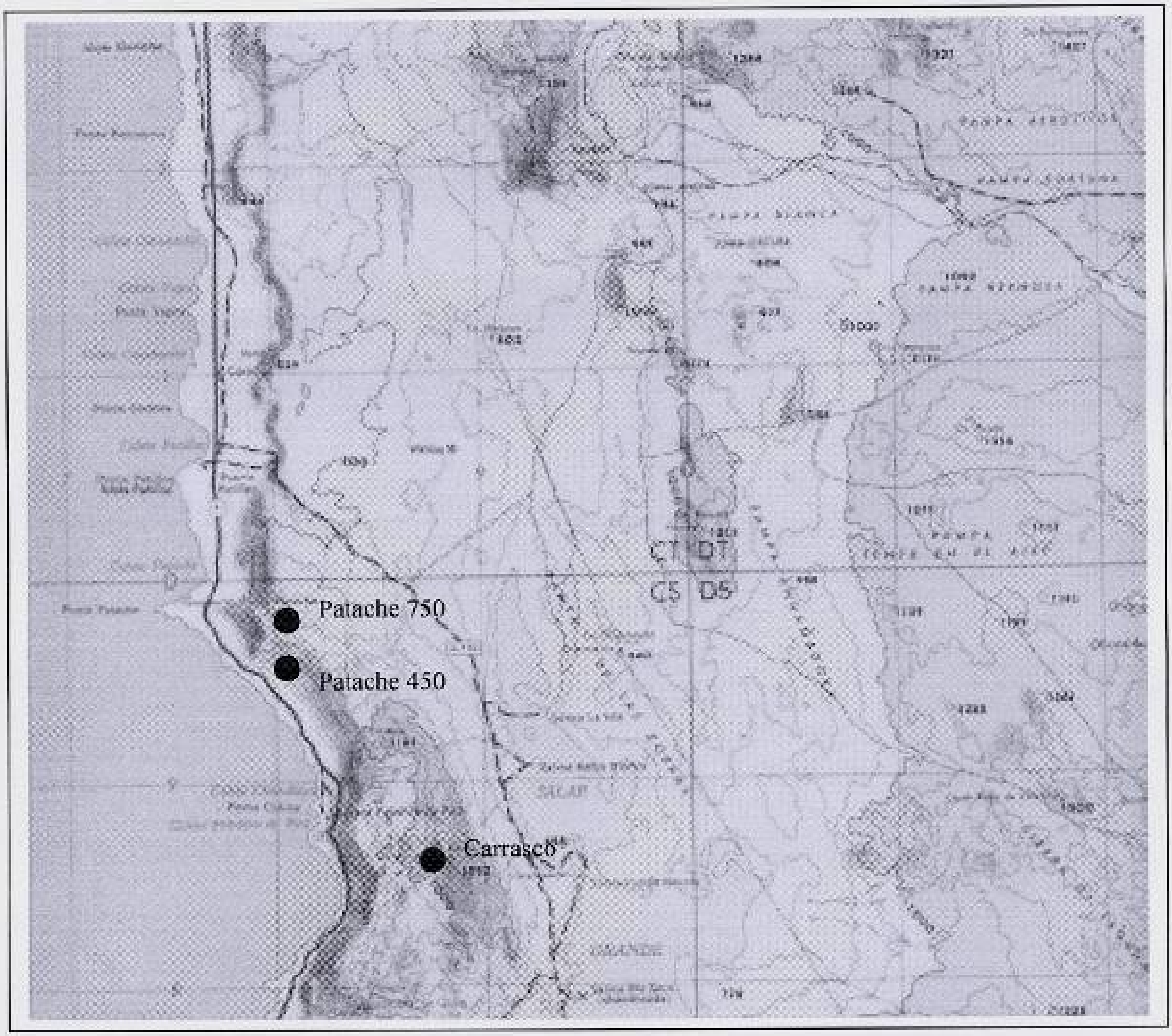


Fig. 7: Field sites

c) In Alto Patache 750 m, visual analysis was done of the presence of fog and fog water collected was quantified in the period.

d) In Alto Patache 450 m, visual record of the height of the base of the cloud, temperature and wind velocity and direction.

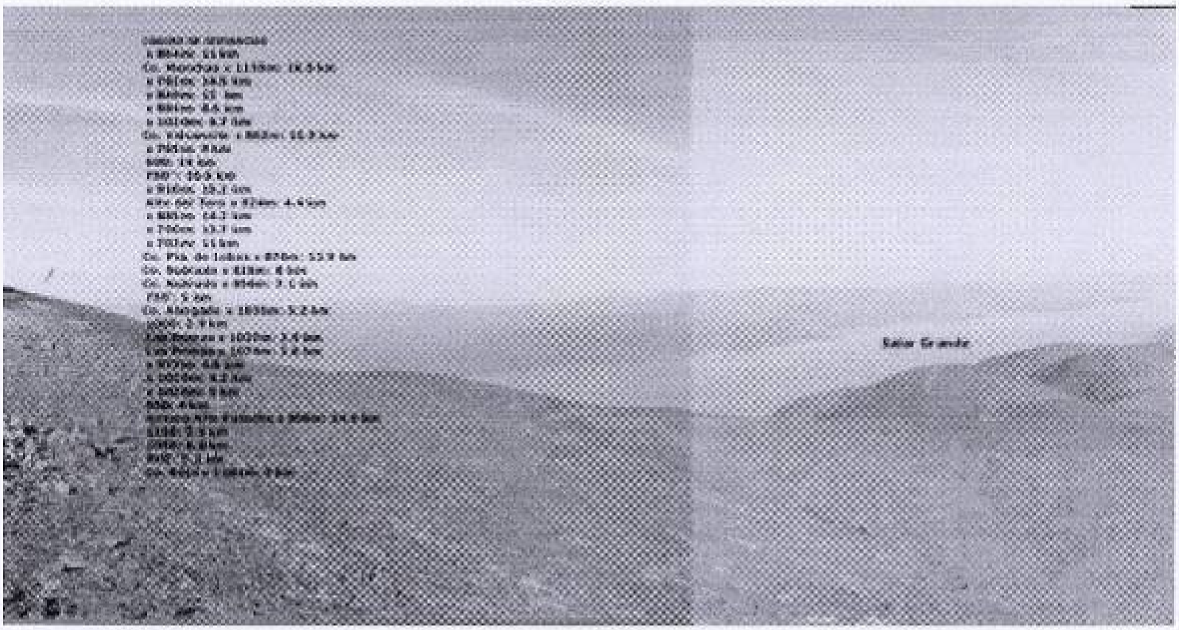


Fig. 8: Distances from Cerro Carrasco

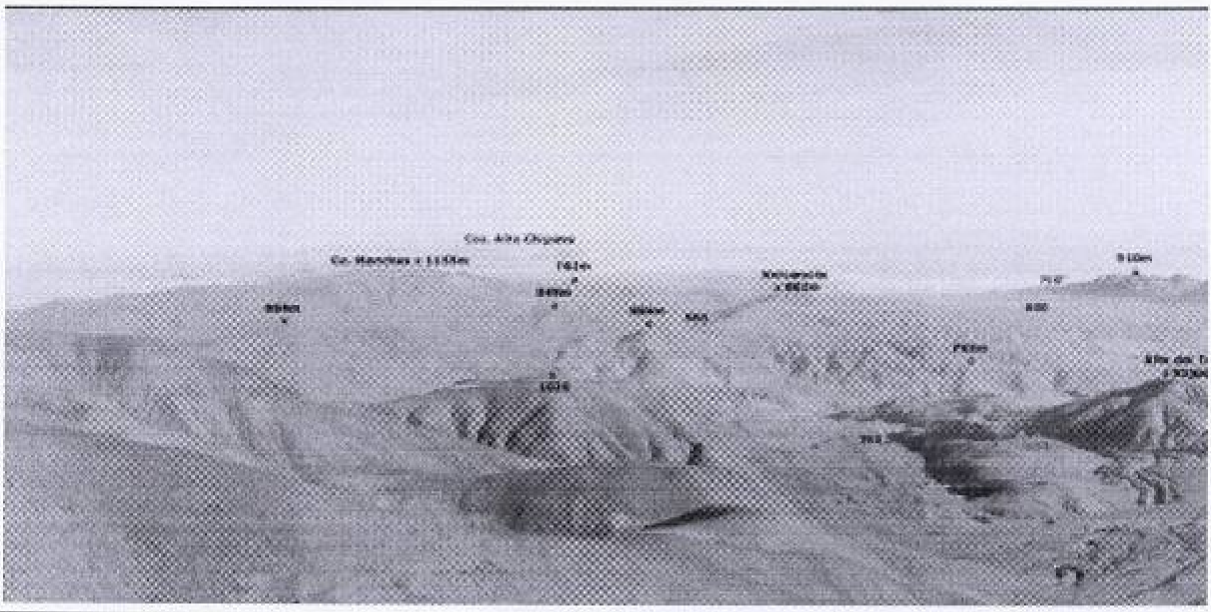
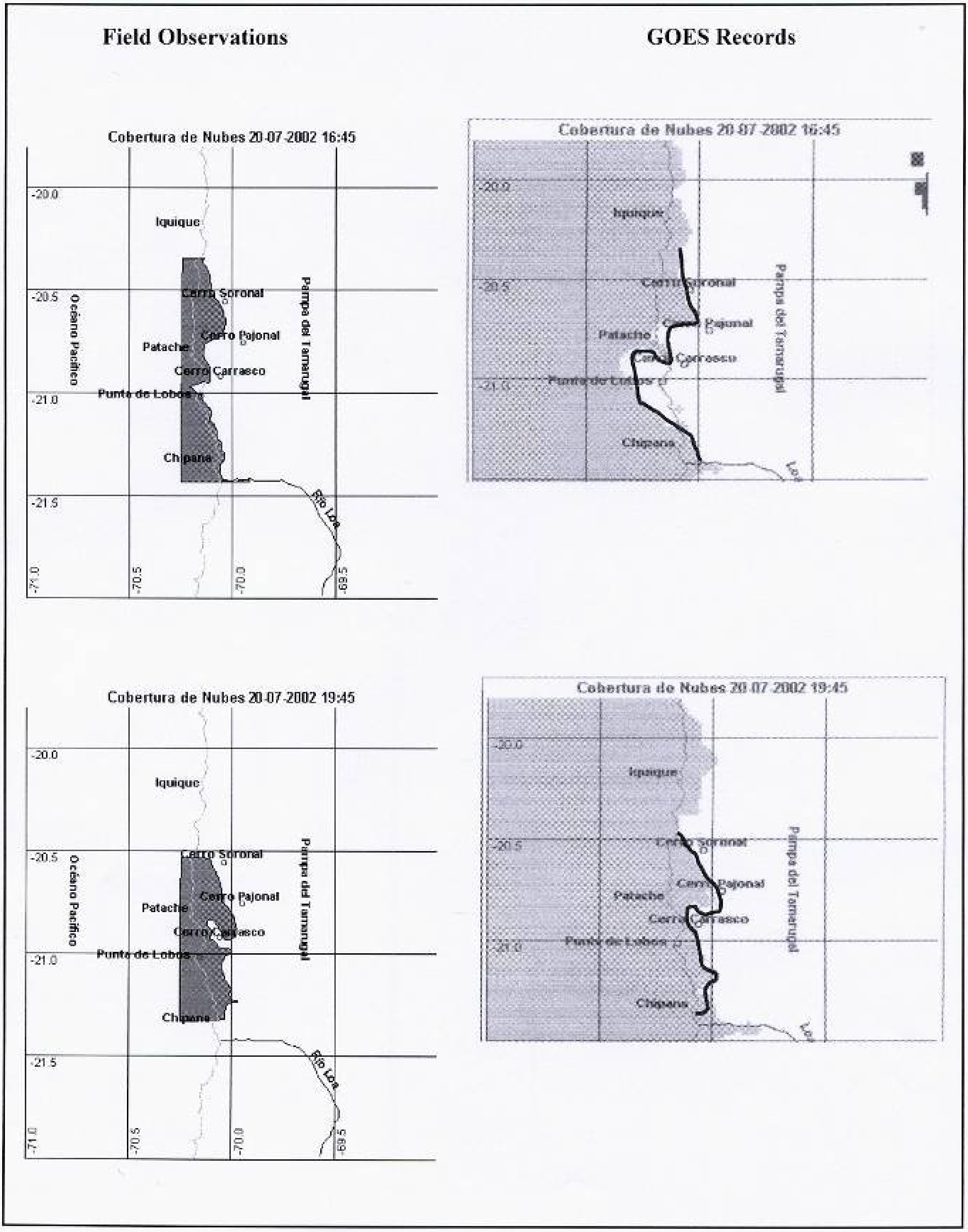


Fig. 9: Mark points from Cerro Carrasco

At the present time, the elaboration of the digital thematic maps of the field drawings are being done, and it is expected to have the information processed at the end of this year. In this opportunity, some results will be shown in order to illustrate the potential of GOES to determine areas with frequent cloud/fog presence.

Preliminary results show concordance between what was observed in the GOES images and the field observations. The comparison of the maps obtained by GOES and by the observers in Cerro Carrasco can be seen in the set of couple maps shown in Fig 10, There are similarities between both maps, this means that the digital process done from the satellite images are in concordance with what the observer saw at the same time and place. Even though this visual comparison show that they are very similar, it is necessary to do a digital process to make the matching and quantify the differences and similarities of both temathic maps.


Field Observations
GOES Records
Cobertura de Nubes 20-07-2002 16:45
-20.0
Iquique
-20.5
Cerro Soronal
Océano Pacífico
Cerro Pajonal
Pampa del Tamarugal
Patache
Cerro Carrasco
-21.0
Punta de Lobos
Chipana
-21.5
Río Loa
-71.0
-70.5
-70.0
-69.5
Cobertura de Nubes 20-07-2002 16:45
Cobertura de Nubes 20-07-2002 19:45
Cobertura de Nubes 20-07-2002 19:45

3. Conclusions

Fog is an hydrological resource that is being used in many parts of the world. In order to use fog water it is necessary to do a survey on its temporal and spatial behavior. The most frequent methodology has been done primarily until today in an empirical way in local scale. In order to study a wide area, remote sensing can be an efficient tool to give a quantification of the surface covered by cloud and the frequency of it. Verification of the results of GOES images processes done in a field work in July 2002, showed that there is a high concordance between the data processed in GOES and the data processed by observers in different sites of the study area in Tarapacá, Chile. This results are important for the identification of foggy places and can be used for operational projects for fog water supply. Since the results give a preliminary information, it is necessary, once the site for the location of massive fog collector system is defined, to install SFCs to approach the potential of water collection by artificial devices. Testing the GOES possibilities is the beginning of a scientific issue, since new satellites have been put in operation in the last years, and probably their capacities are better than the ones showed in this paper.

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