Radiation, Advective and Orographic Fog in Tarapacá Region, Chile

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Since July 1997 until March 2001 a geographical survey was done in Northern Chile to recognise the origin and behaviour of fog in the coast and inland locations of Tarapacá Region. Radiation fog was found in Pampa del Tamarugal about 50 km from the sea, advective fog in the coast and orographic fog in a few coastal sites near mountain ranges with elevations above 1.000 m.a.s.l. To understand the relief and its influence on the path of fog from the coast to inland locations was an important objective in the research. Fog water collected in a Standard Fog Collectors (SFCs) showed in 3 ½ years an average of 8.5 L m^{-2} d^{-1} in the coast, 1.1 L m^{-2} d^{-1} inland at 12 km from the coastline, and only in few days, water was collected in the inland site in Pampa del Tamarugal in ten months of observations. The methodology used to collect meteorological information and fog water collection based in campaigns of field work of 15 days in mid summer and mid winter during three years did not show the results expected, but gave important clues on fog formation and dissipation along the mountain range that separates the coast from the inland site of Pampa del Tamarugal.

1. INTRODUCTION

Fog has been studied widely in Chile, specially as a water resource for human consumption (Schemenauer and Cereceda, 1994a; Cereceda and Schemenauer, 1998). Actually there are at least seven sites with operational or scientific projects in the country. Science and technology are important in these type of research: the understanding of cloud physics and chemistry and its behaviour is crucial as well as the technology to use fog water as an hydrological resource.

In the last four years one of the focus of the investigation carried out in the Region of Tarapacá in the North of Chile in the Atacama, the most arid desert of the world, has been the understanding of the geographical factors that determine the origin and behaviour of fog. Radiation fog in inland locations, and advective and orographic fog in the coasts have their causes based in the planetary atmospheric circulation and the local geographical features.

2. THE STUDY AREA AND METHODOLOGY

The study area is located in the Region of Tarapacá from Junín to Loa River (19º40´S-21º30´S – 70º10´W-69º40´W). The extension of the coastline is approximately 200 km and the width toward the interior, an average of 50 km. The total area is about 10.000 km^2. From west to east, the relief is formed by a narrow coastal plain (average 5 km); a cliff of 400 to 1000 m; a mountain range, Cordillera de la Costa, with peaks of 1500-2000 m (width of 50 to 100 km); a tectonic basin of an average width of 100 km called Pampa del Tamarugal. The study area reaches the piedmont of the Cordillera de los Andes (Osses et al., 1998)

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This research was done during the years 1997-2000, with the following steps: Cartographic and GIS analysis to find the places where the topographical features would be favourable to the formation of fog. This aspects were reported in the First Conference on Fog in Vancouver (Osses et al., 1998). Two Standard Fog Collectors were installed a the coastal location of Alto Patache (20º49´S; 70º09´W – 850masl) and in Station Tillandsias located in Cerro Guatalaya 12 km from the coast (20´12´s; 70ºW – 1050masl). The data was collected in a weekly basis since july 1997 until march 2001. Forty five kilometres inland, in Pampa del Tamarugal in Estación agrícola Universidad Arturo Prat (20º20´S; 69º43´W – 950masl). A SFC was installed in may 1999 and data was collected until march 2000; since in light fog is difficult to collect water in an SFC, daily observations on presence or absence of fog were recorded. Surveys in four field campaigns of 15 days were done during winter and summer of 1997, 1998 and 1999 in different sites with standard fog collectors and manual instruments to measure temperature, humidity and wind parameters at different hours of the day and night. To recognise the presence of orographic fog a study of vegetation in the fog oasis was done according to literature and in field surveys.

3. RESULTS

The typical stratocumulus cloud of Northern Chile is formed at hundreds of kilometres from the coast in the Pacific Ocean. It moves toward the continent in altitudes between 500 and 1000 m as a compact mass of air and water droplets (Cereceda et al., 1997). In

the Tarapacá Region it impacts the high cliff formed near the coastline at the same altitudes forming the advective fog that is shifted inland according the relief features and wind direction and velocity. The liquid water content varies with altitude. From August to December of 1997 SFCs were installed in the cliff of Alto Patache at 750 and 850 masl. The lower SFC had a yield of less than half of the higher one that registered an average of 17.0 L $m^{-2}d^{-1}$.

Advective fog moves inland through corridors or paths formed between the high mountains of the Cordillera de la Costa, until the heat of the land evaporates the droplets of water. Fog water collection is much higher in the coast than inland. The distance that fog can penetrate depends on the atmospheric features: temperature, humidity and wind speed. The data of Alto Patache (coast) and Tillandsias in Cerro Guatalaya (12 km from the coast) show that in the coast the average from July 1997 until December 2000 was 8.5 L $m^{-2}d^{-1}$ while in the interior it was 1.1 L m^{-2} d^{-1}. In Pampa del Tamarugal (45 km from the coast) from May 99 to March 2000 only ten days between June and August had fog events. In only four of them water was collected in the SFC with no more than 750 cc in the period. Patache and Tillandsias have the same year and seasonal variations and respond to El Niño and La Niña phenomenon in a similar way. El Niño of 1997/98 had the highest water collection (Table 1). The average of years 1998-2000 was 7.4 L m^{-2} d-1.

Table 1. Water collected in SFC in Alto Patache

Year	**Months**	**L m^{-2} d^{-1}**	**Months**	**L m^{-2} d^{-1}**
1997	Aug-Dec	17.0	Jan-Dec	
1998	Aug-Dec	9.0	Jan-Dec	8.1
1999	Aug-Dec	13.8	Jan-Dec	7.6
2000	Aug-Dec	9.6	Jan-Dec	6.6

The seasonal variation is very notorious, summer and autumn are the months with the least yields, and winter and spring are the most productive. From June until September water collection has the best rates (Figs. 1 and 2).

In relation to the atmospheric parameters that control the shift of fog along the Cordillera de la Costa toward Pampa del Tamarugal, in the few days where fog water was collected inland, a pattern was visualized. During the field campaign of August 4-12, 1998, thirty observations each four hour of the day and night were done in 5 consecutive days when fog was present. The SFC collected 1,5 L of water in 9 events in Pampa del Tamarugal, and 21 L in 16 periods in Alto Patache in the coast. Fog was recorded inland during the nights and in the mornings at 0200, 0600 and 1000 o´clock, in the coast was

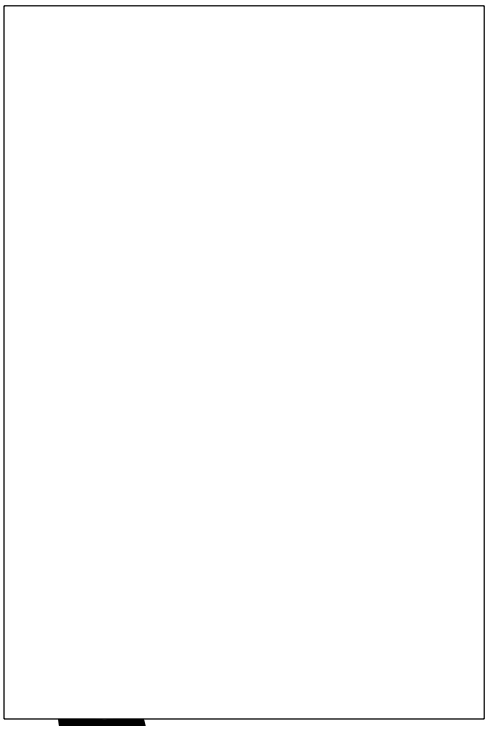

Fig 1: Fog water collection in Alto Patache

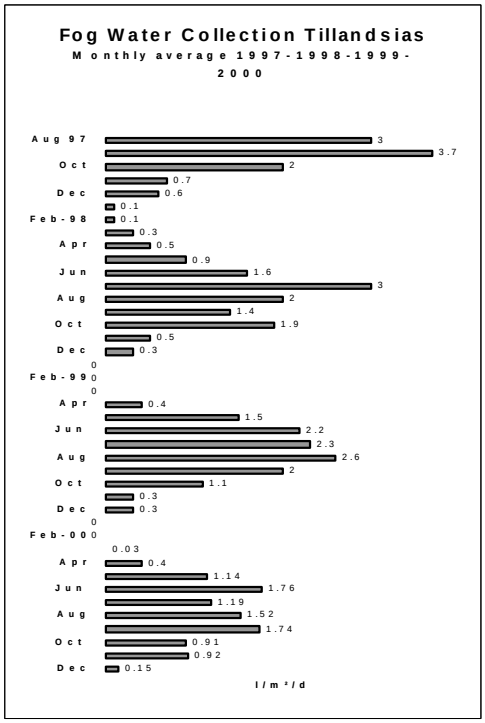

Fig 2: Fog water collection in tillandsias Cº Guatalaya

more erratic, but still predominant in the same hours. In six observations done in Pampa del Tamarugal, fog was present in the coast in the last four hours.

Calm was almost permanent inland and the light gusts where from 210º to 240º (SSW-SW) the direction of the corridor from the coast to the Pampa; in the coast wind was generally from the south and the speed was always less than 5.5 m^{-s}. Temperatures in Pampa oscillated from 2ºC to 27ºC during the period; during fog events it was between 2ºC and 12ºC inland and between 8ºC and 10ºC in the coast. This data may indicate that either fog was present all the way from the coast to Pampa by the corridor, or fog was dissipated and the humid air mass that arrived to the Pampa condensed and formed radiation fog due to the nocturnal winter cold. The other possibility is that the humidity of the atmosphere is derived from evaporation during the day from the salt flats present in the area. The hours when fog was present, the low temperatures and the calms or light winds, are typical of radiation fog.
Nevertheless, during these field campaigns, two heavy fog events where surveyed along the corridors and the most important difference was that the wind speed that was persistent along the way and reached Pampa. Probably the best way to monitor these fogs will be with remote sensing (GOES and NOAA); a project has been approved by the Chilean Commission of Science and Technology to do it between 2001and 2004.

Many days during the weekly field work and the campaigns, fog was observed in the coastal cliff in certain summits, while the rest was clear and sunny. The sites were ratified by local residents as typically being covered by clouds. This suggests the presence of orographic fog which is formed due to factors such as upwellings in the sea, altitude, form of the relief and the shape of the coastline. According to a survey of the fog oasis done by Sielfeld et al., 1995, there are seven vegetated areas in the zone. In this opportunity, they were recognised and studied from the geographical point of view. In general, all of them coincide in the shape of the coast, they are located in points and have wide bays in their southern part. They are located in altitudes near 800m and have a mountain that is outstanding in the southern area with summits from 945m to 1592masl. This higher mountain may be the feature that makes the air mass to move inland due to the predominant wind from the south and the southwest to ascend and cool by expansion, condense the water vapour and form the fog (Table 2).

During episodes of advective fog, it may be that the influence of orographic fog result in a major liquid water content in the air mass and more potential for water collection for domestic, ecological, agriculture and forestry purposes.

Table 2: Fog oasis and geographical features

Fog oasis	**Point**	**Bay size**	**Mountain**	**Masl**
Junín	Punta Junin	small	Junín	1096
Ballena	Punta Ballena	medium	No name	945
P. Gruesa	Punta Gruesa	medium irregular	Oyarbide	1469
A. Patache	Punta Patache	big	Cº Rojo	1161
Pabellón de Pica	Punta Colina	medium	Carrasco	1592
P. Blanca	Punta blanca	big	Chipana	1300
P. Chipana	Punta Chipana	big	Quebradi-llas (E)	1196

4. CONCLUSIONS

In the Atacama Desert of Chile, the three types of fog can be observed in a very narrow area, no more than 50 km. Radiation fog is formed inland in the cold nights and mornings of winter and have small duration in time. Advective fog is generated in the ocean far from the continent and is transported by the wind to the coast. According to the relief, the advective fog can enter in the continent through corridors in the coastal mountain range of the area. The orographic fog is the most constant and is formed *in situ* in the first windward slope facing the sea. It is local and related to high mountains or special forms of the relief and coastline.

6. REFERENCES

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