Variability of fog as a fresh water resource and its relation with regional and local oceanic-atmospheric-geographic indicators. Atacama Desert Alto Patache Fog Oasis, Chile

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ABSTRACT

Since 1997 fog behavior had been studied and recorded in Alto Patache and Cerro Guatalaya, Atacama Desert in Chile. That year was a strong Niño only similar in his indicators with the event occurred during 2015 – 2016. This research shows the interannual variability relation between these phenomena with the local variation on the coastal stratocumulus and the water obtained from the fog.

This research wants to establish if the water resource that can be obtained from fog is related with ENSO conditions in order to determine his reliability.

We used two Standard fog collectors (Schemenauer & Cereceda, 1994). Regional and local oceanic-atmospheric indices were worked with Satellite images to get the spatiotemporal variability. Local observations and intense field work had been done to get and validate observations.

Main results show a consistent production of fog water in the last 15 years, around 8 $L/m^{-2}/day^{-1}$, with a clear seasonal variation, and a very low decreasing trend in the coast, few kilometers inland there are no variation. Correlations between fog water yields and local indices shows significant results (coastal oktas $r = 0.63$; coastal SST $r = -0{,}40$), but in the macro scale (El Niño 3.4) this association is significant only during summer time ($r = 0.38$). For instance, SST at 1+2 seems to be a “key” variable in the ocean-atmospheric interactions, due to correlate with all the variables analyzed.

The extreme complex relation oceanic-atmospheric in the South East Pacific is reflected in the interannual variability of fog water collected. Nevertheless, the ENSO anomalies in the SEP not always manifest expected variations in fog water yields, supporting the idea that local conditions play a key role in the circumstances that explain the amount of water collected.

1. INTRODUCTION

In this work, we contrast fog-water data record, with local and regional atmospheric and oceanographic variables to assess the main controllers affecting the interanual fluctuations of fog in northern Chile. In this manner, we aim to determine the role of offshore climate and surface ocean conditions in the fog cloud extension, its water content and how these vary through time. We apply a multi-scale geographic analysis, including the use of remote sensing and local observations to provide a complete perspective. We analyze fog spatial and temporal variability under different ENSO scenarios, an aspect that help us to assess the potential of fog water availability in the future for the coastal Atacama Desert. Our main goal is to assess the role of regional-wide forcing on local water availability in the coast of Atacama, including El Niño Southern Oscillation (ENSO) interannual variability (Garreaud et al., 2008). We focus our study in coastal Tarapacá region of Chile (19°-21°30´S). We provide fog-water collection data obtained from the Atacama UC Research Station (AUCRS) (20°49´ S - 70°09 W). The main scientific questions guiding this research are as follows: to identify some of the physical factors affecting the interannual fog water yields variability? In this regard does ENSO variability affects Tarapaca fog-water yields? What is the fate of fog-cloud and associated fog-water resource in the near future under the future modeled climate conditions for the Atacama?

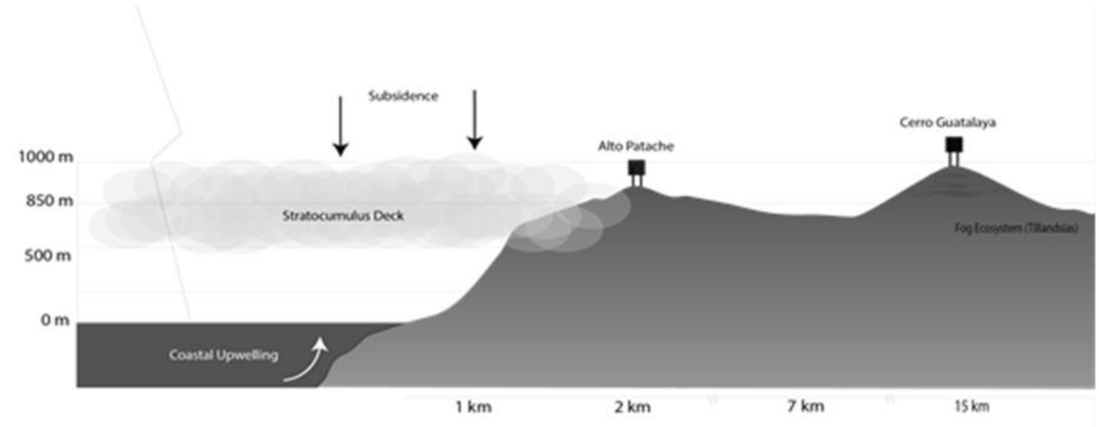

Figure 1. Schematic topographic profile at the coastal Atacama Desert of coastal fog dynamic and SFC location.

Our work focuses on the freshwater-limited Tarapacá region of northern Chile, where the effect of present climate change has been recently consider (Larraín et al. 2002; Cereceda et al. 2008a; Schulz et al., 2010, 2011; Garreaud et al., 2008; Falvey and Garreaud, 2009; Vuille et al., 2015).

We present fog water data (1998 – 2015) obtained by Standard fog collectors (SFC) (Schemenauer and Cereceda 1994) located at two sites: at the summit of the coastal cliff at site (AUCRS), (850 m a.s.l.; ~3.5 km lineal distance from the coastline), and at the top of Cerro Guatalaya (1050 m a.s.l.; ~12 km lineal distance from the coastline) see figure 1.

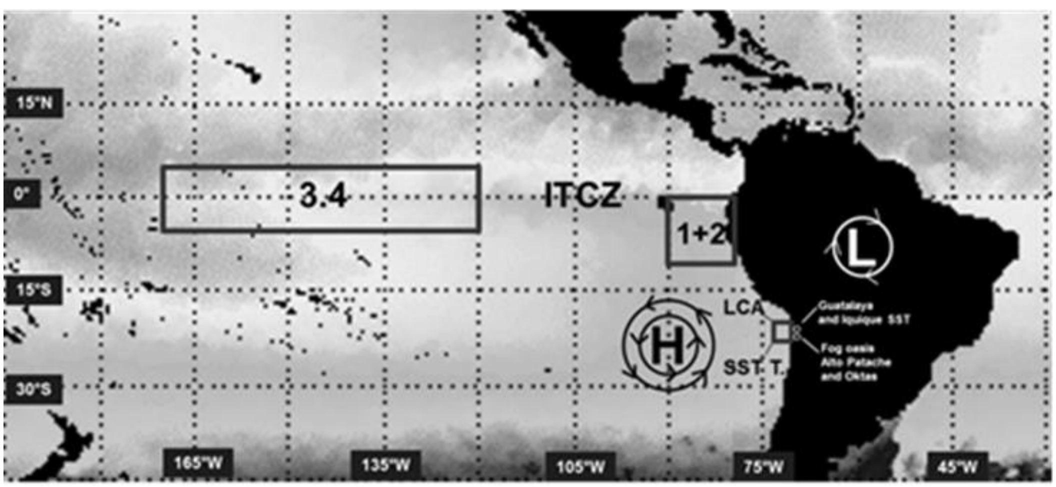

Figure 2.South Pacific basin including Inter Tropical Convection Zone (ITCZ), High pressure (H), Low pressure (L) and the location of regional and local indices

1.1 Methodology

For seasonal analysis, based in Alto Patache fog water yields data we divide in trimester according to 3 months with higher (July, August, September –JAS-) and lower (January, February, March – JFM-) period, coinciding with year trimester calendar, completing with April, May, June (APJ) and October, November, December (OND).

In order to assess the relation between fog and ocean-atmosphere components, we select multi-scale indices. These indicators are mapped in figure 2 and their respective characteristics are explained in table 1.

Variable	Indicator	Scale	Coordinates (point or area)	Source	Time data available	Analyzed time data	Temporal scale data	Temporality used
Fog water	L/m-2/day-1	Local	20°49´S - 70°09´W (Alto Patache)	Centro del Desierto de Atacama UC	1998 - Present	1998 - 2014	Monthly	Monthly
	L/m-2/day-1	Local	20°12´S - 70°00´ W (Cerro Guatalaya)	Centro del Desierto de Atacama UC	1998 - 2013	1998 - 2014	Monthly	Monthly
Cloud cover	Okta	Local	20°32'12"S - 70°10'41"W	Dirección Meteorológica de Chile (DMC)	1981 - Present	1998 - 2014	Daily	Monthly
	Low Cloud Amount (LCA)	Tarapacá	19°S-21°30'S; 72°-70°W	NASA - ISCCP	1983 - 2009	1998 - 2009	Monthly	Monthly
Sea Surface Temperature (SST)	SST Iquique	Local	20°12'16"S - 70°08'52"W	Servicio Hidrológico y Oceanográfico de la Armada, Chile (SHOA)	1984 - Present	1998 - 2014	Daily	Monthly
	SST Tarapacá	Tarapacá	19°S-21°30'S; 72°-70°W	NOAA - Optimum Interpolation (OI) SST V2 Data	1989 - Present	1998 - 2013	Monthly	Monthly
	SST ENSO 1+2	Regional	0° - 10°S; 90°-80°W	NOAA/ National Weather Service	1950 - Present	1998 - 2014	Monthly	Monthly
	SST ENSO 3.4	Regional	5°N-5°S; 120°W-170°W	NOAA/ National Weather Service	1950 - Present	1998 - 2014	Monthly	Monthly

Table 1. Multi-scale oceanic-atmospheric indicators analyzed

1.2 Results

Our measurements of water collected by the SFC at Alto Patache show mean maximum values over 14 $L/m^{-2}/day^{-1}$ during August and September, which is in contrast with the less than 1 $L/m^{-2}/day^{-1}$ collected during February and March. Even more, the water yields from June to October concentrate over 75% of the yearly amount of water collected with an average of mean maximum values of 11.4 $L/m^{-2}/day^{-1}$.

Cerro Guatalaya presents for August and September a fog water concentration over 78%, but presents much lower yields, the mean maximum values for the same period (June-October) is a little bit higher than 1.5 $L/m^{-2}/day^{-1}$ and during summer is practically 0 $L/m^{-2}/day^{-1}$ (See figure 3).

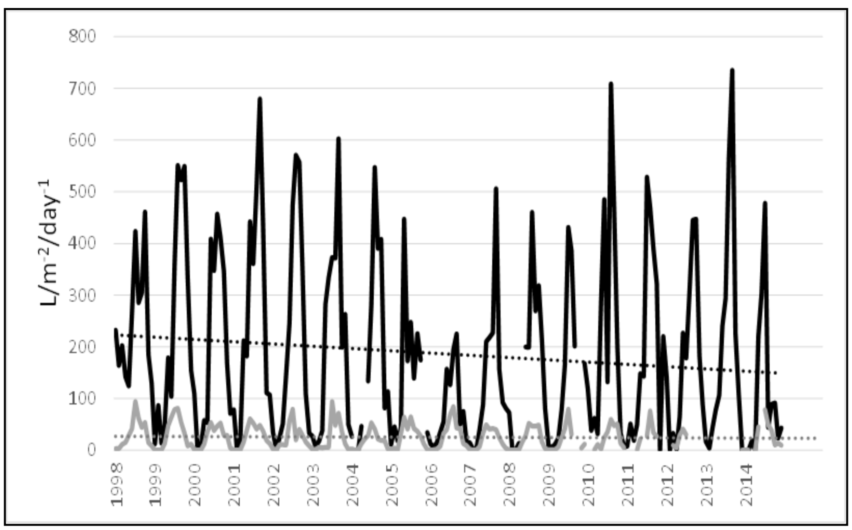

Figure 3. Interannual variability of fog water yields at Alto Patache (black line) and Cerro Guatalaya (grey line) for the period 1998-2014. Dotted lines indicate the trend for the period.

The fog water yields of Alto Patache and Cerro Guatalaya presents a strong and positive correlation with the *oktas* (r = +0.60 and r = +0.68 respectively), confirming that the Sc clouds is the main source of moist in the coastal cliff, here typified as advective marine fog.

The SST at 1+2 present a strong and negative correlation for the complete study period with the fog stations (r=-0.66 at Alto Patache and r=-0.57 at Cerro Guatalaya; both at 99% confidence level). For instance, SST at 1+2 seems to be a "key" variable in the Sc/fog ocean-atmospheric interactions, due to SST 1+2 also correlate with the rest of variables analyzed (r=+0.66 with SST Iquique; r= +0.88 with SST Tarapacá; r=-0.66

with LCA Tarapacá; r=-0.48 with oktas; all at 99% of confidence level).

1.3 Conclusion and recommendations

We found some expected and significant positive correlations between fog water interannual variability and presence of cloud cover at different scales, and significant negative correlations between SST and fog water yields.
Probably the most interesting and strong correlation is the one between 1+2 and the rest of the oceanic-atmospheric indices for all the study period, for instance, SST at 1+2 seems to be a “key” variable in the Sc/fog ocean-atmospheric interactions. Exist a positive correlation between SST 3.4 or ONI and fog water at Alto Patache during summer (JFM), but not during the rest of the seasons (AMJ, JAS, OND)

The use of fog as a water resource seems to be feasible on time, despite ENSO specific conditions or PDO phase, due to its low interannual variability, specifically during the season when most of the water is collected. Both SFC present similar monthly, seasonal and interannual trends, with differences in the amount of water collected and maximum month peaks in water yields that response to local geographical conditions, like coast distance, altitude and topography. Confirming the results obtained by Larraín et al. (2002) and Cereceda et al. (2008a), now under a longer period of analysis, and maintains the interest in extending this valuable time series

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2. REFERENCES

Cereceda P, Larraín H, Osses P, Farías M, Egaña I. (2008a) The spatial and temporal variability of fog and its relation to fog oases in the Atacama Desert, Chile. *Atmospheric Research*, **87**, 312-323.

Cereceda P, Larraín H, Osses P, Farías M, Egaña I. (2008b) The climate of the coast and fog zone in the Tarapacá Region, Atacama Desert, Chile. *Atmospheric Research*, **87**, 301-311.

Falvey M., Garreaud R. (2009), Regional cooling in a warming world: Recent temperatures trends in the southeast Pacific and along the west coast of subtropical South America (1979-2006), *Geophysical Research*, 114.

Garreaud, R, Barichivich J, Christie DA, Maldonado A. (2008), Interannual variability of the coastal fog at Fray Jorge relicts forests in semiarid Chile, *Geophysical Research*, **113**, G04011.

Larrain, H., Velásquez, F., Cereceda, P., Espejo, R., Pinto, R., Osses P., Schemenauer R. S. (2002). Fog measurements at the site "Falda Verde" north of Chañaral compared with other fog stations of Chile. *Journal of Atmospheric Research*, **64**, 273-284.

Núñez, L. and Varela J., 1965: “Sobre los recursos de agua y el poblamiento prehispánico de la Costa del Norte Grande de Chile”, Estudios Arqueológicos, Departamento de Arqueología y Museos, Universidad de Chile, Antofagasta, N 3-4, 1-41.

Osses, P, Cereceda P, Larraín H, Schemenauer RS. (1998) Influence of relief on the origin and behaviour of fog at Tarapaca, Chile, *First International Conference of Fog and FogCollection, Canada*, 245-247.

Osses, P, Cereceda P, Schemenauer RS, Larraín H, Lázaro P. (1998) Diferencias y similitudes de la niebla entre Iquique (Chile) y Mejía (Perú). *Revista de Geografía Norte Grande*, **25**, 7-13.

Schemenauer, R. S., Cereceda, P. (1994): A proposed standard fog collector for use in high elevation regions. *Journal of Applied Meteorology*, **33** (11), 1113-1322.

Schulz, N., Aceituno P., Richter, M. (2010): Phytogeographic divisions, Climate Change and plant dieback along the coastal desert of Northern Chile. *Erdkunde*, **65** (2), 169–187.

Schulz, N, Boisier JP, Aceituno P. (2011): Climate change along the arid coast of northern Chile. *International Journal of Climatology,* **32** (12),1803–1814.

Vuille, M., Franquist, E., Garreaud, R. Lavado, W., Bolivar Cáceres, C., 2015: Impact of the global warming *hiatus* on Andean temperature. *Geophysical Research Atmospheres*, **120,** 3745–3757.