Long-term spatiotemporal variability of stratocumulus (Sc) cloud cover and its relation with fog water yields in the coastal Atacama Desert, Chile

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ABSTRACT

Large-scale Sc variability in the South East Pacific is well understood. However, at local scale the interannual variability and spatial distribution of Sc cloud cover as well as its relation to fog water yields is not properly comprehended. The aim is to analyze and characterize the spatiotemporal variability of fog and its relation with fog water yields in the last 20 years. Two daily GOES satellite images were automatically processed during nighttime of September and February from 1995 to 2015. The variability of Sc was related to fog water yields collected by a SFC since 1997 located in the summit of the coastal range of Atacama desert, northern Chile (20°49´S – 70°09´W). We explore the spatiotemporal long-term Sc/fog variability and its relation with collected fog water. The presence of Sc at the coastal Atacama, as well as the collected fog water during September is quantitative higher than February. Analysis of Sc cloud cover presence shows positive lineal tendencies in analyzed areas that coincide with cloud cover observations from coastal airports (Muñoz et al., 2016), a decline is only observed at 1200m asl. ENSO is presented as an indicator of higher variability of Sc and fog water yields during February, but no clear relations were found during September, when most of fog water is collected. El Niño conditions, during February, shows mainly an increase in cloud cover, opposite during La Niña years. The high frequency of Sc cloud cover and lower spatial variability distribution during September within the concentration of the water resource in this season reveal the potential of fog water as a dependable source in an extreme arid environment.

1. INTRODUCTION

The extensive Sc deck at the SouthEast Pacific (SEP) is produced by the thermal inversion created by the large-scale air-subsidence in the subtropical Pacific Anticyclone, intensified by the Humboldt cold Current and the upwelling of even colder waters to the surface of the eastern Pacific (Rutllant et al., 2003; Cereceda et al., 2008). In the coastal Atacama Desert, the SEP stratocumulus (Sc) cloud meets the coastal cliffs to produce a highly dynamic advective marine fog (see figure 1), which embraces a major feature of the local climate, providing humidity to a hyper-arid environment and forming fragile and unique ecosystems (Latorre et al., 2011). In this regard, the Sc cloud annual cycle in coastal Atacama is well-known (Cereceda et al., 2008; Farías et al., 2005), but our knowledge of the detailed spatiotemporal variability of fog and how this changes in concert with the SEP oceanographic and atmospheric realm, remains mostly unknown. The SEP climate variability is mainly controlled by the El Niño Southern Oscillation (ENSO), which seems to exert a direct influence on fog variability (Garreaud et al., 2008; Park and Leovy, 2004; Schulz et al. 2011). Nonetheless, this important matter still needs to be assessed with more detail along the Atacama coastline, where for the most part we lack of extended field-recovered-data as those recovered in Estación Atacama UC –Universidad Católica- Oasis de Niebla Alto Patache (UC Atacama Station, Fog Oasis Alto Patache –FOAP-)(see figure 1).

2. DATA and METHODOLOGY

GOES satellites images were processed to comprehend the Sc/fog variability at coastal Atacama during diverse ENSO years. We analyzed the seasonal spatiotemporal percentage of Sc presence and frequency during September (1995 to 2015) and February (1997 to 2015), months that present the maximum and minimum values of fog data collected (L/m^2/month) by a Standard Fog Collector (SFC) (Schemenauer and Cereceda 1994) since 1997 to present at FOAP. Here we process two daily hours (03:39 and 07:39 UTC), that correspond to the maximum time fog presence (Farías et al., 2005; Cereceda et al., 2008a). The identification of low clouds is based in the short (3.8 µm) and long (10.9 µm) thermal infrared wavelengths, widely used (Ellrod, 1995; Underwood et al. 2004).

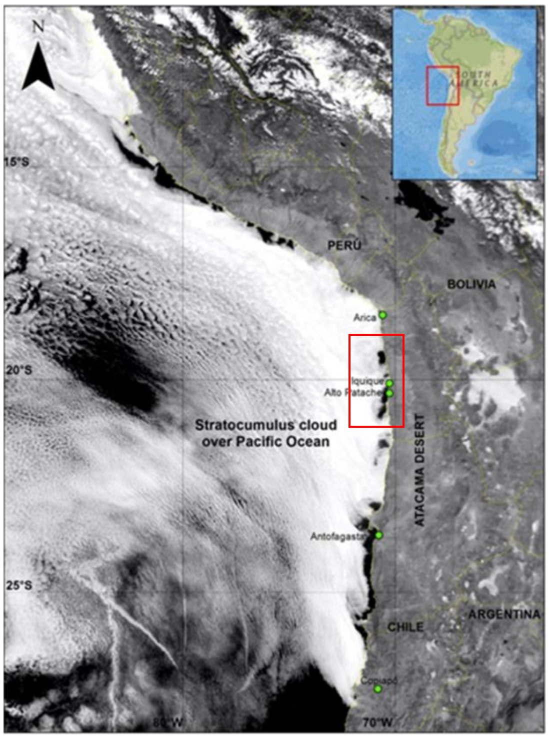

Figure 1. The stratocumulus deck at the coastal Atacama Desert. This cloud results in the existence of a well defined fog belt within a vertical stretch between about 900 – 1200 m asl at the coastal Cordillera; the rectangle corresponds to the study area analyzed with GOES satellite (base image: Sensor Aqua-MODIS, august 1st 2014, 18:43 UTC; source: *Aqua/Modis L1 product*).

The long-term spatiotemporal identification of Sc and fog, allows to analyze its variability in different zones (see figure 2), offshore and inland, its behavior during diverse ENSO scenarios and its relation with the fog water yields collected at FOAP.

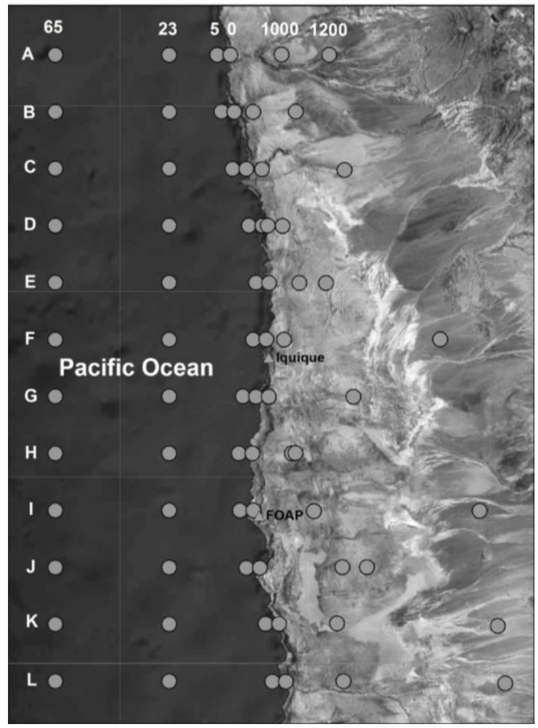

Figure 2. Study area in coastal Atacama. Points correspond to analyzed areas, where from west to east are located at 65 km offshore, 23 km offshore, 5 km offshore, over coast line, over 1000m asl and over 1200m asl. The latitudinal distance between points (letters) is approximately 21 km.

3. RESULTS

The presence and frequency of Sc or fog at coastal Atacama has a strong temporality, the presence average over the ocean is 90% higher in September than February, in the area between coast line and the terrain altitude of 1000m asl. is 88% and in the rest of the area over 1000m asl. is 82% higher respectively. In terms of fog water collected at FOAP, the amount has similar temporal variations, where September is 93% higher.
Longitudinally, Figure 3 (a and b) shows that during September Sc presence decrease from west to east at all latitudes, with the biggest variability in the coast and inland zone, mainly at 1000m (s=0.16). During February the variability increase, mostly in the norther part (see figure 4a), where even coastal Sc or fog presence could be higher than offshore areas, associated to the formation of orographic fog in detriment of advective marine fog. Surprisingly in the

southern part, the west-east tendency returns (see figure 4b).

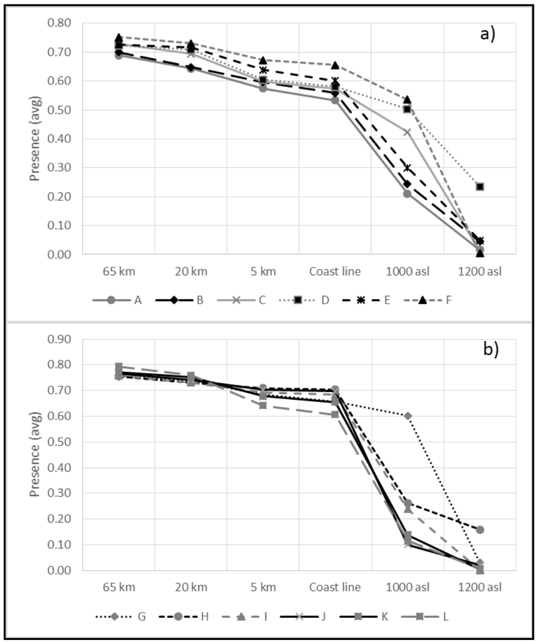

Figure 3. Longitudinal profile of September averages for period 1995-2015. Letters correspond to analyzed latitude.

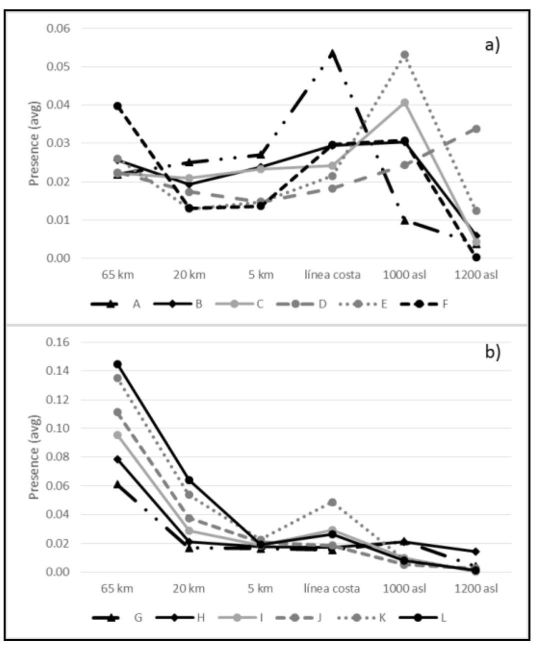

Figure 4. Longitudinal profile of February averages for period 1997-2015. Letters correspond to analyzed latitude.

Latitudinally, during September there is a decrease from south to north, specially in the offshore areas. Inland zones, varies according to coast distance, areas in D, F and G, altitudes of 1000m or 1200m asl are closer to the coast, revealing the relevance of the local component (see figure 5a). During February, the decrease (S to N) is significant just in the most offshore zone (65 km) (see figure 5b).

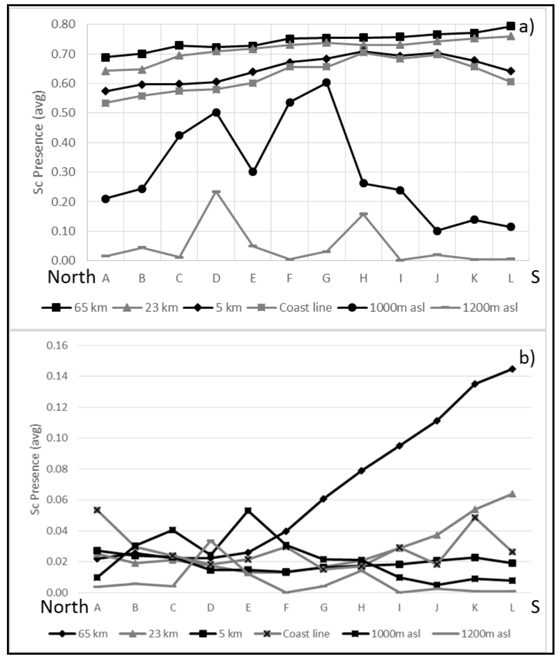

Figure 5. Latitudinal variations of Sc/fog presence, a) correspond to September, and b) February

The variability of Sc/fog presence present a relation with ENSO only observed during February (see figure 6), same situation occurs with fog collected fog water. The Oceanic Niño Index (ONI) correlate positive and significant (98%) with the 3 zones averages (r=0,67 with Ocean; r=0,66 with coast-1000m; r=0,65 with above 1000m).

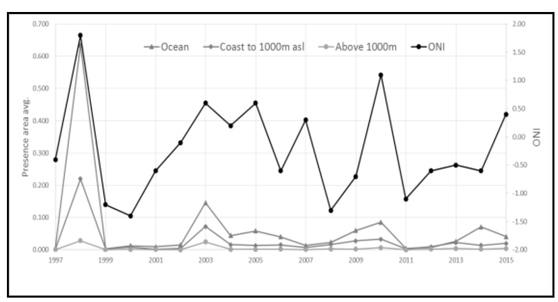

Figure 6. Variability of ONI and zonal Sc/fog presence averages along analyzed period (1997-2015) during February.

El Niño years (ONI ≥ +0.5) present a positive percentage difference of 96%, 92% and 91%

over La Niña year (ONI $\leq$ -0.5) in amount of Sc/fog presence average Sc in the ocean, coast-1000m and above 1000m areas respectively.
Finally, the amount of Sc/fog presence in the different areas shows positive lineal tendencies, only negative trends were found at 1200m asl areas, consistence with the decrease in the inversion layer altitude (Quintana & Berrios, 2007).

4. CONCLUSION

The Sc cloud at coastal Atacama has a strong temporality, its presence at different zones (offshore and inland), as well as the fog water collected at FOAP is around 90% higher during September than February.
In a longitudinal profile, the Sc presence decrease from west to east. Only during February, in the northern part of the study area, greater Sc presence were found at the coast and inland areas. Latitudinally, there is a decrease from south to north, mainly during September in offshore areas. February shows a bigger variability, the norther negative trend is only observe in the western offshore area. Local geographical and atmospheric variables seems to be the relevant in coastal and inland variability.
ENSO shows a relation with Sc/fog presence variability during February, when ONI shows positive and significant correlations with the cloud cover in ocean and inland areas. El Niño years presents over 90% bigger amount of Sc/fog than La Niña years in all areas.
The amount of Sc/fog presence present a positive tendency in all areas, also described by Muñoz et al. (2016), the only exceptions are the areas at 1200m asl, which could be related to the decrease in the inversion layer altitude.

5. REFERENCES

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