Coastal Fog, Satellite Imagery, and Drinking Water: Student Fieldwork in the Atacama Desert

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Abstract

This paper discusses the role played by undergraduate geography students at the Pontifical Catholic University of Chile in conducting research on advection fog in the Tarapaca Region of the Atacama Desert. Research results show that an enormous amount of fog water can be collected for domestic purposes, productive activities and in the restoration of degraded ecosystems. Students are involved in intensive fieldwork measuring, spatially, stratocumulus clouds and fog conditions and comparing results with GOES imagery. Within the geography program students are expected to participate in four field experiences as part of their training. This research endeavor provides them an excellent opportunity to gain such experience.

Introduction

This paper describes the student fieldwork component of a major research endeavor (funded by the National Commission of Science and Technology, Chile) that is being conducted on the desert coast of the Tarapacá Region of Chile, and how geography students from Pontifical Catholic University of Chile are participating in this project. The research centers on understanding the different types of fog that occur within a study area, the causes of their formation, their geographical distribution, their potential use by the populations living in the area, and their influence on vegetation and animals within the various ecosystems (Cereceda *et al*., 2002). The results show that an enormous amount of fog water can be collected for domestic purposes, productive activities and in the restoration of degraded ecosystems (Larrain *et al*., 2002).

Fog is studied in Chile as a potential water resource and an important factor in determining the presence of certain arid and semiarid ecosystems in the Atacama. Remote sensing techniques through the use of GOES satellite images are used to ascertain the spatial and temporal patterns of a single, extensive stratocumulus cloud that forms advection fog. Geography students working in teams gather important fieldwork data to validate research findings.

Since 1980 the Geography Institute of the Pontifical Catholic University has been doing research on fog and fog water collection. A component of this research uses undergraduate students who work in teams to process data and satellite images. However, the most important activity

undertaken by these students relates to fieldwork, usually in arid and the semi arid areas under very difficult weather conditions. Several generations of students, now geographers, started their research training by processing data and imagery and conducting fieldwork for this research project. The results of their work have been very successful, both with respect to their scientific findings and in their professional lives. Through the years, more than 100 students have participated in this experience, and most of these students have found jobs in environmental fields throughout Chile. As a result of their work, people in several places within Chile as well as in other parts of the world, use fog water for domestic and other purposes (Schemenauer and Cereceda, 1994; Schemenauer *et al*., 2003).

Background

The Atacama Desert is nestled along the northern coast of Chile, between the Pacific Ocean and the Andes Mountains. This region receives almost no rainfall. Most of the precipitation is in the form of fog, which blows in from the Pacific Ocean as warm air crosses the cold Humboldt (Peru) Current. The fog conditions in the Atacama are similar to those found along Baja California, and the Skeleton Coast of Africa's Namib Desert. Thus, what is discovered about the fog conditions in the Atacama might apply to other areas of the world.

Several aspects of fog have been studied in the arid and semi arid environments of Chile. The geophysical and geographical aspects of clouds and fog have been examined in order to understand their spatial and temporal behavior. Satellite images and measurements in the field have been conducted to learn about the potential fog water collection. Research in biogeography has been undertaken to understand the importance of fog and rain in the fragile ecosystems (fog oasis) of the Atacama. And studies on water consumption and demand by settlements in the region have been investigated. An average of 7.6 l/m2/day of water was measured using a standard fog collector (SFC) (Schemenauer and Cereceda, 1993) during the period 1997-2001 in the study area located at Alto Patache (Larrain *et al*., 2002).

Three types of fog exist in the Atacama. Orographic fog is situated in a narrow area close to the coastline in the mountains. Advection fog covers a wide area of the coast and inland for several kilometers. And radiation fog occurs in small patches during clear nights over moist ground (Farias *et al*., 2001; Cereceda *et al*., 2002). The work associated with this research endeavor mainly relates to advection fog.

Fog along the desert coastal areas of Chile, Peru and Ecuador forms when stratocumulus clouds cover huge areas in the South Pacific, advance toward the west coast of South America and are intercepted by coastal mountains/hills. The bottoms of the clouds are approximately 700 meters (2,300 ft.) above sea level; whereas, the tops, strongly related to the fluctuations of the thermal inversion layer, vary between 900 to 1300 m (2,970 to 4,300 ft.) (Espejo, 2001). Stratocumulus clouds are being studied by several scientific groups due to their influence on the world's climate (Garreaud, 2001).

Geography Program in Chile

As in many countries of the world geography is not a subject taught per se at pre-college education in Chile. Rather, both physical and human geography - with an emphasis on the geography of Chile - are part of Social Studies courses in elementary and secondary schools.

Rather than applying for admission to an undergraduate program, with the option of deciding on a major while in college, high school graduates must apply to specific professional programs that have different admission thresholds and different durations. This rigid system demands that high-school graduates make career decisions while in their teens before being admitted to college.

Currently, only five universities – about ten percent of higher education institutions in the country – offer geography as a professional career. They and several others also have programs to prepare teachers of History and Geography in their facilities of Education. The Professional Geographer program at Catholic University, which most of the authors of this paper are affiliated with, is typical: a five-year (ten semesters) career leading to a degree of "Licenciatura" at the successful conclusion of four years and to the title of Professional Geographer after five years including the completion of a professional internship.

One distinguishing element in the education of professional geographers in our program complements the established curriculum of classroom courses and seminars with yearly two-week fieldwork seasons. These fieldwork experiences are mandatory for students in years 2 through 5 and are done in teams organized and supervised by faculty members in their specialties. More advanced students play important leadership and mentoring roles for younger students. One such team fieldwork is described in this paper.

The empirical study of the fog, for academic and scientific purposes or for water resources applications, requires a high level of fieldwork, given the very dynamic nature of meteorological variables. Commonly, weather stations are used to record basic climatic data. The observation of fog behavior is an excellent way to have students familiarize themselves with different cloud conditions and the study area's terrain and biogeography, train them in the application of measuring instruments and cartographic work, and learn about the importance of scientific rigor and teamwork.

Given the demands on our students we are pleased that attrition is relatively minor. Our program accepts a freshman class of about 65 students out of hundreds of applicants and graduates about 40 professional geographers. The experience of repeated team work on the field helps develop valuable qualities that serve our graduates well in their professional careers.

Objectives

The field research objectives are:

1. to identify the presence and delineate the extent of a stratocumulus cloud to validate in situ the GOES images;
2. to record the following information above, in, and below the cloud deck: temperature, wind speed and direction, and fog water collection;
3. and to determine the altitude of the top and the bottom of the cloud bank.

Students are involved with each of these objectives. A requirement for students to participate in this research project is their interest to work outdoors, and to investigate and deal with natural resources. Also, they must be able to work in teams, follow instructions from the professors, and be flexible enough to solve unexpected problems. Acceptable grades in a student's related coursework are considered as part of the selection criteria.

Study Area

The study area is located in the Region of Tarapaca (Figure 1) from Junin to the Loa River (19º40' S to 21º 30' S, and 69º40' W to 70º, 10' W). The length of the coastline is approximately 200 km (124 miles) and the width toward the interior is an average of 100 km (62 miles). The total area is 20,000 km^2 (8,000 square miles). However, since ground truth conditions are determined by the visual ability of the observers relative to relief features, field measurements were limited to a smaller area of about 6,000 km^2 (2,400 square miles).

Field Stations

Preliminary cartographic analysis and fieldwork were done in the study area to locate a mountain high enough to be above the top of the stratocumulus clouds. This location would become an observation station from which the top of the clouds could be measured as well as other weather data recorded. The place chosen was Cerro Carrasco at 1592 m (5,254 ft.), which is located west of Salar Grande and southeast of Cerro Rojo and Punta Patache. A road leads to the summit, an important aspect for the field procedures. From the summit, it is possible to view panoramically coastal and inland areas. This location permits an observer to do careful cartographic work, and define, with the help of binoculars, the distance and altitude in relation to the relief (summits of hills) the presence or absence of clouds. Photographic views were created to train and assist students in these observations (Figures 2, 3 and 4). The task of the student researchers is to determine the extent of the cloud coverage within the study. This information is drawn on 1:250,000 maps of the area and later digitized and compared to the information on GOES images. Also, from this station the standard weather data (temperature, wind speed, and wind direction) are recorded.

A second station was installed at 15 km (9 miles) northwest from Cerro Carrasco in the Alto Patache area. This station is located at 800 m (2,640 ft.). From this location, fog water collection is measured using a Standard Fog Collector (SFC). Weather data are also recorded.

Finally, a third field station was located in the coastal cliffs in the Patache area at 450 m (1,485 ft.). Here, the altitudes of the bottoms of the clouds are recorded, and temperature, wind speed and direction are measured.

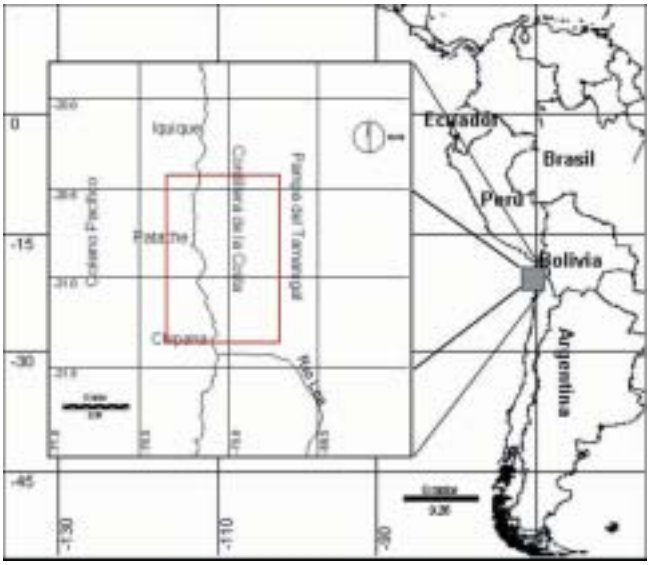

Figure 1 The study area

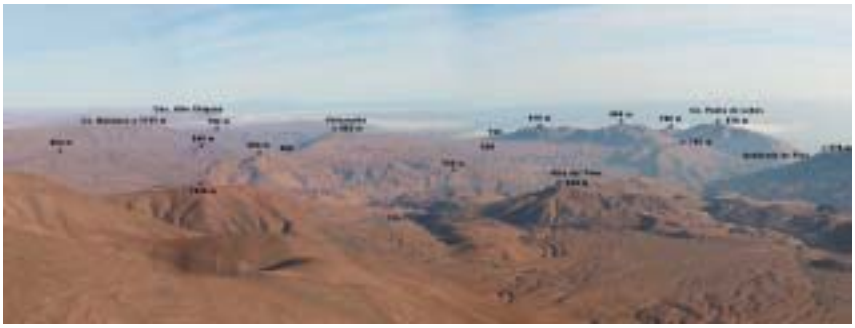

Figure 2 View from Mt. Carrasco to the southwest with the altitude of the hills.

From Alto Patache, seven SFCs were installed from 800 m to 350 m (800, 750, 700, 650, 550, 450, 350 m, respectively) in order to determine the altitudinal variation of fog water collection between both stations.

Each station has the necessary instruments (topographic map, digital printed picture of the area, compass, altimeter, GPS, clinometer, thermometer, anemometer, wind vane, watch, binoculars, hygrometer, VHF radio) and forms (Table 1) are provided to record the data. In the case of the Carrasco observation station, 100 maps at the scale of 1:250,000 are provided to draw on with a highlighter pen the cloud cover. Figure 5 shows an example of a field map drawn by students and the corresponding digitized map produced from the field map. (The orange color on the field map indicates the presence of fog based on field observations, and the blue colored map shows the same information but in a digital format for GIS use.)

The information from the three field stations is collected in synchronization with the GOES satellite at the following local times 3:10, 4:45, 7:45, 9:10, 13:45, 15:10, 16:45, 18:10, 19:45, and 21:10 for a period of ten successive days.

Each station is installed with basic camping equipment that provide the necessary facilities to support a team of three observers. A team of three is used in order to give individual members adequate time to rest, and to avoid the loss of information or the reduction in the quality of data collecting due to people being tired.

As previously indicated, the observers are undergraduate students from the Geography Institute. These "student-observers" are instructed in the operation of the research equipment at the stations, and how they should recognize cloud and fog conditions from their respective sites. These learning procedures help make them "specialists" in the field area, and assure the quality of their observations.

Three practical aspects are considered in establishing the time period for a field campaign. First, a time when a stratocumulus cloud and fog are likely to occur must be determined. Second, university vacations must be taken into account in order to allow students to stay 15 days in the field. Third, the phases of the moon are considered so that nocturnal illumination is suitable for the observations at night.

Table 1 Data sheet

STATION	CARRASCO						
ELEVATION							
DATE							
OBSERVER NAME							
TIME	C a^o	TEMP	W.D.	W.S.	S.D.E.	HIGH CLOUDS	OBSERVATIONS
03:10							
04:45							
07:45							
09:10							
13:45							
15:10							
16:45							
18:10							
19:45							
21:10							

Figure 3 View from Carrasco to Punta Patache

Figure 4 Altitudes and distances from Mt. Carrasco to the surrounding hills.

2002 Field Campaign

A field campaign was conducted during a 15-day period in July 2002. Previous field campaigns had been offered in July during the university's winter vacation period. During this period, GOES images were obtained and processed, and teams of "student-observers" operated the field stations and coordinated measurements between the three locations. These activities were

effectively done over a 9-day period from the 17th to the 25th of the month.

Daily results show a strong spatial correlation between the field observations and the processed GOES images. Correlations between field observations and satellite imagery for the nine day period are presented in Table 2.

Table 2 Correlations between visual observations and GOES imagery

Date	Correlation (%)
July 17	68.44
July 18	87.06
July 19	14.74
July 20	67.17
July 21	99.16
July 22	95.29
July 23	69.53
July 24	82.67
July 25	79.09
AVERAGE	**73.68**

Figure 6 compares the GOES images with field observations from Mt. Carrasco for two dates. The similarity between the Figure 6 maps means that the digital processing done from the satellite image shows a coherent result with what the observers registered in situ. Even though the visual comparison of the maps are very similar, it is necessary to do additional digital processing of the spatial information obtained in the field of the stratocumulus clouds in order to quantify and classify the differences and similarities between both thematic maps, and thereby, obtain a correct understanding of the satellite imagery's relationship to cloud behavior.

As a result of the student fieldwork, 100 GOES images have a corresponding ground truth image in real time and space. Also, about 900 pieces of data were recorded on temperature, wind direction and speed, altitude of the top and bottom of the clouds, and fog water collection at different altitudes. This information will permit the characterization of the stratocumulus clouds and fog in the study area during July 2002. It is important to point out that the pixel resolution of the GOES images is 4 km x 4 km. Thus, the level of the student-field observations is much more detailed than the imagery, especially during the daylight hours when events could be better visualized.

The meteorological data of the field campaign continues to be processed and some correlations have been found between the temperature and the altitude of the top of the

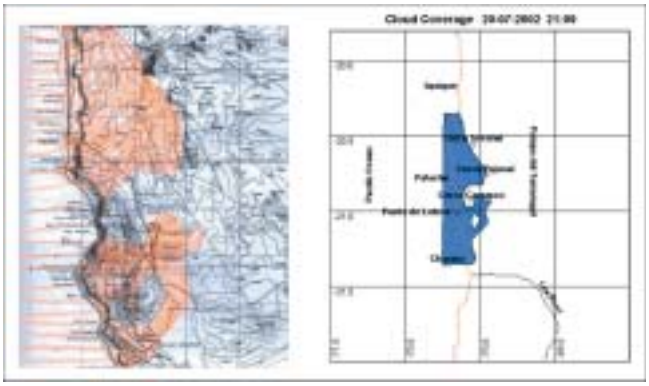

Figure 5 Map drawn in the field and its corresponding digitized map

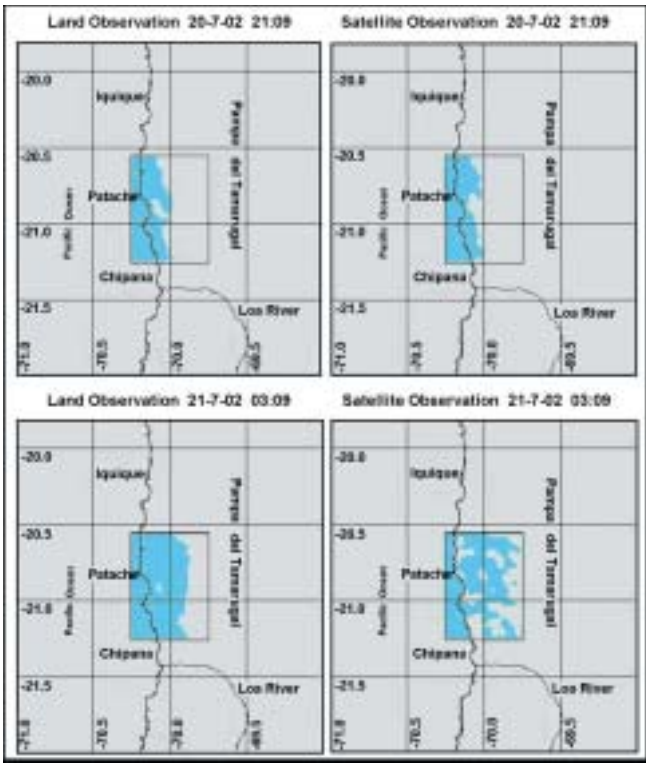

Figure 6 Thematic maps of field observations and GOES images

cloud, diurnal cycles and the width of the stratocumulus cloud.

Conclusions

Until now, the most frequent methodology used to understand cloud behavior and evaluate the water potential of fog has been the empirical studies dealing with a small area. To investigate a larger area, remote sensing can be an efficient tool for measuring cloud coverage, and thereby fog, and its frequency.

As mentioned earlier, the Geography Institute has been conducting fog research since 1980. The 2002 field campaign, like previous campaigns, provided a very good

opportunity for the students to acquire professional, scientific and even academic experience, since those in advanced courses must generally teach to their younger companions about the diverse aspects of the geographic discipline. Also, the experience to work in the field allowed them to improve their theoretical knowledge and become familiar with the application of what they learned into the classrooms.

The results of our 2002 field campaign show that an important correlation exists between the information provided by GOES and the real time information gathered in the field by student observers. These results are important for identifying places with fog and can be used in the implementation of operational projects of fog water supply. Since these results provide only preliminary approximations, a SFC would need to be installed and monitored at any location being considered for a major fog water collection system. The exploration of the possibilities with GOES images is the beginning of an important avenue of scientific and applied research, especially now that new satellites and sensors are available with better capacities.

When doing their fieldwork, these young people have the opportunity to develop their degree thesis that can deal with such topics as biogeography, remote sensing, anthropology or meteorology. Guided by their professors, they can develop their first journal publications and/or prepare presentations for conferences and seminars.

Finally, their fieldwork can provide an entry point for careers in activities related to the use and management of water resources.

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