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Environmental monitoring network along a mountain valley using embedded controllers

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ABSTRACT

This paper presents the design and implementation of an atmospheric observing system to study downslope winds in the Laja River Valley, southern-central Chile. Practical design issues are discussed based on the first two years of operation, as well as scientific results that demonstrate the potential of the measurement system. The system consists of a network of eight meteorological stations that characterize the winds along the Laja River Valley, Chile. The meteorological network extends over 90 km, beginning with the station at the Antuco Ski Center at 1395 m.a.s.l. and ending at the Charrua Electric Plant at 153 m.a.s.l. The meteorological stations were designed to employ an embedded controller and high-performance instruments with low power consumption. In order to transmit data to the base station, a communication protocol was developed using SMS messages. Graphic tools are also available in the project webpage to visualize received data. Data reported in this work show that the meteorological network is able to identify and characterize downslope winds.

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1. Introduction

Downslope winds have been studied in mountains all over the world and they exhibit one common characteristic: in certain conditions they can become dangerous windstorms. A complete study of the downslope winds requires in-situ observations because their origin and behavior are highly sensitive, among other local factors, to the existing topography which can amplify their strength. In this work an observational system is developed to study downslope winds along the Laja River Valley – Chile, located at ~37.4°S in the west side of the Andes Mountain in South America. Downslope winds in the Laja River Valley, locally known as "*Puelche*" winds, are common all year round, affecting the communities located in the front line of the effects of this phenomenon. *Puelche* events involve warm, dry and strong winds that in extreme cases can lead to fire alert conditions. Due to the lack of meteorological stations in the study area, special care should be taken in the selection of the observing technologies to monitor the phenomena, being data quality the most important concern. Since the study area is surrounded by mountains that are snow-covered in winter, the proper use of batteries and solar panels to power meteorological stations is a concern as well. Lead-acid battery performance, for instance, can decline 20% at zero degrees Celsius [1], and solar radiation decreases dramatically in winter at these latitudes. Solar panels are not an adequate solution as they can be covered by snow for long periods, with consequent effects on their performance. Thus, the meteorological stations should be powered only by batteries. With this restriction, the meteorological stations have to be highly power-efficient. The chances of vandalism are reduced in stations without solar panels, which is a real concern in remote places.

According to the authors of [2], the Santa Ana is a downslope wind in Southern California, USA, that has similarities to the *Puelche* wind. In 2007, one of the largest fires in California history was driven by especially strong Santa Ana winds [3]. Using data provided by local automated weather stations in California, some weather prediction models have been validated [3–5] for which a high spatial resolution in the observations is required (<4-km horizontal grid spacing).

As a first approach to building the meteorological network required for this project, we took a look at commercial solutions offered by the instrumentation market. With more than three decades since the company was founded, Campbell Scientific Inc. (CSI) has provided advanced data loggers and sensors that can be configured using high-level programming language. This equipment offers a rugged solution, as well as low development time, which ultimately can reduce operating costs. CSI systems are widely used in meteorology [6,7], but also in hydrology [8], oceanography [9],

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Nomenclature

GSM	global system for mobile communication	IDE	integrated development environment
SMS	short message service	LP3500	embedded controller
SIM	subscriber identity module	WXT520	multi-sensor
RTC	real time clock	M10	GSM modem
SRAM	static random access memory	WINDCAP	wind module
EEPROM	electrically erasable programmable read-only memory	RAINCAP	rain module
Sx	wind speed maximum	PTU	pressure, temperature and humidity module
Sm	wind speed average	St	station
Dm	wind direction average	m.a.s.l.	meters above sea level
Ta	air temperature	EMN	environmental monitoring network
Ua	relative humidity	AWS	automated weather stations
Pa	atmospheric pressure		

limnology [10] and other fields of applied physics [11]. Meteorological measurements to study the climatic change in the Demokeya forest (Sudan), for instance, were logged with CSI's CR-1000 data logger, which sampled every 6 s, and averaged/stored every 30 min [12]. Authors of [13] described an observing network dedicated to monitoring extreme weather events in California, USA. Extratropical winter storms on the North American west coast represent risks to lives and property, requiring coordinated actions to reduce negative effects. Their observing system supports the management of water supply and emergencies in California, as well as providing inputs for a numerical weather forecasting model. The network is composed of 43 CSI meteorological stations that transmit real-time data every hour. Among the meteorological measurement systems in Chile, CEAZA-MET is a network of 35 stations clustered around Coquimbo Region (30°S, 70.3°W). CEAZA (Center for Advanced Studies of Arid Zones) has operated these stations since year 2010. The stations employ the CSI CR-1000 data logger and provide meteorological data to validate climate models that help to understand and predict events such as droughts and frosts. This network takes hourly measurements of essential parameters, including air temperature, relative humidity, atmospheric pressure, wind speed and direction, and solar radiation.

A second approach to implementing the meteorological network consists of introducing engineering design in the main components of the network: the data logger, sensors' technologies, and data telemetry. With the numerous microcontrollers available today in the market, there are multiple approaches to constructing data loggers. Microcontroller-based environmental monitoring systems described in the literature support, among other applications, solar energy potential assessments [14–17], precision agriculture [18,19] and provision of early warnings of environmental emergencies such as poor air quality [20]. Authors of [21] proposed a global network for monitoring solar radiation across an extended geographic region in Sierra Nevada, Spain. This solar prospecting system has fifteen automated meteorological stations using an ATmega 16 microcontroller from Atmel Corporation (http://www.atmel.com). Solar radiation measurements, air temperature, and relative humidity are sent to the base station once a day via the Global System for Mobile Communication (GSM) cellular infrastructure. A 64 KB EEPROM completes the hardware components required in the design. Authors of [22] described a low-cost microcontroller-based system to monitor crop temperature and water status. The microcontroller is a PIC16F88 from Microchip Technologies (http://www.microchip.com) that takes measurements at one-hour intervals. Current consumption is approximately 13 mA during active measurement periods, dropping to 0.34 mA in sleep mode. Authors of [23] described another application in agriculture using a MSP430F449 microcontroller from Texas Instruments (http://www.ti.com). They present a GSM-based wireless monitoring system for field information. The system automatically reports, in real-time, the environmental measurements including air temperature, relative humidity and wind speed, as well as information about the population of the oriental fruit fly using the cellular Short Message Service (SMS). Authors in [24] presented a development of a weather monitoring station intended for applications such as agriculture and farming. The data logger design is based on the PIC16F887 microcontroller and utilizes standard meteorological sensors along with signal conditioning circuits.

A slightly different alternative to the microcontrollers are the embedded controllers. With microcontrollers, part of the work involves designing the printed circuit board that integrates the microcontroller with other essential components such as a real-time clock (RTC) and a non-volatile memory for data storage. Embedded controllers can be found in different form factors, some of them adequate for the final application [25].

Authors of [26] presented an environmental monitoring system based on a Mini6410 embedded controller from FriendlyARM (http://www.friendlyarm.net). The Mini6410 is a single-board computer with multiple features, however, it could not be used as a power-efficient data logger since its consumption is up to 0.25 A. Authors of [27] describe the design of a real-time monitoring system to support research in hydrometeorology and hydrology in Iowa, USA. They report around 40 meteorological stations built on the power-efficient LP3500 embedded controller from Digi International. The board consumes less than 20 mA when fully operational and less than 100 μA when powered down. This embedded controller exhibits similar power performance to the highly power-efficient microcontrollers described before, but offering a form factor closer to a single-board computer.

Monitoring systems in remote locations, like the study site of this project, extensively use the cellular network for data telemetry [28–30]. Because of the continued growth of the mobile telecommunication industry, its coverage has also expanded in Chile, even in remote areas inhabited by small communities. Authors of [30] built a monitoring system that transmits meteorological data using GSM-SMS technology. Various performance tests over the transmitted data showed that the method is highly reliable. Thus, it is highly probable that sent and received SMS messages are the same. The SMS is the most common and economically affordable digital transmission service used for sending and receiving text messages [31]. SMS messages can be as long as 160 characters in text or binary format. The SMS is a mature service available since the second generation mobile communication technology and still present today.

In this work, the observational system should provide high spatial temporal resolution measurements, in order to characterize the

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