Status of a Brazilian Automatic Hydro-meteorological territorial network

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***Abstract*— This paper presents a report on the status of a Brazilian network of automatic hydro-meteorological stations. These stations were projected, acquired and installed by the "Centro de Monitoramento e Alerta de Desastres Naturais – CEMADEN" in order to develop and implement a system for monitoring natural disasters. CEMADEN provides early warnings for natural disasters affecting Brazil, analyses and issues alerts associated to floods and impacts of severe droughts. We present the challenges of planning, installing and maintaining such a network, besides collecting and processing a large amount of data generated on an area comprising diversified environments and distinct socioeconomically scenarios.**

Keywords: natural disaster, wireless network, monitoring, data logger.

I. INTRODUCTION

Studies related to anthropogenic climate change presented in the first Intergovernmental Panel on Climate Change report (IPCC, 1990) have already highlighted the possible influence of climate change on the frequency and severity of extreme weather events, which are the main "triggers" for the occurrence of natural disasters of hydro-meteorological origin, such as floods, mudslides, landslides, collapses of yield crops, and of water supply systems by droughts. According to the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation - SREX (IPCC, 2012), even without taking into account climate change, disaster risk will continue to increase in many countries, including Brazil (Xavier and Celaschi 2016), since more people and vulnerable assets will be exposed to extreme weather, for example, in the outskirts of large cities.

The changes in global climate together with the incidence of severe climatic anomalies (Horel and Wallace 1981, Trenberth 1990, Mearns 2010) have triggered a worldwide initiative toward acquiring and processing a large amount of data with the aim of providing better forecast models and reliable warning systems (Basher 2006, Hughes 2006, Koike 2009). It is understood that the challenge of providing such warning services grows immensely with the population density and country area. Moreover, the efficiency of Government initiatives of this kind is far from being restricted to the warning system set-up: the degree of preparedness of a given area (Alfieri 2012, Thielen 2009, Bartholmes 2009) in face of severe occurrences is an obligatory subject of public administrative policies. Prior to accessing the reliability of the overall system, other more technical requirements must be met in order to have an operational sensor network (Basha 2007, Basha 2008). Any minimally operational network must survive the exposure to natural elements, must cope with unpredictable failures and restrictions in power budgets. Two models of alarm generation may be conceived: a localized one, which somehow implements an automatic mechanism of warning using processing resources at every collecting station or a centralized one, which is feed by data provided by stations that work simply as passive elements. The network described here is of this later type.

In face of the impossibility of controlling climate change and following worldwide initiatives (Castillo-Effer 2004, Bartholmes 2009), Brazil has very recently invested in planning, installing, maintaining and controlling a network of different sensors for hydro-meteorological data acquisition, with the first aim of increasing the amount of available data throughout its territory by enhancing the surface coverage density (New 2000) of weather sensors. Recent flood occurrences in Brazilian Itajaí and Mundaú rivers in 2008 and 2011, respectively and landslides in Rio de Janeiro in 2011 have show how vulnerable the population is in face of severe weather and unresponsive administration. On the other side of the hydrological scale, a never registered drought in the south-east part of the country in 2012-2014 are currently restricting access to water to over 40 million people and threatening a reduction in the country's gross product, since most of the Brazilian power generation infrastructure is hydroelectric based (Nobre 2009, Marengo 2014).

The purpose of the article is to present an overview of this national project coordinated by "Casa Civil" – an organ of the Brazilian Executive federal government. The 2012 National Plan for Risk Management and Disaster Response is overview, and the central hole of CEMADEN is pointed out. Section II presents the project architecture and its limitations along with the challenges of deployment and operation. Section III shows the details of the different stages (phases) of installation. The main conclusions are presented in Section IV.

A. Overview

In August 2012, the Brazilian federal government launched the National Plan for Risk Management and Disaster Response which large investments in joint actions. The goal was to ensure safety for those who live in areas vulnerable to natural disaster events. Preventive actions were also intended to preserve the environment and cover 821 municipalities which account for 94% of deaths and 88% of displaced and homeless throughout the country. The observation network includes the acquisition of 9 meteorological radar; 3375 automatic rain gauges, whose data are transmitted continuously (online) to the Centre's data platform every ten minutes; 1375 semi-automatic rain gauges for the Project "Rain Gauges in Communities". The network also includes installation of 500 sensors for monitoring rain and water in the soil, as well 95 agro-meteorological stations for monitoring of the semi-arid Brazilian Northeast region, especially for prediction of the likelihood of agriculture crop failure, as a result of severe drought in the Brazilian semiarid region. Therefore, the environmental observational network of CEMADEN includes the acquisition of roughly 6,000 equipments, and over 75% of them have already been installed. In most cases, the information is transmitted via cell phone through technology 3G / GPRS for storage and management of data, prior to their incorporation in the monitoring platform CEMADEN. All data and information is available CEMADEN freely to the scientific community and society in general, multiplying the intrinsic value of these observational networks in generating new knowledge and its application.

At CEMADEN, a multidisciplinary team of professionals from areas such as hydrology, meteorology, geology, engineers, geography, specialists on natural disasters, computer engineering and computational infrastructure of operating data was then hired to work on research and real time alerts. According to its legal framework, the responsibilities of CEMADEN are: to produce early warnings of relevant natural disasters for protective and civil defense actions across the country, supporting the actions of CENAD – "Centro Nacional de Gerenciamento de Riscos e Desastres"; to produce and release studies aiming the production of necessary information for planning and promotion of actions against natural disasters; to develop scientific, technological and innovation capacity, for continuing improving the natural disasters early warning; to develop and implement observation systems for monitoring natural disasters; to develop and implement computational models, to operate computational systems needed to the elaboration of alerts; to promote capacitation, training and support to activities of post-grad in correlated areas of action.

II. DCPs Stations Deployment and Challenges

The National Plan of Risk Management and Response to Natural Disasters established different types of data collection units. In the following, we describe the current number of installed stations: i) ~3600 automatic pluviometric stations named DCP-Pluvio (DCP or data collection platform, Fig. 1a), individually composed of: one rain gauge, one cabinet for the data logger, GPS and other functional units, a GSM/GPRS communication link, one (solar) power module; ii) 500 automatic stations called DCP-Acqua (Fig. 1b), composed of one cabinet for the data logger, GPS and other functional units, one rain gauge, sensors to monitoring soil moisture at two distinct depths (10 and 20 cm), that are primarily to be installed in the semi-arid region plus a GSM/GPRS communication link, one (solar) power module; iii) 95 automatic stations called DCP-Agro (Fig. 1c), composed of one cabinet for the data logger, GPS and other functional units, assembling a variety of sensors: one rain gauge, 4 soil temperature sensors, 4 soil moisture sensors, a differential anemometer and radiation and air humidity sensors plus GSM/GPRS communication and (solar) power modules; iv) 1700 semi-automatic stations called DCP-Semi, each one composed of a rain gauge, battery and a user friendly interface with a data logger, to be installed in risk areas and are operated by local community teams. Teams which are specially trained, aiming to promote the engagement and awareness of local inhabitants that live on areas of risk and v) ~280 hydrologic stations called DCP-Hidro composed of a radar water-level sensor, rain gauge, video camera for river monitoring, communication and (solar) power modules.

Fig. 1. Pictures showing the most common DCP models installed. From left to right, (a) DCP-Pluvio, (b) DCP-Acqua and (c) DCP-Agro.

Presently, this network is under continuous growth and maintenance as shown in the DCP-pluvio map presented in Fig. 2. Each DCP-Pluvio works as a stand-alone gathering node, periodically sending, via GSM/GPRS (Halonen et al 2003) and FTP protocol, two types of reports: a specific string of weather data (according to the DCP sensor set) and a status report. DCP-semi stations only implement a local memory buffer which his owner must download in order to send it to CEMADEN data server. The data volume processed at the center is about 50 Gigabytes of daily data upload and 100 Gigabytes of data flow with 15000 external daily access. CEMADEN monitoring service operates on 24/7 regime with green, yellow, orange and red operational mode alarms, with at least four experts on duty: a meteorologist, a hydrologist, a geologist and an expert in natural disasters.

Fig. 2. Positioned DCPs "Pluvio" deployed by CEMADEN as in May 2016.

The National Plan defined several priority areas in the country based on an initial risk analysis for the choice of each site, depending on criteria such as: presence of radio base stations less than 5 km away from intended DCP site, deficiency of local hydro meteorological data, existence of risk areas and population density. As shown in Figure 3(a), 51% of the Brazilian population (~ 200 million inhabitants) is presently attended by the network (that is, live in an area monitored by one or several DCP). From this total 45% is regarded as priority and less than 3% are still living on unattended sites. In terms of city number, Figure 3(b) shows that 15% of cities are located in risk areas and therefore are monitored. The 3% remainder in Figure 3(a) and Figure 3(b) is still uncovered and are natural installation targets for the next years. Finally, the National Plan intends to monitor all areas, even if under the non-priority status.

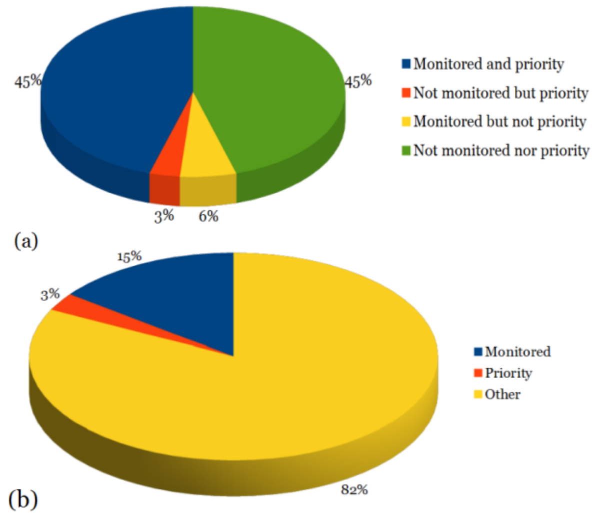

Fig. 3. (a) Percent of the total population (200 million inhabitats) assisted by the network installation plan until 2014 according to monitoring and priority status. (b) Percent of the total city number (5563) assisted by the network until 2014. 15% or the total city number is monitored.

On the micro level, several are the challenges of installing and maintaining this wireless network with a variety of sensor types and configurations across the 8.5 million kilometers squared of the Brazilian territory. The installation process has a series of procedural steps not only to define ideal sitting but also to warrant the proper equipment ownership at the installation site. Since the site is rarely a public domain, prior to installation, it must be inspected by an UNESCO advisory team (Project 914BRZ2018/MCTI) and checked against a set of minimum requirements. Ideal installation conditions involve the choice of a minimally flat terrain and unobstructed areas (stations located at least 10 m away from trees, buildings etc and 30 m away from sealed roads or highways) due to solar powering. Depending on the terrain type, options are not readily available. For obvious reasons, the site should not be located inside cultivated areas and, most important of all, from the property headquarters the station must be clearly seen. If the site is technically approved, the process goes to the time consuming phase of acquiring formal documents and contract signatures by local authorities and land owners.

A detailed block diagram of all the phases necessary for an every DCP type installation is shown in Fig. 4. Each phase may be further divided in the following steps:

- ✓ phase 0 – DCP site definition, database consulting for evaluation of site potential risk, installation mission planning, DCP configuration, logistics, establishment of partner agreements;
- ✓ phase 1, setup of installation kits, advisory team formation, civil defense support request, field work, preparation of inspection report, delivery of installation authorization, database feeding and logistics;
- ✓ phase 2 (if the site is approved), setup of installation kit for local site, partner contact support (government agencies, local authorities etc), installation WBS (work breakdown structure) and DCP data exchange test; and, if the installation does not succeed,
- ✓ phase 3, comprising system diagnostics, attempt of implementing remote solution, field work (system solution and optimization), eventual DCP repositioning;
- ✓ phase 4, quality test, network operation and DCP monitoring.

Overall we report excellent public acceptance of both advisory and installations teams. Locals are much more concerned nowadays with the issues of climate change and the impact on their lives of severe weather. In certain areas, installation teams are even courteously received, since the stations are viewed as a confirmation of administrative concern for their lives and be protected from impact of extreme events.

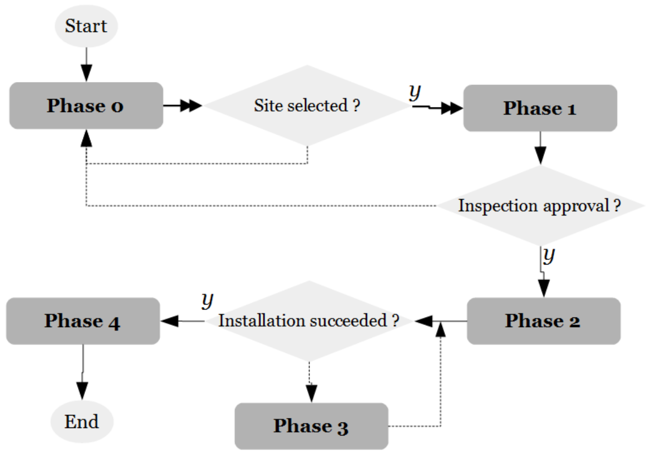

Fig. 4. Block diagram representing the installation phases.

A block diagram of the DCP internal structure is shown schematically in Fig. 5 bringing the common and main elements for most DCPs and is specific for two types: a DCP-pluvio and a DCP-acqua, the last one with an additional soil humidity sensor shown with dashed lines in that figure. External communication is provided by a General Packet Radio Services (GPRS) modem (RS232/RS445 interfaces, Global System for Mobile communication - GSM 900 MHz and GSM 1800 MHz bands, max. downlink rate ~90 kbps, max. uplink rate ~42 kbps) and an external antenna of two types, depending on the DCP location. In urban areas, a single monopole < 2 dBi antenna gain is sufficient. Rural zones require higher gains and the same GPRS modem is connected to a >10 dBi Log-periodic antenna. The DCP data logger is the responsible for the analog-digital conversion for all sensor units which include a tipping bucket rain gauge (Habib et al. 2001, Wang et al. 2008) (200 ± 0.5 mm bucket diameter, 500 mm/h capacity and ± 2% or ±3 % accuracy in the 0-250 mm/h and 250 – 500 mm/h interval, respectively) and internal humidity, temperature and control box lock sensors. Such internal data measurements are periodically registered and sent for maintenance reasons. The power module has a battery bank (12V/36 Ah), a solar panel (maximum power 20W/17.4V @ 25°C) and a charge control unit.

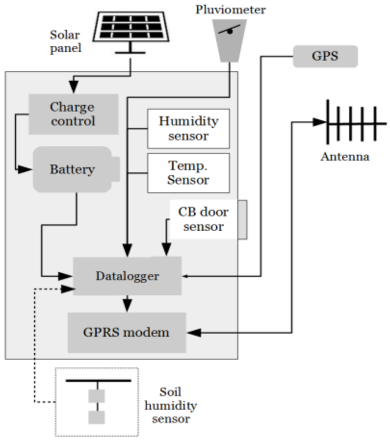

Fig. 5. Schematic representation of DCP-acqua (added soil humidity sensor) and DCP-pluvio.

III. DCP COMMUNICATION NETWORK

The purpose of this section aims to present how the GPRS/GSM network is important in the exchange of messages between the DCPs. Today Brazil is one of the largest markets in the world for mobile communication (GSMA London Office 2016). Recent data estimate that over 90% of the Brazilian population is covered by mobile connections. VIVO is the largest mobile operator in Brazil that is owned by Telefonica and has 29 % of the Brazilian market share. The second largest mobile operator in Brazil, TIM is owned by Telecom Italia with 27 % of the Brazilian market share. CLARO is the third largest mobile operator in Brazil that is owned by America Mobil and has another 25 % of the Brazilian market share. The fourth largest mobile operator in Brazil OI is currently owned by CorpCo, a joint venture with Portugal Telecom. The CEMADEN monitoring and alert system is served by those four major GSM/GPRS/3G service providers.

A partial view of one layer of the CEMADEN national monitoring network is shown in Fig. 6. The functional roles of this network are accessible on time at www.cemaden.gov.br/mapainterativo/#. At every single DCP location you find the rain volumes for the last 4, 24 hours, and the accumulated precipitation for the last seven days. Data exchange at the CEMADEN DCP-Pluvio monitoring system network (Fig. 6) is provided by the standard Global System for Mobile Communications – GSM, which has become the default global standard for mobile communications world wise. Data communications employs packet data transport via GPRS (General Packet Radio Services). GPRS is a packet oriented mobile data service on the 2G and 3G cellular communication system's global system for GSM. A major advantage of GPRS is its simplified access to the packet data networks like the internet. The packet radio principle is employed by GPRS to transport user data packets in a M2M structured way between GSM DCP stations and external packet data networks. These packets can be directly routed to the packet switched networks from the automatic hydro meteorological stations. GPRS throughput and latency are variables that depend on the number of other users' simultaneity sharing the service. The GSM/GPRS transponders installed in the DCPs provides data rates up to the third (3G) generation of mobile telephony. The M2M communication interface for periodic data transmission is heavily dependent on the four major cell phone carriers mentioned above. Although the feasibility of such communication system has been demonstrated, there are clearly limits for both quality of service delivered (QoS; national coverage area of the GSM/GPRS network, service call time) and sensitivity to climate change (service loss during heavy rainfall).

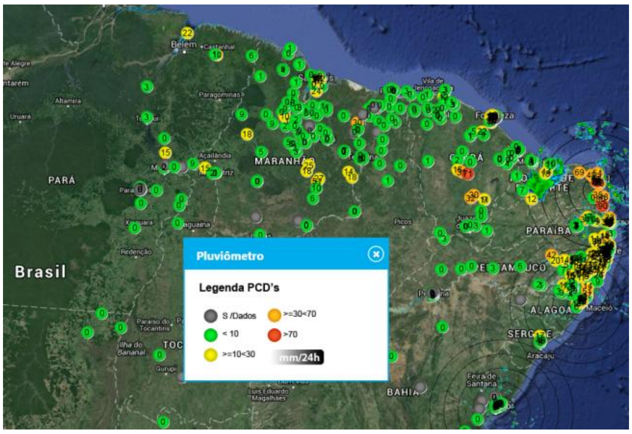

Fig. 6. Positioned DCPs "Pluvio" deployed by CEMADEN as in 11/05/2016. Different colors at the caption indicate the rain volumes in mm/24h.

IV. CONCLUSIONS

The environmental observation network monitored by CEMADEN is essentially to provide in situ information relevant for monitoring activities and the elaboration of alerts for those municipalities with risk areas of natural disasters. Also, it is useful for subsides generating scientific knowledge, which can help to understand environmental phenomena involved and triggering of natural disaster related to geo-hydro-meteorological conditions in order to continually seek significant improvements in the prediction of these phenomena as well as improving the advance and precision of natural disaster alerts issued by the institution. In addition, as a Centre of science technology and innovation, is committed to generate scientific knowledge and technological advances in the area of natural disasters, culminating in applications relevant to society.

ACKNOWLEDGMENTS

We are grateful to Dr. Carlos A. Nobre, Dra Regina C.S. Alvalá, Dr. Marcelo E. Seluchi, from CEMADEN, Marcos A. Rodrigues Sidney Cunha and Germano Beraldo from CTI for important discussions. This work is supported by the MCTI – the Brazilian Ministry of Science, Technology and Innovation. Special thanks to Silvestre R. de Aguiar Jr, from Coordenação Geral de Meteorologia, Climatologia e Hidrologia - SEPED/MCTI - Secretaria de Políticas e Programas de Pesquisa e Desenvolvimento.

REFERENCES

A.L. Xavier, and S. Celaschi, *Monitoring the 2013-14 drought in the São Paulo State – Brazil using GRACE equivalent groundwater measures.* DLR Conference on Climate Change – DLR-CCC-2016, Cologne, Germany, April, 2016.

A.L. Xavier, D. Bonatti and S. Celaschi, *Rain gauge simulator and first tests with a new mobile climate alert system in Brazil*. Journal of the Brazilian Computer Society, 22:2, June 2016.

L. Alfieri, L, P. Salamon, F. Pappenberger, F. Wetterhall, J. Thielen, *Operational early warning systems for water-related hazards in Europe*, Environ. Science & Policy, 21, pp 35-49, 2012.

R.C. Alvalá, P.I.M. Camarinha, and V. Canavesi, *Landslide susceptibility mapping in the coastal region in the State of São Paulo*. AGU Meeting of the Americas, Cancum. Mexico 2013.

E. Basha, and D. Rus, *Design of early warning flood detection systems for developing countries*. Information and Communication Technologies and Development. ICTD-2007 International Conference on, IEEE 2007.

E. Basha, S. Ravela, D. Rus, *Model-based monitoring for early warning flood detection*, Proceedings of the 6th ACM Conference on Embedded Network Sensor Systems, pp 95-308, 2008.

R. Basher, *Global early warning systems for natural hazards: systematic and people-centered.* Phil. Trans. R. Soc. 364, pp 2167-2182, 2006.

M. Castillo-Effer, D.H. Quintela, W. Moreno, R. Jordan, & W. Westhoff, *Wireless sensor networks for flash-flood alerting*. Proceedings of the Fifth IEEE International Caracas Conference on Devices, Circuits and Systems. Vol. 1, pp 142-146. 2004

R.O de Araújo, and R.Silva, *Socio-environmental vulnerability and disaster risk reduction: the role of Espírito Santo State (Brazil)*, Ambient. Soc., 17(4). São Paulo, 2010.

T. Fiolleau and R. Roca, *An algorithm for the detection and tracking of tropical mesoscale convective systems using infrared images from geostationary satellite*. Geoscience and Remote Sensing, IEEE Transactions on, 51(7), pp 4302-4315, (2013).

GSMA London Office. http://www.gsma.com/spectrum/wp-content/uploads/2012/10/gsma_brazil_obs_web_09_12-1.pdf. Site visited in May 2016.

E. Habib, W.F. Krajewski, and A. Kruger, *Sampling errors of tipping-bucket rain gauge measurements.* Journal of Hydrologic Engineering 6(2), pp 159-166, (2001).

T. Halonen, J. Romero, J Melero, GSM, *GPRS and Edge Performance. Evolution Towards 3G/UMTS*. 2nd Edition. John Wiley and Sons, Ltd. 2003

Horel, J. D. and Wallace, J. M. *Planetary-Scale Atmospheric Phenomena Associated with the Southern Oscillation*. Mon. Wea. Rev., 109, pp 813–829, 1981.

D. Hughes, P. Greenwood, G. Blair,G. Coulson, F. Pappenberger, P. Smith, and K. Beven, *An intelligent and adaptable grid-based flood monitoring and warning system*. Proceedings of the UK eScience All Hands Meeting, p. 10. 2006.

N. Koike, *Catching the wave: real-time tsunami warning systems.* Potentials IEEE, 28(5), pp 14-17. 2009.

K.E. Trenberth, *Recent Observed Interdecadal Climate Changes in the Northern Hemisphere*. Bull. Amer. Meteor. Soc., 71, pp 988–993, *1990.*

J.A. Morengo, *Vulnerability, impacts and adaptation (VIA) to climate change in the semi-arid region of Brazil*. In Brazil and climate change: vulnerability, impacts and adaptation, CGEE, Brasília/DF, pp 127-155, 2009.

J.A. Morengo, *Assessment of Impacts and vulnerability to Climate Change in Brazil and Strategies for Adaptation Options*. Fapesp Research Program on Global Climate Change. 2014.

F. G. L. O. Mearns, *Approaches to the simulation of regional climate change: A review*, Rev. of Geophysics, 29(2), pp 191-216, 2010.

M. New, M. Hulme, and P. Jones, *Representing Twentieth-Century Space–Time Climate Variability. Part II: Development of 1901–96 Monthly Grids of Terrestrial Surface Climate*, J. Climate, 13(13), pp 2217-2238 (2000).

C. Nobre, *Brazil and climate change - the context. In Brazil and climate change: vulnerability, impacts and adaptation,* CGEE, Brasília/DF, pp 11-19. 2009.

P. Pinho, S. Finco, and C. Pinho, *Overview of the Brazilian centre for natural disaster monitoring and alerts (CEMADEN),* Proceedings of the Fifth International Conference on Management of Emergent Digital EcoSystems, pp 302-305, 2013.

J. Thielen, J. Bartholmes, M. Ramos, A. Roo, *The European Flood Alert System - Part I: Concept and development*, Hydrol. Earth Syst. Sci., 13, pp 125-140, 2009.

J. Wang, B.L. Fisher and D.B. Wolff, *Estimating Rain Rates from Tipping-Bucket Rain Gauge Measurements,* J. Atmos. Oceanic Technol., 25, pp 43–56, 2008.

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