Prototype of the Mexican spatial data infrastructure for climate raster models and satellite imagery (“VISTA-C”)

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Abstract. In the face of climatic uncertainty and its impacts on agriculture yields, there is a growing need for public institutions of subtropical countries to access as reliable as possible meteorological models and transmit a representation of their results in an effective way to stakeholders in agriculture. In many of these countries however, broad climatic regions and point-based statistics remain the core of these representations. The use of satellite imagery is largely limited to visual assessment, although it could serve as complementary data to meteorological raster models and the basis for spatially consistent quantitative impact assessments of meteorological events. In view of this situation in Mexico, a project developed by the Institute of Geography at UNAM university, and promoted by the National Institute of Geography and Statistics, consisted in the development of a climate monitoring system, which includes three main features: 1) a modular array storage system containing NOAA and GOES satellite imagery acquired though a receiving station (ERISA), 2) a climate modeling scheme based on successive error corrections of climate raster maps and associated models using the above mentioned imagery, and 3) an online, dynamic geovisualization of the results of the models. We discuss the implemented technologies and illustrate the VISTA-C prototype which has been released.

1. Introduction
Climatic variability and environmental pollution impact multiple aspects of the survival strategy of human societies. Especially, food security, public health, disaster mitigation, are aspects which appear as a priority in the national agenda of many sub-tropical countries [1, 2]. For example, strong elements of evidence support that climatic change induces the occurrence of more frequent extreme hydrometeorological events causing droughts or floods [3].

Government institutions acknowledge important limitations in their capability to respond the associated crisis [4]. Consequently, there is a growing need for these institutions to access as reliable as possible meteorological and impact models and propose a representation of their results in an effective way to a range of stakeholders [2]. In the last decade, with the purpose of making available key information to a growing audience, geoportals with cartographic representation displays have been developed for government agencies. In Mexico, variables such as environmental, demographic, economical, have been released by multiple agencies e.g. [5-8]. However, these agencies recognize several limitations in the technology of these platforms, which may still hinder an optimal impact on the public and on targeted stakeholders.
At the international level, the GEOSS infrastructure has been a decentralized effort for international collaboration (Global Earth Observation System of Systems; [9]) in the climate, meteorology and agriculture topics, with the development of web-based geopортals such as EUMETSAT (Europe), CMA (China), and GEONETCast (United States of America: [10]). In Central America, the regional www.servir.net geospatial data portal is part of this GEOSS international network [10].

However, by its decentralized design, this international effort largely depends on the capacity of the participant countries. In many of the sub-tropical countries, broad climatic regions and point-based statistics remain the core of climate representations. The use of satellite imagery is largely limited to visual assessment, although it could serve as a valuable complement to meteorological raster models and the basis for a spatially consistent tool for risk management.

In this research, promoted by the National Institute of Geography and Statistics in Mexico (INEGI) and developed at the Geography Institute of the National Autonomous University of Mexico (GI-UNAM), we propose to enhance the participation of Mexico in the global network and create the Mexican spatial data infrastructure for climate raster models and satellite imagery (VISTA-C platform), with the generation of robust climatic raster models, the storage of these models and associated satellite imagery in a spatial data infrastructure, and the advanced geovisualization of the meteorological / climatic time sequence outputs of these models through the development of online cartographic applications.

2. Data and methodology
To illustrate the establishment of the VISTA-C platform, the following developments are presented: 1) the technological architecture of the platform supporting the acquired satellite imagery, 2) the construction of robust climate raster maps at two scales (at the national level and at regional scale in the Mexico Central Valley) and the incorporation of satellite imagery in the models for useful applications, and 3) the geovisualization of time sequences of the results of these models.

2.1. Data and technological architecture of VISTA-C
The acquisition of satellite imagery by the ERISA receiving station at the GI-UNAM allowed the collection and archiving, since 1996, of most variables registered as Essential Climatic Variables (ECV) by GCOS [11], over the Mexican terrestrial and maritime territory. Most of these are derived from AVHRR and GVAR sensors, from the NOAA and GOES satellite constellations (see table 6 in [12]). The acquisition of a GOES-R Nextgen ground station is planned at the end of 2016, and a GEONETCast America antenna (part of the GEOSS network) has just been acquired.

Apart from satellite data, point-based climatic data was fundamental for the construction of climatic raster maps; information from the national meteorological station network was stored at national level (daily data from 1979 to present). Additionally, in the Mexico Central Valley, time series of autonomous meteorological stations were collected since 2014 for this project.

The technological architecture that has been applied for the VISTA-C platform includes a satellite receiving station, a modular array storage system (24TB), a spatial database, a geoportal and a visualizer (see figure 1). Several components of this architecture are common to the platform of the Mexican National Climate Atlas [13] named UNIATMOS, although the focus of that platform is not on raster climate models. The metadata of both infrastructures are handled with Geoserver, OpenLayers and Geonetwork. Features of our data handler and visualizer are further explained in section 2.3.
2.2. Construction of climate raster maps

The generation of robust climate raster maps allows the use of archive satellite imagery to build prospective models of biophysical variables for agroclimatic applications [14]. A range of initiatives has focused on the generation of climatic information in Mexico; however, quality criteria in terms of processes have often been neglected. For example, simple interpolation schemes involving static parameters such as topography do not take into account the coherence of the relationships between climate variables within a dynamic physical framework.

Two strategies have been developed in the Geography Institute in order to establish robust climatic raster models in Mexico. Both consist in down-scaling a well established numerical climatic model to a higher spatial resolution. In the case of the national level, a Global model (IPCC AR4 climate change scenarios) was used; the temperature and precipitation simulations of the Atmosphere Ocean General Circulation Models (AOGCMs) were corrected for systematic errors via the Climate Predictability Tool (CPT; [15]) and their representation downscaled to a 50x50km grid (see [14]). In the case of the Mexico Central Valley, the precipitation variable from the MM5 model was downscaled using the objective analysis by successive corrections ([16], cited by [17]). The variable was first assessed for coherence and consistency and then downscaled to a 4x4km grid, the interpolation process benefitting in this case of the high spatial frequency of meteorological stations in the Mexico Central Valley.

Next, variables derived from the acquired and stored satellite imagery were selected for associated applications of the mentioned climate rasters: NOAA-derived NDVI images (a proxy for soil moisture conditions) in the semi-arid northern regions of the national grid, and Landsat - derived impervious surface ([18]) in the urbanized Mexico Central Valley.

2.3. Geovisualizer of time sequences of the raster maps

The visualizer of atmospheric tendencies and climatic scenarios in VISTA-C was based on Mapserver, Openlayers and other applications/tools. Three major differences with the Mexican National Climate Atlas [13] that impact on the visualization are 1) our system includes a satellite imagery ground station for near real time modeling and visualization, 2) we developed an application that takes advantage of the OpenLayer capabilities to handle multi-date raster datasets for dynamic visualization, and 3) Geonode was implemented as an additional collaborative tool in order to scale up the use and reuse of...
spatial data among the scientific community in and other stakeholders in Central America. The two first features of the visualizer are similar to the global NOAA geovisualizer [19].

The Central American SERVIR platform [10] also offers a dynamic visualization although it is built on the proprietary Google Earth API and on the kml format. That technology has very attractive assets for visualization but on the other hand is deficient in terms of metadata handling, a highly sensitive point for scientific data.

3. Results

The VISTA-C geovisualizer, set on the maritime, satellite – derived variable option (in this case, AVHRR-derived Superficial Sea Temperature), is illustrated in figure 2.

Climate raster maps were generated for the Mexico Central Valley region (figure 3a: precipitation). Urban impervious surface of the Mexico megalopolis (see figure 3b) extracted using the GI-UNAM methodology of Couturier et al. [18] from Landsat imagery (stored in the VISTA-C platform), is an input for a series of sensitivity experiments for precipitation broadcast with the MM5 model, in order to try and solve for discrepancies between predicted and observed precipitation patterns (see [17]). In the future, vertical profiles derived from GOES-R, acquired from our ground station, may also enhance the comprehension of the MM5 model in the Central Mexico Valley [17].

Figure 2: The VISTA-C Visualizer (June 2005 AVHRR-derived Sea Surface Temperature).

Figure 3: (a) Precipitation raster map in Mexico Central Valley (mm/h) as a result of our MM5 downscaling method (b) Precipitation distribution and urban impervious surface derived from Landsat imagery in Mexico Central Valley (pink tones).
Finally, figure 4 illustrates multiple-year cumulative precipitation raster maps derived from the AOGCM model corrections, with the modality of time sequence visualization at national level. In this case, AVHRR – derived NDVI imagery was used for spatial drought representations associated to climate change in the region, modeled by Magaña et al. [14]. NDVI images are potential predictors of hydrological drought and changes in soil moisture, using surface temperature projections as predictors [14].

![Figure 4](image_url)

**Figure 4.** Time series of a precipitation raster map from 33 year cumulative daily data along dry season months in Mexico, derived from global climate models down-scaling with objective successive corrections.

In both case studies, satellite imagery derived variables were used to extend the climate raster models’ explicative power and are susceptible of generating improved climatic spatial representations.

4. Conclusion
International collaborative efforts such as the GOESS network need substantial improvement in the participation of subtropical countries in terms of robust regional climate modeling and cartographic online applications. In this paper, we present the first spatial data infrastructure in Mexico dedicated to the online representation of climatic raster models and associated satellite imagery for climate applications. Two of these applications are exemplified at regional and national levels, for which the online platform may be of utility in climate change mitigation (case of the raster at national level for soil moisture prediction in the Sonora Northwestern Mexican region) or risk management (case of the regional raster for precipitation extreme events prediction using complementary impervious surface information). Also, an extension of Openlayer in Geoserver was an effective way to obtain an attractive design for time sequence displays on the platform. At the international level, the NOAA platform also makes use of OpenLayers with a remarkable design which offers an outstanding user-friendly interface to handle multi-temporal spatial data. Some characteristics of this platform may stir future designs for our VISTA-C visualizer. The use of free software enables public universities of sub-tropical countries, which are confronted with repeated budget constraints due to volatile global finances, to build and maintain useful interfaces for national priority issues in a sustainable, reproducible manner.

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