Geocentric Reference System for the Americas (SIRGAS)

Research Agenda - April 2014

1. Problem formulation

The amount and variety of geospatial information captured remotely by passive (cameras) or active (radar) sensors located onboard satellites have increased steadily over the past twenty years and all forecasts suggest that trend will continue in the coming decades. Remote sensors are used to collect detailed and updated information about processes that may be related to the action of man (Urbanization, infrastructure, exploitation of natural resources, etc.) as well as of the nature (crustal movements, changes in sea level, presence of dissolved water vapour in the atmosphere, etc.)

The social and economic development involves a variety of human actions that change severely the natural environment (residential areas, roads, agriculture, farm forestry, various pipelines, etc.). The result of such actions should be recorded for legal and taxation purposes, to become inputs for formulating development plans and to manage available resources.

Many natural processes affect the development and social sustainability, in some cases engendering a drastically major disasters (earthquakes, volcanic eruptions, floods, droughts, hurricanes, etc.). To prevent such disasters and mitigate their consequences it is necessary to understand the mechanisms that trigger them and thus it is necessary to capture information about the variables that govern them.

The border between natural processes and antropogenic ones is not a thin and sharp line, but a broad, diffuse band, within which it is difficult to quantify which proportion of the resulting effect is due to an agent or another. The available evidence underpinning hypothesis that large-scale human activities significantly alter the dynamics of natural processes, but much work is still required to quantify conclusively the anthropogenic impact. Such work can only be based on reliable and sustained information along time of the main dynamic process variables that we are trying to understand.

Traditionally, the geosciences have divided the world into different 'spheres' to facilitate their study (geosphere, hydrosphere, atmosphere, cryosphere and biosphere). It is now accepted that these areas interact in a complex way so that is not possible to understand the dynamics if the parts are studied separately. The current trend is to conceptualize the 'Earth System' as a set of complex subsystems, whose study is even a more complex process after considering the link between them. The study of this complex system is only possible on the basis of information attributes like: i) accuracy*,* to quantify the intrinsic uncertainty of each data source; ii) accuracy, to allow comparing and merging data from different sources; iii) spatial and temporal location to correlate temporal processes under study; iv) globality to fully understand the Earth system; v) continuity over time to identify the different spectral modes that reflect changes in the planet.

Summing up:

- the number and diversity of spatial information captured by satellites dedicated to the Earth observation grows at a steady pace
- society increasingly depends on this information to:
  - shaping the spatial data infrastructures that are the foundation of both legal security of property rights, the tax base of States, as well as planning and management of social and economic development; and
  - understand and develop strategies for coexistence with the processes of change experiencing by the planet, whether due to acts of nature or man or a combination of both;
- the main attributes of spatial information captured with artificial satellites depend (in many cases, drastically) on the time and spatial location of the satellite (implying knowledge of the satellite orbit) and the characteristics of the captured information (georeferenced).

The sustained trend over the last decade turned the global systems supported by satellite navigation (GNSS) in the main tool to determine the time, T, and the three geometric coordinates (rectangular, [$X(T)$, $Y(T)$, $Z(T)$] or conversely ellipsoidal coordinates latitude, longitude and height [$\phi(T)$, $\lambda(T)$, $h(T)$]), either of a satellite orbiting Earth, and the vertex of a parcel in the field. There are no indications that this trend will go to change in the near future; on the contrary, it is expected to increase in the quantity and variety of GNSS applications.

Many problems involving the gravity field of the Earth can not be addressed using the ellipsoidal height $h(T)$, because the work required to move a body (for example, a volume of water) between two points of known ellipsoidal height cannot be derived from such coordinates. To calculate such work it is required to know the difference in gravitational potential between two points and that difference is quantified using the physical height, $H(T)$ which, in general, differs from the ellipsoidal, $h(T)$ up to ±100 m at the global scale. The classical technique of 'geodetic leveling' remains irreplaceable to determine reliable physical heights. The current trend is to replace the GNSS technology complemented by a geoid model, which will be feasible in the medium term for many but not for all practical applications. A fundamental contribution to the feasibility of this idea comes from a special kind of satellite Earth observation -the gravimetric ones- which are making a decisive contribution to improving the geoid model.

The notion of spatio-temporal localization inevitably leads to system coordinates, since it is not possible to imagine a coordinate that is not uniquely associated with a system. And the notion of reference system inevitably leads to the reference frame, which is the practical realization of the reference system. If the system is essential to develop the theoretical framework in which we can understand a problem, the reference frame will allow for measurement that allow its study. Thus the geosciences and geo-engineering disciplines need both of systems and frameworks to which they can link spatial location coordinates, that is the geometric coordinates [$X(T)$, $Y(T)$, $Z(T)$] o [$\phi(T)$, $\lambda(T)$, $h(T)$]), the physical height, $H(T)$ and the time T for which they are valid.

SIRGAS is concerned with providing frameworks for the geometric coordinates and the physical height in the Latin America and the Caribbean region. Such frameworks should be consistent at the global scale, because the spatial information derived from satellites is, by its very nature, global and can not be linked to a regional or national reference framework without degrade their attributes.

Likewise, they must serve for the development of spatial data infrastructures, analysis of natural phenomena that generate natural disasters as well as to provide basic support to the study of geodynamic processes and global change presently experienced by the Earth System. The SDI do not require extreme precision and accuracies in the implementation of the framework, but must provide legal certainty and allow reliable access through simple and inexpensive procedures. Studies oriented toward the understanding of the geodynamic and global change, also required to anticipate the consequences of natural disasters require extreme precisions and accuracies in the range of few millimeters, for determining the geometric and physical coordinates. And such applications also demand that these attributes remain unchanged over time to ensure that the signals of change that we intended to measure are actually caused by changes in the Earth system and not by unstable frames of reference.

2. Open problems in research

2.1 Maintenance of high precision of the reference frame

One of the biggest challenges SIRGAS (and generally Geodesy) is facing is the maintenance of the frame of reference, i.e. making the precision and accuracy of the framework geographically homogeneous (same quality anywhere) and that they remain unchanged with time (the same quality at any time). For this it is necessary to accurately measure any change in the position of the reference stations due to a number of geophysical processes. Many of these processes occur with some regularity, e.g. continental drift, deformation of the crust in regions tectonically active, isostatic adjustment, crustal response to tidal forces and the hydrological and atmospheric loads, etc.; others are episodic and generally abrupt, by e.g. earthquakes and volcanic eruptions.

The state of the art with respect to the maintenance of terrestrial reference frame assumes that the change experienced by positions taken as reference points as the combined result of all these processes is linear in time, that is, that the reference points move with a constant speed. With the current accuracy of geodetic measurements this simple working hypothesis cannot be held valid, because measurements demonstrate nonlinear variations in many reference stations, caused by elastic (or quasielastic) response of the Earth surface to the variable load exerted on it by the hydrosphere and atmosphere. But most dramatic yet these nonlinear variations are episodic, and occurring abruptly with earthquakes of large intensity and / or near the surface of the Earth. Such phenomena produces not only a change of considerable magnitude at the positions of reference stations, but also in their speeds, which experience show that take years to stabilize at a constant value, similar to what they had before the earthquake.

We lack at present a unified criterion as to how Geodesy should keep the precise terrestrial reference frame. This issue is a permanent part of the SIRGAS research agenda where it is addressed from two perspectives complementary: one immediate term (three to five years) is to use the SIRGAS observational existing infrastructure in the region to model the not linear displacements; and a more long-term (five to ten years) relies on expanding the regional observational infrastructure with other geodetic techniques different from GNSS techniques and to calculate reference frames per epoch (e.g. one per month).

2.2 Real-time availability of the framework of reference

Georeferencing of spatial information that will belong to spatial data infrastructures of the countries of the region is mostly done with GNSS. The current trend is aims to reduce costs and simplify georeferencing process to the point of making it almost 'invisible' for many producers of spatial information. The techniques used for this purpose is mainly based on Internet connectivity via leverage between the reference stations and the agent that captures spatial information, so that it can achieve the georeferencing information captured while you are capturing (in 'real time') and performing a minimum set of simple procedures. Real time implementation of these techniques is also a permanent part of the SIRGAS research agenda.

2.3 Establishment of vertical reference frame associated with the terrestrial gravity field

Another major challenge facing geodesy in general and particularly SIRGAS is the establishment (and future maintenance) of a vertical reference frame for physical height, *H(T)*. This task involves a variety of long-term actions (of the order of ten years), which in SIRGAS member countries have reached a variable but in all cases insufficient progress. Such activities include: i) the establishment of a mandatory gravitational Reference potential with overall validity and universally accepted; ii) the realization of this level in the different countries in the region by combining sea level measurements performed with tide gauges in the continental coasts and ocean altimetry satellites at sea; ii) Linking gravimetric networks and first-order leveling in all countries of the region and of these with reference gauges and fundamental points SIRGAS; and the continental adjustment of all these networks.

2.4 Geodetic study of geophysical phenomena

2.4.1 Contributions to the study of the atmosphere

For the realization and maintenance of the framework, SIRGAS uses a distributed network of continuous measurement GNSS stations across the continent. The GNSS signals are electromagnetic waves passing through the atmosphere just as the rays of a tomograph traverse the organs of a patient undergoing a tomographic study. The analogy is so valid that medicine tomographic techniques do not differ conceptually of which have been developed in the field of Geodesy to extract GNSS measurements information on different variables of the atmosphere.

SIRGAS research plans include the use of GNSS measurements for mapping spatial-temporal distribution of water vapor and free electrons in the Earth's atmosphere. Water vapor is dissolved in the lower layer of the atmosphere (the troposphere) and is the main greenhouse gas. It is also a critical variable in the meteorological models used for synoptic forecasts, hence the importance of map dynamics throughout the continent. The free electrons are the highest region of the atmosphere (the ionosphere) and its influence is decisive for satellite supported navigation technologies, radio wave communication and on board radar satellites or ground above the horizon.

2.4.2 Contributions to the study of sea level

A noticeable effect of global warming is the increase in sea level caused by thermal expansion of the oceans and melting of large glaciers masses. Measurement of the mean sea level is carried out with two complementary techniques: ocean satellite altimetry (radar), which have the advantage of measuring in particular the oceanic planet's surface and the disadvantages that their data series are relatively short (twenty); and gauges, which have the advantage of having a long series of data (centuries) and the disadvantage of measuring just specific locations on the mainland and island coasts. As gauges are fixed to the crust of the Earth, its records show variations in sea level coupled with vertical crustal movements in the proposed site of the gage. To ascertain the variation in sea level is thus necessary to determine also the vertical movements of the cortex, a task that is part of the SIRGAS research plans.