ETRUSCO-2 Workshop
Ground Based Space Geodesy Networks Required to Improve the ITRF

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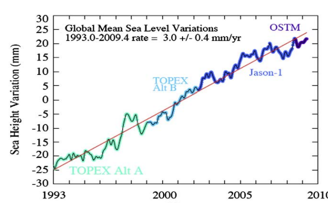
The Earth is a very dynamic planet and as a result, natural hazards disrupt our lives, cause havoc, and levy greats costs on society. Everything is moving. In the "solid Earth" we see plate motion, earthquakes, solid Earth tides, volcanoes, uplift, and all kinds of local motions. The ice is melting releasing large amounts of water. In the oceans, the volume is changing as water is added and water temperature is rising; and tides, currents, tsunamis, and weather are moving water around, often to places that we consider to be land. The dynamics of the atmosphere is connected to the oceans and can be observed in structure in the Earth rotation. Space geodetic techniques provide tools to measure these changes; and ground-based and space-based gravimetric techniques provide complementary tools to help us understand how mass is moving around on, above, and under the Earth's surface. The more accurate and comprehensive the measurements, the better we will understand the nature of these global change phenomena, how they are linked, and how they effect our lives. Measurements allow us to model the effects, perhaps to predict, but even more important, to plan long-term actions and make reasonable policies that will allow us to better contend with current trends and future conditions.

Common threads in these measurements are the reference frame and precision orbit determination (POD). The reference frame provides the stable coordinate systems that allows us to measure change (link measurements) over space (thousands of kilometers), time (decades and even generations), and evolving technology, and is defined by an accurate, stable set of ground station positions and velocities, in a global network of co-located space geodesy "Core Sites" including SLR, VLBI, GNSS, and DORIS where available. The reason for the co-location is that each of the techniques makes its measurement in a different way and thus each measures something a little different, with a different set of systematic errors. Each technique has different strengths and weaknesses, and the combination (through co-location) allows us to take advantage of the strengths and mitigate the weaknesses of each. An essential element in this combination is the accurate determination of the inter-technique vectors (site ties). These are determined through very accurate ground surveys between accessible instrument reference points and then careful extrapolation and modeling to the inaccessible system invariant points. The POD allows us to accurately model the conservative and non-conservative forces in satellites and better understand the geodetic sources of those forces. The measurements by the network stations for the reference frame and POD must be precise, continuous, robust, reliable, and geographically well distributed.



Source: Lemoine, F.G., et al. Towards development of a consistent orbit series for TOPEX, Jason-1, and Jason-2. J. Adv. Space Res. (2010), doi:10.1016/j.asr.2010.05.007

The Global Geodetic Observing Systems (GGOS) is an element of the International Association of Geodesy (IAG) that works with the IAG Components to provide the geodetic infrastructure necessary for monitoring the Earth systems for global change. Studies by the US National Research Council and other similar organizations, have articulated the measurement requirements necessary to provide the insight to understand the trends for various geodetic disciplines. The conclusion is that the most stringent requirement comes from sea level, which appears to be rising at the average rate of about 3 mm per year with annual variations that are not well understood, and the uncertainty in the reference frame (Earth center of mass, scale, EOP, etc) is still nearly a cm, so it is not clear whether or not other effects are influencing our measurements. The NRC study

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concludes that we will need 1-mm measurement accuracies with sub-mm/year precision to address sea level. Measurement requirements for other disciplines are not far behind.

GGOS has set its geodetic-network measurement requirements to provide the reference frame with mm accuracy and 0.1-mm/year precision. The means of providing the reference frame is through a global network of well distributed “core sites” with newer technology co-located SLR, VLBI, GNSS, and DORIS. Existing sites with lower levels of co-location and technology to help would further supplement the network to further enhance global coverage. In addition, a more dense network of GNSS stations would be necessary to distribute the reference frame globally so that users anywhere on the Earth could position their measurements in the reference frame at any time. Further detail on GGOS are given in: “ GGOS: Meeting the Requirements of a Global Society on a Changing Planet in 2020”. Eds. H.-P. Plag and M. Pearlman. Springer 2009. p. 332.

Simulations have been conducted by Erricos Pavlis to scope the network to meet the GGOS requirements. The network will need approximately thirty globally distributed, well positioned, Core Sites with modern technology and proper operating conditions; 16 of these Core Sites must track a complex of GNSS satellites with SLR to calibrate the GNSS orbits. Simulations continue to better understand the dependence of the space geodesy data products on system and network parameters. There are presently seven Core Sites with legacy technology systems in operation; another six to eight core sites are in the process of testing or construction. Most of the sites have legacy technology, but in many cases upgrades are underway toward new technology systems.

Co-location takes place, not only at ground stations, but also on satellites. Many of the LEO satellites have two or three tracking systems on board. This combination has provided orbits with cm level accuracies to support altimetry and other active satellite-borne systems. Space-borne co-location will help strengthen the overall network combination, in particular through ranging to the GNSS constellations.

The path forward to improve ground system performance is known and being pursued by practitioners with each technique. In SLR, newer systems are using higher pulse repetition rates (0.1 – 2 KHz) for faster data acquisition; smaller, faster slewing telescope for more rapid target acquisition and pass interleaving; capabilities to ranging from LEO to GNSS and even synchronous satellites; more accurate pointing for greater link efficiency; narrower laser pulse widths for greater precision; new detection systems for greater ranging accuracy; greater temporal, spatial, and spectral filtering for improved signal to noise conditions; more automation for operational economy (24/7) and greater temporal coverage; and modular construction and more off the shelf components for lower fabrication/operations/maintenance cost. Laser ranging has long been a tool to study lunar science and fundamental constants; it has now been expanded to receivers in space for time transfer, improved spacecraft ephemerides, and planetary science.

The reference frame relies on the core of geodetic satellites including LAGEOS-1 and -2, Etalon-1 and -2, and the newly added LARES satellites. Additional geodynamic satellites will add strength; studies are underway to see if Starlette and Stella can strengthen this constellation. Work continues on more efficient arrays with narrower satellite signatures to improve ranging accuracy. Improvements have been proposed to improve the productivity of the GNSS arrays (See Dell'Agnello et al.). Facilities are now available that can do a much better job of measuring array properties, examine different options, optimize designs, and setting specifications. More groups are building arrays and many new satellites with arrays are being planned.

Aside from these, a major step in the improvement of SLR results would be standardization in the way we screen and preprocess our data at the stations prior to shipment.