# ESAS2017 White Paper

**Title:** Terrestrial Reference Frame

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***What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?***

We measure and monitor the Earth's environmental system (its oceans, ice, land, atmosphere) not only to understand the processes of global change, but to also enable educated decisions on how to cope with these changes. Space agencies like NASA are heavily investing in satellites to make these measurements. Many of these depend on a highly accurate and stable terrestrial reference frame (TRF) within which to interpret the data and understand trends in the processes of change.

The TRF is the foundation for virtually all space-based, airborne and ground-based Earth observations. Positions of objects are determined within an underlying TRF and the accuracy with which objects can be positioned ultimately depends on the accuracy of the TRF. Through its tie to the celestial reference frame by time-dependent Earth orientation parameters it is also fundamentally important for interplanetary spacecraft tracking and navigation. The TRF determined by geodetic measurements is the indispensable foundation for all geo-referenced data used by science and society. It allows different spatial information, such as imagery from different space and airborne platforms, to be geo-referenced and aligned with each other. And it plays a key role in modeling and estimating the motion of the Earth in space, in measuring change and deformation of all components of the Earth system, and in providing the ability to connect measurements made at the same place at different times, a critical requirement for understanding global, regional and local change. Providing an accurate, stable, and maintainable TRF to support numerous scientific and societal applications is an important goal of the International Association of Geodesy's (IAG's) Global Geodetic Observing System and of NASA's contribution to it, the Space Geodesy Project.

The TRF is maintained though a global network of ground sites with co-located SLR, VLBI, GNSS, and DORIS stations. The most accurate global TRFs currently available are the International Terrestrial Reference Frames (ITRFs) produced under the auspices of IAG's International Earth Rotation and Reference Systems Service. Requirements for the ITRF have increased dramatically. Today, the most stringent requirement comes from critical sea level programs: a global accuracy of 1.0 mm, and 0.1 mm/yr stability. This is a factor of 5-10 beyond current capability. Future Earth observing satellites will have ever-increasing measurement capability and should lead to increasingly sophisticated models of the Earth system. The accuracy and stability of the TRF need to dramatically improve in order to fully realize the measurement potential of current and future Earth observing satellites.

***Why are these challenges/questions timely to address now especially with respect to readiness?***

The National Research Council issued two seminal reports in recent years (2007 and 2010, respectively):

- "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond"

- "Precise Geodetic Infrastructure: National Requirements for a Shared Resource"

The first report, known as the "Decadal, Survey", was the NRC response to the requests of NASA and other agencies to generate a consensus of recommendations from the Earth and environmental science and applications communities regarding: (1) high-priority flight missions and activities to support national needs for research and monitoring of the dynamic Earth system during the next decade, and (2) important directions that should influence planning for the decade beyond. The NRC recommended that:

> *"The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth-observing systems and restore its leadership in Earth science and applications."*

The NRC then recommended that a number of critical Earth observing missions take place over the next decade. These missions have a common denominator in the need for an accurate and stable International Terrestrial Reference Frame that enables the precise location of the spacecraft and their scientific instruments. This, in turn, allows the unambiguous referencing of all scientific data from plate-tectonic displacements to sea-surface height, establishing a key link between the geodetic infrastructure and the space missions.

The second cited report from the NRC addressed the precarious state of the critical national geodetic infrastructure, and recommended that:

> *"The United States, to maintain leadership in industry and science, and as a matter of national security, should invest in maintaining and improving the geodetic infrastructure, through upgrades in network design and construction, modernization of current observing systems, deployment of improved multi-technique observing capabilities, and funding opportunities for research, analysis, and education in global geodesy."*

In its present form, the geodetic observing system infrastructure is quickly deteriorating, and products such as an accurate and stable ITRF are in jeopardy. This deterioration is impeding current infrastructure from being able to meet the new, more stringent science requirements needed to support the key scientific questions connected to societal challenges.

***Why are space-based observations fundamental to addressing these challenges/questions?***

In response to the recommendations of the NRC Report on Precise Geodetic Infrastructure, NASA launched in 2011 a major effort to upgrade the ground-based geodetic infrastructure. Under the NASA Space Geodesy Project, a pioneering next-generation, geodetic observation system is taking shape. Activities include engineering and fieldwork relating to the realization of the first prototype fundamental geodetic site that employs the next-generation of VLBI, SLR, GNSS and DORIS instruments. Simulations indicate that a well-distributed, global network of about 32 such next generation sites co-locating all four space-geodetic observing techniques is needed in order to meet the target requirement on the TRF of 1.0 mm accuracy and 0.1 mm/yr stability. However, connecting the independent VLBI, SLR, GNSS, and DORIS networks together to form the ITRF is an ongoing challenge. Ground survey measurements can determine the distance between the reference markers of the different space-geodetic observing instruments that are co-located at the same site, but not between the phase centers of the instruments. Additional measurements and analyses are required to determine the offset of the phase center from the reference marker of each instrument. While the Space Geodesy Project has plans to determine the distance between the reference markers of the instruments, there is no plan to determine the offsets between the reference markers and the phase centers. Establishing and maintaining the ties between the observing instruments is a major weakness in current determinations of the ITRF.

An alternative to connecting the observing techniques on the ground is to connect them in space by co-locating all four techniques on the same dedicated satellite. This approach overcomes many of the technical limitations of measuring and maintaining precise ground co-locations, such as variable environment, and the complexity of modeling the ground antennas. Moreover, it obviates the need for proximate ground co-location of all the geodetic techniques. One approach to doing this is that of the Geodetic Reference Antenna in SPace (GRASP) mission concept. GRASP is envisioned to be a compact, stable platform with no moving parts on which all four space-geodetic observing techniques are co-located. The spacecraft is small enough that the entire spacecraft, including all instruments, can be placed into an anechoic chamber in order to measure the distance between the phase centers of the instruments before launch. Simulations have shown that the target requirement on the TRF can be met after flying GRASP for just three years. Space-based observations like those envisioned from GRASP are needed in order to improve the ITRF to its target accuracy in a reasonable amount of time.