Paper 10: Space Geodetics

Proof of any theory comes through direct observation or by direct measurement.

Space geodetics is a relatively new and sophisticated physical science that uses a network of radio telescopes, satellites, and ground-based receiver and transmitter stations from around the world to routinely measure the precise dimensions and continental plate motions of the Earth. This technology also forms the framework for modern GPS technology that is more familiar today. Because of its implied sophistication and complexity, it is therefore very important at this stage to investigate space geodetics in the context of an increasing radius Earth.

Space geodetic measuring techniques developed to measure the dimensions of the Earth stem from the early 1970s and include Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Lunar Laser Ranging (LLR), Global Positioning Systems (GPS), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). Observational data are now routinely recorded from each of these measurement techniques and the mathematically treated data from all receiver stations are combined and used to calculate a solution to the global geodetic network—a three dimensional measurement framework of the Earth.

In 1993, when Robaudo and Harrison first combined SLR data, including all global geodetic data from 1976 to the beginning of 1991, as well as VLBI data containing data up to the end of 1990, they allowed all observational stations to have three independent *"X-Y-Z motion velocities"*—vector motions of the ground-based observational stations in three dimensional coordinates. When these motion velocities were used to establish a *"...global geodetic network"* they calculated *"...a Root Mean Squared value of up-down* [variation in Earth radius] *motions of over 18 mm/year."* In other words the radius of the Earth was found to be potentially increasing by up to 18 millimetres per year.

At that time, Robaudo and Harrison considered this up-down motion to be extremely large. They did not consider any increase in Earth radius when making this judgement, but instead compared it to values that were expected from areas undergoing *"crustal rebound"* during glacial melting—the relaxation and rise of a continent after glacial melting—estimated to be less than 10 millimetres per year. It is significant that Robaudo and Harrison *"...expected that most VLBI stations will have up-down motions of only a few mm/year,"* and they went on to recommend that the vertical motion *"...be restricted to zero, because* [they considered that] *this is closer to the true situation than an average motion of 18 mm/year."*

Robaudo and Harrison were, in fact, faced with a daunting problem. When they calculated the 18 millimetre per year variation in Earth radius from 15 years' worth of observational data they found, but did not acknowledge, that Earth radius was potentially increasing by 18 millimetres per year. This value is very close to the value of 22 millimetres per year calculated here using published seafloor mapping, especially when Robaudo and Harrison's error margins are also taken into consideration.

Instead, this value of 18 millimetres per year was assumed by Robaudo and Harrison to be an accumulation of systematic errors during the collection and mathematical and statistical treatment of the raw observational data. Since then, the mathematical formulae and applied correction parameters attributed to this data have been refined, which has enabled all perceived errors to be statistically meaned out to zero.

The application of advanced space geodetic techniques to studies of the Earth has now progressed to the point where estimation of Earth radius and present-day plate motion is quoted to sub-millimetre accuracy. Results of Shen *et al.* in 2011 now show that *"...both geodetic and gravimetric observations support the conclusions that the Earth is expanding at a rate of 0.2 millimetres per year in recent decades."* This is encouraging but this value is a factor of 100 too low when compared with the current 22 millimetres per year rate of increase in radius based on seafloor mapping data.

Space Geodetic Data

One of the primary limiting factors to the accuracy of measurements in all space geodetic measuring techniques is the systematic errors that come from seasonal atmospheric interference to the signals being measured. This atmospheric interference alters the timing of the optical or radio signals being measured due to refraction of the signal as it passes through the atmosphere. To minimise errors, correction factors are routinely introduced during mathematical treatment of the raw measured data. These correction factors make allowance for the variations in wet and dry atmospheric conditions throughout the year.

For SLR, GPS, and DORIS measurements, additional limiting factors also include satellite tracking and modelling of the Earth's magnetic force field. Force field premises imposed on the mathematics are based on adopting a constant universal gravity G, a constant Earth mass M, and a constant product G·M. This product is then used to calculate Earth's surface gravity and to locate the physical centre of the Earth, which is used in both satellite altimetry control and as the X-Y-Z co-ordinate reference point. Satellite positioning and altimetry control are also known to be sensitive to both universal time and to the value of G·M.

In 2002, Koziar showed that, even though Earth mass and the gravitational constant are assumed to be constant for space geodetic purposes, the incremental change in Earth mass can be deduced from SLR observational data. The precise measurement of G.M began in the late-1970s and in his review Koziar takes into consideration measurements that continued into the 1990s. The SLR data were shown to consistently record a slow increase in Earth mass of the order of 3×10^{19}grams/year, which is of a similar order of magnitude of 6×10^{19} grams/year as calculated here using Earth radius derived from seafloor mapping data.

For an increasing radius Earth, the universal gravity constant is also assumed to be constant, while Earth mass has been shown to be potentially increasing with time and is the prime cause of an increase in Earth radius over time. Current known errors in the positioning of the centre of the Earth, and hence the co-ordinate system used by space geodesists, have been quoted as plus or minus 50 to 100 millimetres, so constraining Earth mass to a constant value may well be introducing additional unforeseen errors during data processing.

Recently, Shen *et al.* in 2011 gave a brief overview of how raw observational data is currently treated before using it to calculate a variation in Earth radius. In their overview they used spacial geodetic data published in 2008. In this data *"...there are 1572 readings at present from various stations (including GPS, VLBI, SLR, and DORIS)...Due to discontinuities of many recordings, only 930 recordings...are available for present study."* Also, *"...stations that are very close to each other...are merged to one station...Then, there are 841 stations left...in this study the stations located in active tectonic zones...have been removed from our calculations."* Furthermore, *"Another concern is that the absolute values of the vertical velocities of some stations are beyond 0.02m/year, and so large vertical movements of such kinds of stations are not related to Earth expansion...Hence, such kinds of stations are not included in our calculations...After removing the stations located in the orogenic zones and the stations whose vertical velocities are greater than 0.02m/yr, there are 625 stations left...Our calculations show that the Earth is expanding at present at an expanding rate of 0.24±0.04mm/yr."*

From this discourse on data treatment it can be seen that 60 percent of the raw observational data are eliminated before calculating a rate of change in Earth radius. In other words, all data that might otherwise indicate an increasing radius Earth is removed. This, in effect, smooths out the raw data before making their calculation. By doing this Shen *et al.* then concluded "*...the Earth is expanding at present at an expanding rate of 0.24±0.04mm/yr."* This smoothed and calculated data is now routinely published and used to quantify a limited increase in Earth radius and to continue to discredit any suggestion of large increase in Earth radius.

Space Geodetic Limitations

In conventional publications, the way the Earth is perceived to potentially increase in size is likened to a balloon where it is considered to be merely pumped up with a relatively uniform increase in radius each year. The implications of this pumping up process can be further visualised with the addition of a thin smear of damp clay coating the outside of the balloon to simulate the Pangaea supercontinental crust. By merely pumping up the balloon, the damp clay will stretch and extend to emulate the Earth's supercontinental crusts before breakup. Ultimately, the clay will rupture and break apart simulating breakup of the ancient Pangaean supercontinent to form the modern continents and oceans. By adopting this simplistic balloon example as representative of the Earth it could then be mistakenly perceived that the increase in radius of the Earth can be measured from a relatively few surface measurements. This is what Shen *et al.* tried to emulate for the Earth by eliminating 60 percent of the raw space geodetic observational data before making their increase in radius calculation.

Completion of the Geological Map of the World in 1990 now shows that the Earth's continental and seafloor crusts are not uniform and are far more complex than what this simplistic balloon example implies. The continents in particular comprise a mixture of ancient cratons, orogens, and sedimentary basins, each with their own age and definitional requirements, as well as the relatively modern seafloor crusts which make up around 70 percent of the surface area of the Earth.

Simulating this complex crustal composition during increase in Earth radius can be visualised by varying the balloon example to take into account these different types of crusts. The cratons, by definition, are crusts that have stabilised before about 2,400 million years ago. These can be simulated by partly drying the coating of clay on the surface of the balloon while leaving the underlying clay still damp. By again pumping up the balloon, the dried clay outer crust will crack and fragment to accommodate for the increase in balloon radius. By continuing to pump-up the balloon three things will happen: firstly, the dry outer crust will continue to fragment—simulating ongoing fragmentation of the cratons; secondly, the underlying damp clay will stretch—simulating the opening and extension of sedimentary basins; and thirdly, the soft clay located around the margins of the dry fragments will wrinkle and crumple—simulating formation of geosynclines, orogens and fold mountain belts.

In addition to fragmenting, because of its increased rigidity, the dry outer clay coating will retain a partial super-elevation at the centre of each fragment, allowing it to rise in relation to the rest of the balloon surface during change in balloon radius. The outer edges of each dry fragment will also be forced down into the balloon along the respective margins. Ultimately, the exposed damp clay will then rupture and break apart as the balloon continues to be pumped-up, again simulating breakup of the ancient Pangaea supercontinent to form the modern continents and oceans.

In this second example, even though hypothetical, the pumped-up surface of the balloon is not smooth or uniform. The surface will instead reflect the variation in super-elevation and fragmentation of the dried crusts, the depressed margins around these same crusts, and the relatively uneven surface of the stretched, wrinkled, and ruptured damp clay. In other words the surface of the crusts will be going both up and down depending on where the surface radius measurements are taken from. This pumping up process will then reflect the variability of the up-down motions of the various crusts, identical to what is seen in modern space geodetic measurement of the Earth.

To eliminate 60 percent of the measurements before calculating change in Earth radius, especially when the vertical motions are so small, is therefore seen as potentially misleading and erroneous. In addition, the choice, location, and amount of observational stations distributed around the world may also be biasing outcome of the current space geodetic calculation. For example, "*… removing the stations located in the orogenic zones and the stations whose vertical velocities are greater than 0.02m/yr*" will bias the outcome of the variable radius calculation by removing the very measurements that may show an increase in Earth radius. To overcome these problems it is considered that substantially more observational stations than currently available around the world would be needed before this bias could be minimised and a meaningful increase in Earth radius can be calculated from space geodetic data.