Einstein and Precision Agriculture

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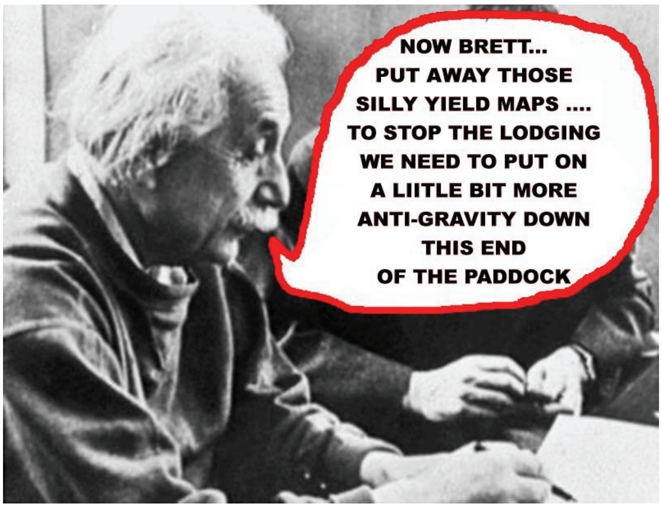
In the earlier part of the 1990's I was asked to give a talk one evening. I had fairly tough opposition as somewhere else in the university a fairly recent Nobel Laureate in physics was giving a talk on how through astrophyical measurements he had confirmed one apsect of Einstein's relativity theory. A brilliant new theory published in 1905. So I told my audience that given the opposition I'd talk on the application of relativity theory to agriculture. If I'd been serious it would have been a very short talk : because I couldn't think of any. Things are not massive enough or fast enough in farming to warrant the relativity theory. Good old Newton will do the trick. At least that's what I thought at the time. Now, the incredible new technology that is GPS has been made possible by a combination of scientific and engineering advances, particularly development of the world's most accurate timepieces: atomic clocks that are precise to within a thousandth of a millionth of a second. The clocks were created by physicists seeking answers to questions about the nature of the universe, questions raised by Einstein, with no conception that their technology would some day lead to a global system of positioning and navigation.
For centuries, the only way to navigate was to look at the position of the sun and stars and use dead reckoning. Even after modern clocks were developed for the Royal Navy by Harrison in England, making it possible to find one's longitude, the most accurate chronometers could yield a position that was accurate only to within a few miles. So until the late 1920s, the most accurate timepieces depended on the regular swing of a pendulum. They were superseded by more accurate clocks based on the regular vibrations of a quartz crystal, which could keep time to within less than one-thousandth of a second per day. Even that kind of precision, however, would not suffice for scientists who wanted to study Einstein's theory of gravity and ***here is the link between Einstein and Precision Agriculture***.

According to Einstein, a gravitational field would distort both space and time. Thus, a pendulum clock on top of Mount Everest, for instance, was predicted to run 30 millionths of a second per day faster than an identical clock at sea level. For light travelling 300 million metres per second this is equivalnent to ...... The only way to make measurements this accurate was to control a clock by the infinitesimal oscillations of the atom itself. Additionally, an atomic clock travelling at high speed in a satellite ticks slightly more slowly than its counterpart on the ground. The difference is extremely small when we're dealing with jets and cars and such, but at velocities approaching the speed of light, the effect is



enormous. In 1938 I.I. Rabi's research on the fundamental properties of atoms and nuclei led to his invention of a technique called magnetic resonance (the basis for the medical imaging of soft tissue) on which the first atomic clock was based. Rabi's student, Norman Ramsey, laid the groundwork for the development of the caesium-beam "fountain" clock and invented the hydrogen maser, devices that redefined timekeeping.

In addition to the clock, when the Soviet Union launched Sputnik on October 4, 1957, it was immediately recognized that this "artificial star" could be used as a navigational tool. The very next evening, researchers at the Lincoln Laboratory of the Massachusetts Institute of Technology (MIT) were able to determine the satellite's orbit precisely by observing how the apparent frequency of its radio signal increased as it approached and decreased as it departed--an effect known as the Doppler shift. The proof that a satellite's orbit could be precisely determined from the ground was the first step in establishing that positions on the ground could be determined by homing in on the signals broadcast by satellites.

In the years that followed, the U.S. Navy experimented with a series of satellite navigation systems, beginning with the Transit system in 1965, which was developed to meet the navigational needs of submarines carrying Polaris nuclear missiles. These submarines needed to remain hidden and submerged for months at a time, but gyroscope-based or inertial navigation, could not sustain its accuracy over such long periods. The Transit system comprised half a dozen satellites that would circle the earth continuously in polar orbits. By analyzing the radio signals transmitted by the satellites--in essence, measuring the Doppler shifts of the signals--a submarine could accurately determine its location in 10 or 15 minutes. In 1973, the US Department of Defence was looking for a foolproof method of satellite navigation. A brainstorming session at the Pentagon over the Labour Day weekend produced the concept of GPS on the basis of the department's experience with all its satellite predecessors. The essential components of GPS are the 24 Navstar satellites built by Rockwell International, each the size of a large automobile and weighing some 850 kg. Each satellite orbits the earth every 12 hours in a formation thatensures that every point on the planet will always be in radio contact with at least four satellites. The first operational GPS satellite was launched in 1978, and the system reached full 24-satellite capability in 1993.

A Chronology of Some Key Developments leading to GPS

1905-1915 Einstein develops his Special and general theories of relativity

1938-1940 I.I. Rabi invents and applies magnetic resonance at Columbia University in 1938. Possibility of atomic clock is discussed.

1954-1956 Zacharias and National Company develop the first self-contained portable atomic clock, the Atomichron.

1957 Sputnik is launched in October by the Soviet Union. Satellite Doppler tracking is inaugurated at MIT Lincoln Laboratory and Johns Hopkins Applied Physics Laboratory (APL) Navy Transit program is started at APL in December.

1960-1965 Rubidium optically pumped clock is introduced. Caesium frequency standards are installed in most international time-standard laboratories.

1964-1965 First position fix from a Transit satellite is computed aboard Polaris submarine.

1967 Transit system is made available to civilian community.

1968 Standards of a Defence Navigation Satellite System are defined.

1973 Development of Navstar GPS is approved by the US Department of Defense.

1974 First GPS test satellite, from Timation program, is launched to test rubidium clocks and time-dissemination techniques.

1977 Test satellite incorporating principal features of later GPS satellites, including first caesium clocks in space, is launched.

1978-1985 Ten prototype GPS satellites are launched, built by Rockwell International.

1989-1993 Series of 24 satellites are launched at about 6 per year. Final satellite is launched on June 26, 1993.

It is often forgotten that GPS is still a military device built by the Department of Defense at a cost of $12 billion and intended primarily for military use. That fact has led to one of the few controversies surrounding the remarkably successful system. As with any new technology, progress brings risk, and GPS potentially could be used to aid smugglers, terrorists, or hostile forces. The Pentagon made the GPS system available for commercial use only after being pressured by the companies that built the equipment and saw the enormous potential market for it. As a compromise, however, the Pentagon initiated a policy known as selective availability, whereby the most accurate signals broadcast by GPS satellites would be reserved strictly for military and other authorized users. GPS satellites now broadcast two signals: a civilian signal that is accurate to within 30m and a second signal that only the military can decode that is accurate to within 10m. The Pentagon has also reserved the ability to introduce errors at any time into the civilian signal to reduce its accuracy to about 100m.

In March 1996, the White House announced that a higher level of GPS accuracy will be made available to everyone, and the practice of degrading civil GPS signals will be phased out within a decade. The White House also reaffirmed the federal government's commitment to providing GPS services for peaceful civil, commercial, and scientific use on a worldwide basis and free of charge.

The future of GPS appears to be virtually unlimited; technological fantasies abound. The system provides a novel, unique, and instantly available address for every square metre on the surface of the planet--a new international standard for locations and distances. To the computers of the world, at least, our locations may be defined not by a street address, a city, and a state, but by a longitude and a latitude. With the GPS location of services stored with phone numbers in computerized "yellow pages," the search for a local restaurant or the nearest petrol station in any city, town, or suburb will be completed in an instant. With GPS, the world has been given a technology of unbounded promise, born in the laboratories of scientists who were motivated by their own curiosity to probe the nature of the universe and our world, and built on the fruits of publically supported basic research.

The moral of this story that governments, economists and the community should remember is that all basic research will turn out to be useful in the long run. It's just a question of how long is long?