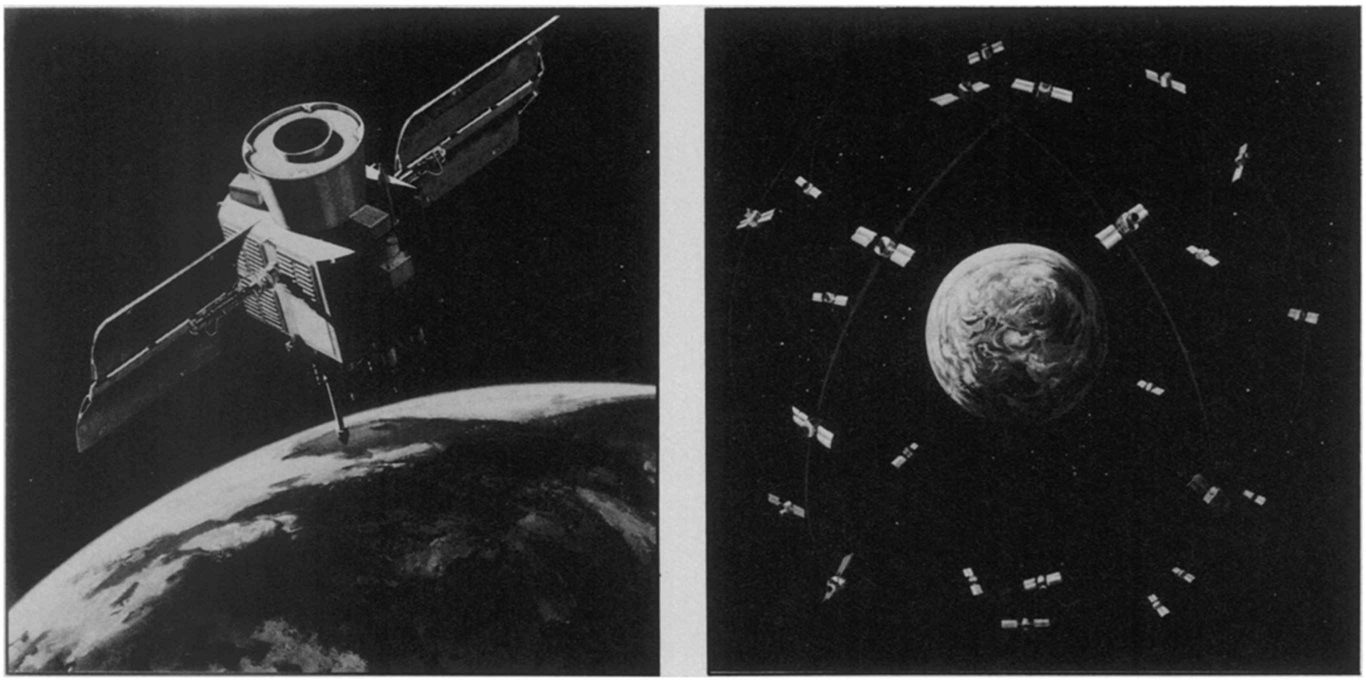
A SERIES Look at the Earth

A unique system of earth surveying might make unexpected use of defense satellites

BY SUSAN WEST



Rockwell, Int'l.

24 Navstar-GPS satellites will send coded navigation messages to armed forces. SERIES can use just the signals, sans the coded messages, to measure the earth by interferometry. Comparing signals from satellites in different orbits gives 3-D position.

Like a parent marking a child's growth, geodesy measures the earth. It monitors the slip along the San Andreas fault, the uplift of the Palmdale Bulge, even the sinking of the ground beneath the White House.

Field surveying and mapping are the common tools of geodesy. A network of permanent markers placed throughout the United States fixes vertical and horizontal reference points for geodesists. Computers, lasers and microwaves have lengthened the geodesist's arm and steadied his aim. Even so, such manual techniques are slow and, when an earthquake strikes or a volcano erupts, human safety preempts the need for a complete, continuous survey record.

In 1974, geodesy gained another tool. Called ARIES, for Astronomical Radio Interferometric Earth Surveying, it determines distances by comparing the radio signals from quasars received by two separate antennas (SN: 8/31/74, p. 136). Unlike conventional field methods, it is an all-weather system and can measure changes even across intercontinental distances. It is so precise, it can measure an east to west distance of 500 kilometers within two centimeters. The unwieldy antennas, however, make the system expensive, slow and less than easily mobile.

Now, Peter F. MacDoran of Jet Propulsion Laboratory in Pasadena, Calif., has another geodetic gimmick up his sleeve. Begotten by ARIES, it is called SERIES — Satellite Emission Radio Interferometric Earth Surveying. So far, NASA's Office for Space and Terrestrial Applications, which also funds ARIES, has given JPL enough money for an initial design study that may lead to a feasibility demonstration next fall. If the system works, says MacDoran, who is also ARIES project manager, "It will be a revolution in earth surveying. It could have the impact of learning to measure angles."

Like ARIES, SERIES will depend on radio interferometry — the technique of comparing radio signals received at two locations. Just as the noise of an explosion reaches observers at different locations at different times, a radio signal from a single source reaches two antennas at different times. In the ARIES system, the signal's arrival is timed by very precise atomic clocks at each antenna. The signals are recorded on tape at each location and combined later in a computer. The combined signals will produce a "fringe pattern" where they are out of phase. The signal delay, and thus the distance, is computed from the fringe pattern.

Though similar in principle, ARIES and SERIES differ significantly. For example, ARIES uses quasars and Seyfert galaxies for a radio source; SERIES will use signals from military satellites. The satellites are part of a Department of Defense system called Navstar-GPS (for Global Positioning System) (SN: 7/2/77, p. 6). The system will consist of 24 satellites; the fourth was recently launched. When all the satellites are operating in 1984, no fewer than four will be visible above the horizon at any given time. Navstar-GPS was originally designed solely for defense purposes. Coded radio signals from the satellites, picked up by U.S. ships or aircraft, for example, will give their precise three-dimensional global position.

But whether it intended to or not, says MacDoran, the DOD has also provided SERIES with a dependable source for radio interferometry, one that is much closer and therefore about 100,000 times "brighter" than quasars. And SERIES need not know the code, stresses MacDoran. "We didn't know the 'code' from quasars, either. We just used them. It's like throwing Brer Rabbit in the briar patch: We're used to it, we grew up with it."

And a different signal source means different receivers. In order to pick up the quasars' weak signals, ARIES requires large, very stable antennas. For example, to measure horizontal or vertical movement across the San Andreas fault, ARIES uses a fixed 64-meter dish antenna at Goldstone, Calif., and a "transportable" (as opposed to easily mobile) nine-meter dish antenna at Pearblossom, Calif. Transportable is a relative term with these antennas. Because of the time it takes to disassemble the nine-meter antenna, move it between locations, reassemble and test it, this pair of stations can only measure about one site per month, MacDoran says.

To pick up the Navstar-GPS signals, which are stronger but are also moving, the SERIES receivers can be less sensitive but must track the signal source much more quickly than ARIES's antennas. The receiver MacDoran has found most promising and that he and co-workers George M. Resh and K. M. Ong intend to test by next fall uses a phased-array antenna. A portable, desktop-size equivalent of the Very Large Array in New Mexico (SN: 8/31/74, p. 126), it is essentially a series of small antennas linked in phase to "see" anything 30° above the horizon. Its wide angle vision means it will not have to be steered and pointed toward a source as are the dish antennas of ARIES. Because it will have no moving parts and will require only a 24-volt source for power (or possibly a solar cell) and access to a telephone line to receive instructions and send data, the unit should be well adapted to the field. And it will be quick. MacDoran says it will be able to spot all four satellites above the horizon in four seconds. (A single measurement requires four satellites, all orbiting at different latitudes, in order to get a three-dimensional fix. Comparing signals from the four satellites gives the north-south and east-west horizontal and vertical distances and synchronizes the station's clocks.)

The agile SERIES will literally run circles around ARIES. The phased-array units can be hitched to a car or left unattended in the field. Because of the antennas' extreme portability, MacDoran estimates a team (which could be one person) will be "in and out in two hours," allowing it to measure as many as two sites per day. Like ARIES, SERIES will be able to cut through fog, clouds, light rain or snow. In addition, SERIES is expected to be about twenty times cheaper than ARIES. MacDoran estimates each of the first eight phased-array units will cost about $100,000; mass production will make them even cheaper.

It may sound like the young stud is about to put the old sawhorse to pasture, but SERIES cannot replace ARIES, MacDoran stresses. SERIES promises to be quite precise at short distances — it will measure 20 kilometers within one centimeter, he estimates — but because of the distance to the satellites, it loses that level of accuracy at distances greater than 200 km. If SERIES is a sprinter, then ARIES is a marathoner — it performs with high accuracy at distances greater than 200 km. It can measure intercontinental distances within five to ten centimeters.

Combining the two systems would be the best of all worlds. MacDoran envisions a grid of stations in which ARIES would anchor points every 200 kilometers apart and SERIES would measure changes over distances between 20 and 200 km. Such a system would take advantage of both SERIES's forté — measuring rapid, small, seismological-scale events — and ARIES's mastery of months- or years-long, geodetic scale changes in the earth's shape.

"[SERIES] could be the device that cements the disciplines of geodesy and seismology," MacDoran says. "If it works, its response capability will be in the seismological range but the permanently placed instruments will put it in geodesy."

Listening to MacDoran, SERIES sounds like the best measuring tool since the ruler. In fact, its unique talents seem to lend themselves to taking on the nastier tasks of geodesy. The unmanned units will be able to take the earth's pulse from places no human dares, or should, tread — active volcanoes, for example, or nuclear waste disposal sites. Not only is it far more satisfactory to sacrifice a machine than a person to a volcano, but SERIES could see through the smoke and fiery hail long after optical methods would be useless. Safety also prevents monitoring of the distortion of the earth near nuclear waste sites; SERIES could be a handy answer. Even along the Trans-Alaska pipeline, where access and environment prevent continuous manual surveying for ground distortion, SERIES antennas could be left unattended.

Oceanography might also benefit from SERIES's nimble skills. Riding atop buoys, an antenna could pick up signals from ocean-bottom transponders and thus survey sea-floor spreading. The rise and fall of open ocean tides and perhaps the formation of tsunamis (sea waves produced by submarine earth movement or volcanic eruption) might be watched over by the accurate eye of SERIES.

Perhaps the most attractive potential role for SERIES is in earthquake prediction. Though researchers have been trying all angles, including radon emission and changes in well water levels, nothing has "really jumped forward" as a clear predictor, MacDoran says. The most promising, because it is directly related, seems to be crustal deformation, he says. According to one current theory, before rocks fail and an earthquake occurs, there is a characteristic crustal change. The ARIES system does not operate on a small enough scale and cannot be moved quickly enough to a potential quake site to pick up a clear signature. Says MacDoran, "SERIES could do it."

In a report published in November 1978, the Committee on Geodesy of the National Research Council states, "The capability of satellite techniques [in geodesy] may be further enhanced by the Department of Defense Global Positioning System. . . . Its

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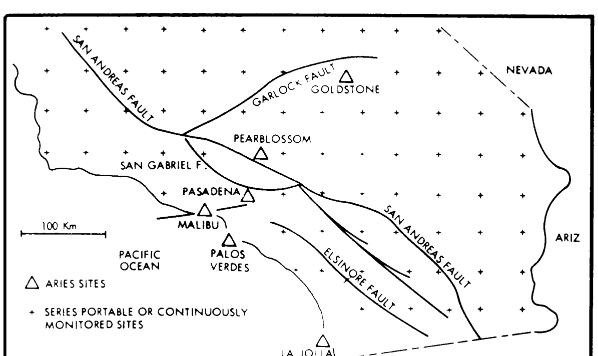
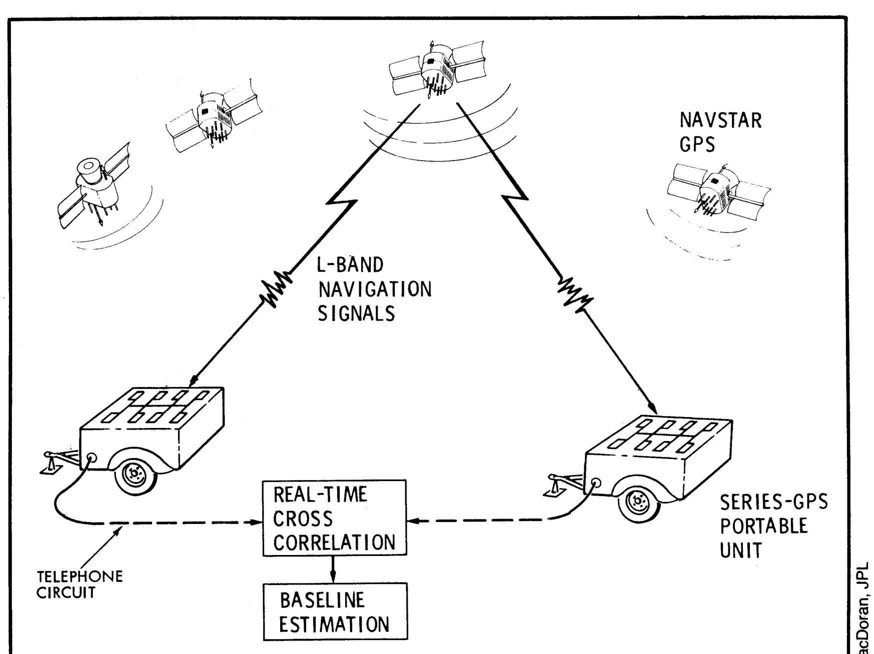


Above: As seen by MacDoran, existing ARIES *stations (triangles) combined with proposed* SERIES *sites (crosses) at every 50 km will give maximum coverage of crustal motion in Southern California. Right: By comparing the signal delay at two portable* SERIES *units, the distance between them can be measured.*



MacDoran, JPL

sources of the disease's symptoms. (Other mosaic animals, such as four-parented mice, can be used the same way once mutations mimicking human disease are available [SN: 11/18/78, p. 344].) Mintz and colleagues hope to propagate the genetic trait to subsequent mouse generations.

Unexpectedly, the work with mosaic mice offered insight into another disease, an anemia. Teratoma cells were found to contain a mutant gene that causes anemia. The gene is called *steel,* because of the gray banded hairs in the coats of mice with that trait.

In the mosaic mice produced from teratoma cells injected into an embryo, the blood-forming tissues with normal and with *steel* genes coexist throughout the developmental stages. Mintz and Claire Cronmiller report in the December PROCEEDINGS of the NATIONAL ACADEMY of SCIENCES that a surprisingly small number of normal cells in the blood-producing tissue's "microenvironment" can prevent the anemia from developing. However, if, in later generations, the normal cells are not present, the *steel* gene is again able to elicit the blood defect.

Mintz foresees "tremendous possibilities" for the transfer of foreign genes into teratoma cells and then into mice. Such experiments offer the possibility of learning whether genes can function in an animal under various conditions, for instance, in the absence of the genes that normally accompany them or without their flanking sequences. Eventually it may be possible to model human disease by actually moving the human gene into a mouse. Mintz anticipates "a useful arsenal to probe differentiation and malignancy."

Finally, mice derived in part from tumors offer a rare opportunity to study traits passed from mother to offspring in the cytoplasm of the egg, rather than in the chromosomes of the nucleus. Cytoplasmic organelles, such as mitochondria, carry genes; yet specific traits in mammals have not been identified. Now Mintz, working with Tomomasa Watanabe and Dewey, reports success in using mouse teratoma cells as vehicles for introducing into mice a convenient mitochondrial gene mutation, one that makes a cell resistant to the antibiotic chloramphenicol. Mintz suspects that research eventually will uncover human disease due to mutations in mitochondrial genes. The investigators say in the October PROCEEDINGS OF THE NATIONAL ACADEMY of SCIENCES, "... the precise roles of extranuclear genes in maternal inheritance and in development and diseases of mammals have remained *terra incognita* and may now become experimentally assessible *in vivo.*"

Other laboratories are beginning to pick up Mintz's technique. While having a tumor for a father is the ultimate skeleton in a mouse family closet, it may become a routine way to attack questions of development and disease in their complex context. □

... SERIES

geometry makes it ideal for geodetic purposes as well. Therefore, in order to optimize the return from this major investment of public funds, we recommend that support be provided for development and refinement of the Global Positioning System with the aim of achieving geodetic accuracy."

So it is no surprise that MacDoran is optimistic about SERIES. Similar systems also receiving support propose using communications satellites or radio sources left on the moon by astronauts, but these do not have the 3-D signal arrangement that the GPS provides. According to MacDoran, a group at Massachusetts Institute of Technology has suggested a system much like SERIES, but it would require the DOD to change its satellites. Recognizing a brick wall when he sees it, MacDoran decided to design a system that would circumvent that problem. Now, the construction and testing lie ahead.

"A lot of good people have looked at it and nobody has found any flaws," he says. "I feel good about that." □