THE HISTORY OF CARTOGRAPHY

VOLUME SIX

# *Cartography in the Twentieth Century*

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THE UNIVERSITY OF CHICAGO PRESS • CHICAGO AND LONDON

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The University of Chicago Press, Chicago 60637
The University of Chicago Press, Ltd., London


Printed in Canada

24 23 22 21 20 19 18 17 16 15 1 2 3 4 5

SET
ISBN-13: 978-0-226-53469-5 (cloth)
ISBN-13: 978-0-226-15212-7 (e-book)

PART 1
ISBN-13: 978-0-226-53470-1 (cloth)

PART 2
ISBN-13: 978-0-226-53471-8 (cloth)

This material is based on editorial work supported in part by the National Science Foundation under Grant Nos. 0322129, 0322200, 0749522, 0749687, 8812674, 9320895, 9975699, and 9975705. *The History of Cartography* has also been made possible by major grants from the National Endowment for the Humanities. For a complete list of financial supporters, see pages [v–viii] of part 1.

DOI: 10.7208/chicago/9780226152127.001.0001

Library of Congress Cataloging-in-Publication Data

The History of cartography.

Includes bibliographical references and indexes.

Contents: v. 1. Cartography in prehistoric, ancient, and medieval Europe and the Mediterranean — v. 2, bk. 1. Cartography in the traditional Islamic and South Asian societies — v. 2, bk. 2. Cartography in the traditional East and Southeast Asian societies — v. 3. Cartography in the European Renaissance — v. 6, pt. 1. Cartography in the twentieth century, part 1 — v. 6, pt. 2. Cartography in the twentieth century, part 2.

1. Cartography—History. I. Harley, J. B. (John Brian), 1932–91.
II. Woodward, David, 1942– III. Monmonier, Mark, 1943–

GA201.H53 1987 526'.09 86-6995

ISBN 0-226-31633-5 (v. 1; alk. paper)
ISBN 0-226-31635-1 (v. 2, bk. 1; alk. paper)
ISBN 0-226-31637-8 (v. 2, bk. 2; alk. paper)
ISBN 978-0-226-90732-1 (v. 3; alk. paper)
ISBN 978-0-226-53469-5 (v. 6; alk. paper)
ISBN 978-0-226-53470-1 (v. 6, pt. 1; alk. paper)
ISBN 978-0-226-53471-8 (v. 6, pt. 2; alk. paper)
ISBN 978-0-226-15212-7 (v.6; e-book)

***Global Positioning System (GPS).*** The Navstar Global Positioning System (GPS) is a multipurpose satellite system developed by the U.S. Department of Defense in the early 1970s. It was primarily designed to provide all-weather real-time spatial coordinates anywhere on (or near) the earth for use in navigation. These coordinates are typically accurate to about ten meters, but with enhancement can be accurate to less than a millimeter. Other countries have pursued similar systems—the Soviet Union's GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema) was also developed during the 1970s, while the European Union's Galileo and China's Compass systems are both scheduled for the 2010s—but Navstar GPS has been by far the most prominent, and for most nonspecialists "GPS" is simply a generic name for a device that provides precise geographic location.

GPS is of central importance to the history of geographic knowledge in the late twentieth century, and the pace of the GPS revolution has been staggering. When the United States used GPS during the Persian Gulf War in early 1991—its first major test—receivers numbered in the thousands, equipment was in short supply, and its military applications made newspaper headlines. By 2010 there were roughly one billion GPS receivers in use around the globe, and only a tiny fraction of these were deployed by the American military. The diffusion of GPS technology thus brought many of the themes of postwar cartography into the everyday lives of commuters, scientists, farmers, and even teenagers: the ubiquity of maps and map knowledge, the transition from static paper maps to dynamic electronic mapping, and the ambiguous status of dual-use military/civilian technology.

Since the impact of GPS on property surveying and personal navigation is addressed in other entries, the goal here is to evaluate the wider cultural-political importance of GPS as a ubiquitous spatial technology. After first explaining the design and subsequent evolution of the system, the rest of this entry analyzes the various uses of GPS since it first began functioning in the mid-1980s. There are two ideas to be addressed in particular: first is the common assumption that GPS is an inescapably military system; second is the countervailing idea that GPS is a neutral technology with no inherent politics. Both these approaches, however, overlook key features of its history. GPS does indeed enable certain kinds of interventions and not others, but its politics are defined less by the military/civilian divide than by a certain approach to local knowledge.

### Designing a Universal System

Construction of Navstar GPS was initially approved by the U.S. Department of Defense in late 1973. The overarching goal was to replace the variety of electronic navigation systems then in use—most of which could be used only in specific areas for specific tasks—with a single, global system. The more immediate goal was to supersede the first-generation satellite navigation system known as Transit, which had been designed by the U.S. Navy in the late 1950s for targeting submarine-fired nuclear missiles. Transit was perfectly adequate for this task, and was widely used for geodesy and civil-marine navigation as well, but coordinates could be calculated only once every few hours, and results were strictly two-dimensional and unreliable on fast-moving vessels (Williams 1992, 238–39; Parkinson et al. 1995). By the mid-1960s both the U.S. Air Force and the Navy were pursuing second-generation projects that could give continuous three-dimensional positioning. GPS combined these various proposals into a joint project that would satisfy all military requirements at once.

The basic idea behind GPS was relatively straightforward. A successful GPS fix relies on precise distance measurements between a receiver and multiple satellites. These measurements are made using signals continually broadcast from each satellite that give its precise location and the time when the signal was sent. Since the signal travels at roughly the speed of light, computing distance just requires knowing how long the signal took to reach the earth. What this means, however, is that all GPS clocks must be synchronized to within a few nanoseconds, since a time error of just 1 millisecond would mean a coordinate error of nearly 300 kilometers. Every GPS satellite is thus equipped with an atomic clock accurate to about three seconds over a million years. Because the clocks in most receivers are not nearly this accurate, usually four satellites are used to solve for four unknown values—three for distance and one to synchronize receiver time with satellite time. Precise timekeeping is so important that in many contexts the entire GPS system can be reduced simply to "clocks in space" (Pace et al. 1995, 204).

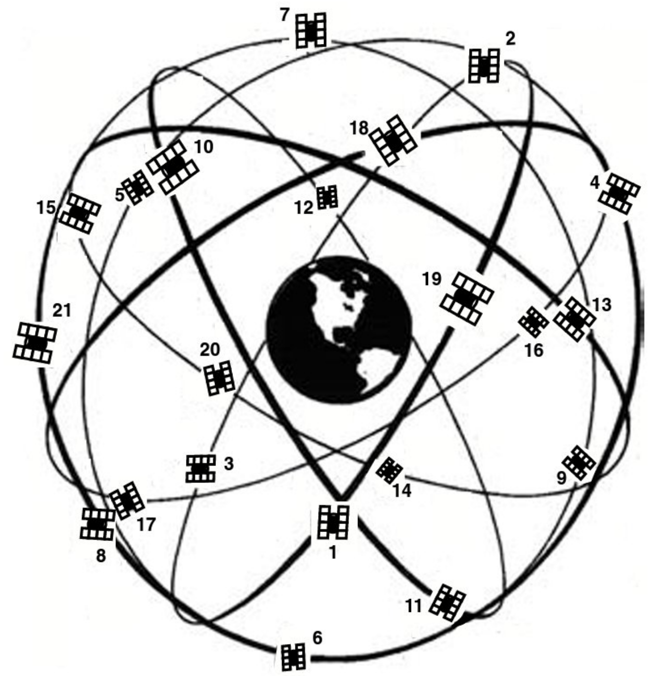


FIG. 333. BASIC DESIGN DIAGRAM OF THE GPS CONSTELLATION. This mid-1980s configuration shows eighteen primary satellites and three spares, but the final constellation has included as many as thirty-two operational satellites. After R. L. Beard, J. Murray, and J. D. White, "GPS Clock Technology and the Navy PTTI Programs at the U.S. Naval Research Laboratory," in *Proceedings of the Eighteenth Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting* (N.p., 1986), 37–53, esp. 50 (fig. 1).

For engineering purposes, GPS was divided into three segments: the satellites themselves, control stations to monitor the satellites, and user equipment. The first—the space segment—was designed as a constellation of nearly identical satellites in very similar orbits. The governing requirement for the arrangement of satellites was to have at least four visible in the sky everywhere on earth at all times. Figure 333 shows the basic design of the constellation as of the mid-1980s: the satellites are in medium earth orbit about 20,000 kilometers above the earth, completing one orbit roughly every twelve hours. Each is about the size and weight of a car (fig. 334) and powered primarily by solar panels. The satellites have a finite lifespan, and new satellites must be launched periodically to replace those that fail.

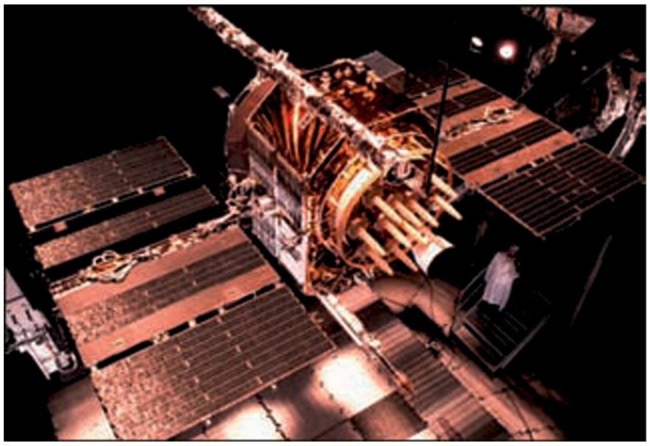

FIG. 334. TESTING A BLOCK II GPS SATELLITE, 1985. The size of the satellite is indicated by the person standing lower right.
Image courtesy of the Arnold Engineering Development Center, Arnold Air Force Base.

The control segment is composed of a number of fixed receiver stations that track the satellites as they pass overhead. These stations are crucial for ensuring the reliability of GPS coordinates, since the accurate broadcast of each satellite's location requires predicting how its orbit will be affected by factors like high-altitude gases and the earth's gravity field, and these predictions are not always correct. Actual measured satellite paths are thus continually processed to give new orbit-prediction data, which are subsequently uploaded to each satellite along with ongoing clock synchronization. In the Cold War–era 1970s, the main consideration for siting ground stations was that together they should provide as much tracking coverage as possible while still being located on U.S. military bases (fig. 335).

Finally, the user equipment segment was designed to include a great variety of receivers, from multiantenna sets built into aircraft to portable receivers powered by batteries. The most important engineering distinction was between military and civilian equipment. Civilian uses were taken into account from the beginning (and were crucial for maintaining adequate funding from the U.S. Congress), but the military wanted to be able to deny GPS to unfriendly forces if necessary and to restrict the use of GPS for high-accuracy targeting. GPS satellites were thus designed to transmit signals on two frequencies at once, one of which is encrypted for military use. Not only could the civilian signal be turned off in wartime, but access to both signals also enables direct correction of the effects of the earth's ionosphere, thereby giving authorized users an accuracy advantage.

Given how closely these parts are interrelated, it is difficult to identify any single feature that sets GPS apart from earlier systems, and apportioning credit for its design has been controversial. The main contest has been between two leaders of proto-GPS projects from the 1960s. The leader of the Navy's Timation project, Roger L. Easton, has argued that "the GPS invention" was using space-based atomic clocks to measure distance (Easton 2005). In contrast, the director of the Air Force's Project 621B, Bradford W. Parkinson, who subsequently went on to lead GPS in the 1970s, has instead identified the GPS signal structure—an early use of a code division multiple access (CDMA) signal—as the "keystone technology" (Parkinson and Powers 2010, 31). Not surprisingly, these are exactly the technologies that had been pursued by the Navy and the Air Force, respectively. Easton and Parkinson have both been awarded medals as the "inventor" or "father" of GPS, but the intractability of their dispute over its key innovation suggests that assigning a definite inventor is not a useful exercise. GPS was a synthetic project both technologically and bureaucratically, and GPS-like ideas can be found in both satellite and terrestrial precedents as early as World War II. The creation of GPS, like most complex technical systems, was more a question of engineering and project management than groundbreaking novelty.

Since the initial design of the system in the early 1970s, most of its basic features have changed only slightly. GPS satellites, for example, have been made more robust, and the constellation has been tweaked in response to budget fluctuations. Similarly, beginning in 2005 several new ground stations, generally sited on non-U.S. land, were added to the tracking network to allow constant monitoring by at least three receivers simultaneously. GPS signals have likewise been modified as policies for civilian and military capabilities have changed. After discovering that early civilian receivers were more accurate than expected, the military began intentionally degrading the civilian signal. But this practice—known as Selective Availability—was discontinued in 2000, and later satellites were designed to broadcast using additional frequencies to improve both civilian and military accuracy alike (Lazar 2002).

The combined effect of these changes, however, has been relatively minor compared to the impact of the radical miniaturization and falling price of user equipment. Figure 336, for example, shows the change in the size of portable military receivers between 1978 and 2004. Not only did they become smaller and lighter, but the later equipment also began displaying electronic maps rather than just raw coordinates. Civilian receivers likewise transformed from specialist instruments to mass-market commodities complete with small color map display screens and up-to-date digital maps. The

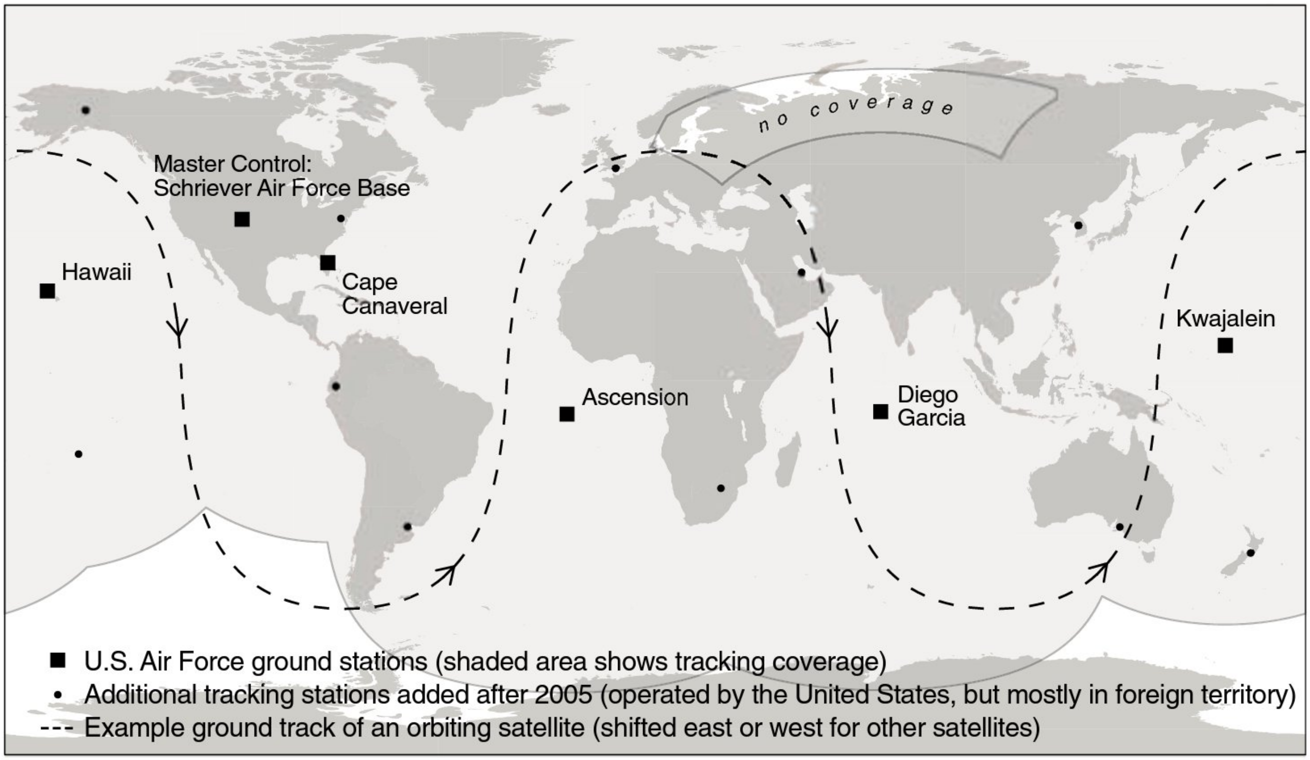


FIG. 335. MAP OF GPS TRACKING STATIONS. Uniform global GPS coordinates still rely on the particular political-physical geography of the earth, since satellites must be continually monitored from a network of ground stations.

Image courtesy of William J. Rankin.


FIG. 336. GPS RECEIVERS IN THE FIELD, CA. 1978. In 1973 the designers of GPS had hoped to eventually produce a portable military receiver weighing less than twelve pounds (5.5 kg). The Manpack of 1978 (left) weighed 14 kilograms, while the Defense Advanced GPS Receiver (DAGR) of 2004 (right) weighed about 400 grams and fit comfortably in the hand.

Left, from Lazar 2002, 45; permission courtesy of the Aerospace Corporation, Los Angeles. Right, image courtesy of the National Museum of American History, Smithsonian Institution, Washington, D.C.


FIG. 337. FIRST GPS WRISTWATCH, PRO TREK. Sold by Casio in 1999 for $895; ten years later GPS watches were no larger than their non-GPS counterparts and cost just over $100.
Size of the watch body: 6.5 × 6.5 cm.

cost of an entry-level receiver fell from $1,000 to $100 between 1992 and 1997, and the smallest receiver in the early 2000s was the size of a wristwatch (fig. 337). Even the most optimistic predictions in the 1980s for the diffusion of GPS turned out to be far too conservative (Kumar and Moore 2002, 69, 79).

This ubiquity has had a profound effect on the way GPS has been understood. Rather than being seen just as a positioning and navigation technology, beginning in the mid-1990s GPS began to be described as new kind of public utility, alongside electricity, gas, and water (Pace et al. 1995, 184). The product to be delivered was location, and the marginal cost was essentially zero. One of the most common analogies was between GPS and the Internet, as both were sponsored by the U.S. military and eventually transformed into open platforms (Aporta and Higgs 2005). The basic idea here was that forecasting GPS's future uses—or even providing a comprehensive list of current ones—became essentially impossible. More conceptually, however, the larger implication was that GPS should not be seen as simply a tool for making geographic space legible. Rather, GPS became a replacement for traditional space (and time) altogether. Both the spaces of day-to-day experience and the spaces constructed by representational maps were superseded by a space that was more immediately calculable, less historical, and almost perfectly uniform (Kurgan 1994; Rankin 2011).

## The Uses (and Abuses) of GPS

The history of GPS after it first became operational is largely a history of how it has been used. The major trends are relatively clear: civilian applications quickly outnumbered military uses, and GPS became tightly integrated into other systems of communication and geographic management. Evaluating the impact of these trends, however, is less straightforward, as the social consequences of GPS have been wide-ranging, often unanticipated, and at times contradictory. The recent history of GPS thus raises questions relevant to any history of infrastructure: With the transformation of GPS into a multiuse utility, what is gained and what is lost? Who wins and who loses? Two issues are especially important here: the relationship between civilian GPS and its military origins and the politics of action at a distance.

Two of the most significant early uses of GPS were in cartography and war. The surveying industry began to adopt GPS in the mid-1980s while the constellation was still incomplete. Its effect was profound. GPS not only solidified the decades-long transition from traditional astronomical and angular methods to black-box electronic equipment, but it further untethered surveying from the geography of national states. The widespread use of the GPS world datum (WGS84) enabled everything from cross-border engineering projects to reliable measurement in international waters, and it became a de facto standard for global geographic information systems (GIS) platforms. More broadly, GPS signaled a shift in the very nature of mapping. As the tools of mapping merged with the tools of navigation, it became increasingly difficult to distinguish mapmaking from map use. The famous tales by Lewis Carroll and Jorge Luis Borges about maps on the same scale as the territory thus apply quite well to GPS, since using GPS for fishing management, offshore drilling, or coordinating archaeological sites is effectively mapping at a scale of 1:1. GPS is used both to make a record of important points and to return to them; traditional mapping problems of selection and representation need not arise at all (Rankin 2011, 440–51).

The impact of GPS on military strategy was no less decisive. During the Persian Gulf War, GPS lowered the cost of precision bombing and enabled large-scale troop coordination in the featureless Iraqi desert, both of which gave the U.S. a substantial advantage. After the war GPS quickly became a core component of a "precision revolution" in American strategy that prioritized smaller, more mobile, and more technologically advanced forces. GPS also changed the geography of war, since GPS-guided missiles and bombers can be launched thousands of miles from their target. The dream—unrealized, to be sure—is to remove soldiers from the battlefield altogether (Rip and Hasik 2002).

The multiplication of civilian GPS applications in the 1990s and 2000s largely followed these precedents of automation and tighter geographic coordination, but the mass commercialization of GPS also raised entirely new issues. Most of the best-known uses of GPS had been under development since the early 1980s, such as automobile and aircraft navigation, close control of farm equipment for precision agriculture, or the direct measurement of tectonic plate drift. The use of GPS for time synchronization—in cell phone networks, power grids, or even municipal stoplights—also extended earlier techniques. But in the late 1990s several applications began to proliferate that had not been anticipated and did not sit easily within traditional descriptions of GPS as a positioning, navigation, and timing (PNT) system. Foremost among these was the use of GPS for tracking (of wildlife, criminals, children, or cargo) and amateur mapping by artists and activists. These applications have provoked the most debates about the nature of GPS, raising questions of civil liberties, privacy, and the democratization of cartography.

There have been primarily two ways that scholars have interpreted the spread of civilian GPS. First is a pessimistic assumption that GPS is an inherently military technology and that its widespread use represents the militarization of civil society. The strongest versions of this argument claim that GPS (along with its cousin, GIS) has created a cultural obsession with precision so pervasive that techniques of military targeting end up blending seamlessly into practices like targeted marketing. Not only has GPS turned American consumers into "militarized subjects" (Kaplan 2006, 708), but the integration of GPS into everything from cell phones to traditional hunting practices will "deliver American militarized realities" abroad as well (Mark H. Palmer and Robert Rundstrom in Aporta and Higgs 2005, 748). A less forceful version of this interpretation also drove much of the debate in the early 2000s about competition between GPS and the European Union's civilian (and partly commercial) Galileo system. Many observers, from American pundits to foreign heads of state, distrusted claims that a system maintained by the U.S. military would remain reliably accessible, despite high-level assurances (Han 2008).

The second interpretation—often explicitly opposed to the first—instead posits GPS, and technology in general, as an inherently neutral tool that can be used either for good or for evil, regardless of its origins. Optimistic scholars tend to emphasize the usefulness of GPS for things like tracking endangered species, clearing landmines, or the rapid mapping of Haiti after the 2010 earthquake (fig. 338). Optimists also stress that although GPS can be used for top-down surveillance by police or employers, it can also be used for bottom-up "sousveillance" to hold governments accountable, such as when marginalized citizens use GPS for reporting broken street lights in New Jersey or mapping informal settlements in Kenya. Even advanced missile guidance has its good side, since surgical strikes on infrastructure obviate the senseless killing of area bombing (Klinkenberg 2007).

FIG. 338. RAPID HUMANITARIAN RESPONSE USING GPS. Coverage of Port-au-Prince, Haiti, by the collaborative project OpenStreetMap before (left) and two days after (right) the 2010 earthquake.

Image courtesy of William J. Rankin.

Belief in technological neutrality also undergirds certain kinds of pessimism as well. Jerome E. Dobson and Peter F. Fisher, for example, have issued strong warnings about the coming mass-surveillance society and the potential for a new "geoslavery" enabled by coercive GPS tracking. For them, the worry is not the military, or even GPS itself, but its exploitation by unscrupulous corporations and individuals; arguing that technology is neutral is important rhetorically for defending GPS against these abuses (Dobson and Fisher 2007; Herbert 2006).

There are good reasons to challenge military essentialism. Claiming that technology is inherently neutral, however, is no less problematic. Certainly, the assumption that military-sponsored technology can only further militarist goals is empirically unfounded. Yet it is also true that every technology is inevitably designed for certain tasks and not others and therefore is prejudiced with specific capabilities and constraints. Technological systems are also always being modified to further privilege some uses over others. Military pessimists tend to simplify this history to confirm their suspicions; technological neutralists, however, tend to overlook it altogether. Neutralism can also be rather fatalist. Saying that technology inevitably has both positive and negative social effects can easily imply that any attempt to steer the course of technological progress will prove futile.

For GPS, both its initial design and its ongoing evolution suggest that a different interpretation is necessary. First, GPS was explicitly designed so that it could serve more than just military interests. One of the basic military requirements in the late 1960s was that it use only one-way broadcast from satellites to users rather than two-way communication. The latter would have been technologically simpler, but any ground transmission could be used by the enemy for tracking and targeting. For this reason, civilian agencies—especially the Federal Aviation Administration and the National Aeronautics and Space Administration (NASA)—initially expressed little interest in GPS and instead proposed systems that would broadcast users' locations back to a satellite to enable active air traffic control or ship monitoring. These systems also would have only supported a limited number of receivers at once (Stansell 1971, 107). In other words, it was precisely the involvement of the military—and its lack of neutrality—that made GPS an open system that could support unlimited nonmilitary users, with features like privacy and anonymity prioritized over tracking and surveillance.

Second, by the early 2000s the military had decisively lost much of its control over GPS, after a long struggle with civilian agencies and corporations. Not only had President Bill Clinton annulled the military's Selective Availability policy, but the governance of GPS was changed so that top-level responsibility was shared between the Departments of Defense and Transportation. Even more important was the civilian development of local and regional augmentation systems to increase accuracy and reliability (fig. 339). These systems had effectively thwarted Selective Availability in the 1990s, and because they were used for life-critical applications like harbor and air navigation, they likewise drastically reduced the military's ability to disable the civilian signal in wartime (Pace et al. 1995, 20–27). The very existence of these ongoing technological and policy changes make it difficult to see GPS as neutral, and again military interests tended to align with individual privacy, since similar augmentation systems have enabled some of the most Orwellian GPS applications, such as indoor tracking (Trimble 2003).

If GPS is neither inherently militaristic nor inherently neutral, what is it? The answer need not be so grandiose. The key conceptual feature of GPS is that it replaces lumpy, historical, human space with a globally uniform mathematical system. By extension, the central political fact about GPS is that it substitutes a locally available grid of geographic coordinates for other kinds of local knowledge and encourages intervention without local commitment. This intervention can be initiated from afar—precision bombing, humanitarian relief, GPS tracking—or it can be projected outward, as with activist mapping. In all cases, however, the goal is to encourage action and to bridge the political divide between center and periphery. This has been the goal of most official mapping from the sixteenth century forward, but the relationships GPS constructs are much less mediated, since GPS is not a technology of representation. GPS can also be wielded by almost anyone, not just institutions with massive resources. The relevant political distinction is therefore not between state and nonstate, military and civilian, or even good and bad, but between local and nonlocal decision making. And thus with GPS the basic political question, as ever, is not what or how, but by whom.

WILLIAM J. RANKIN

SEE ALSO: Cold War; Cruise Missile; Geodesy: Satellite Geodesy; Hydrographic Techniques: Global Positioning System in Hydrographic Mapping; Property Mapping Practices: Global Positioning System and Property Surveying; Warfare and Cartography; Wayfinding and Travel Maps: In-Vehicle Navigation System

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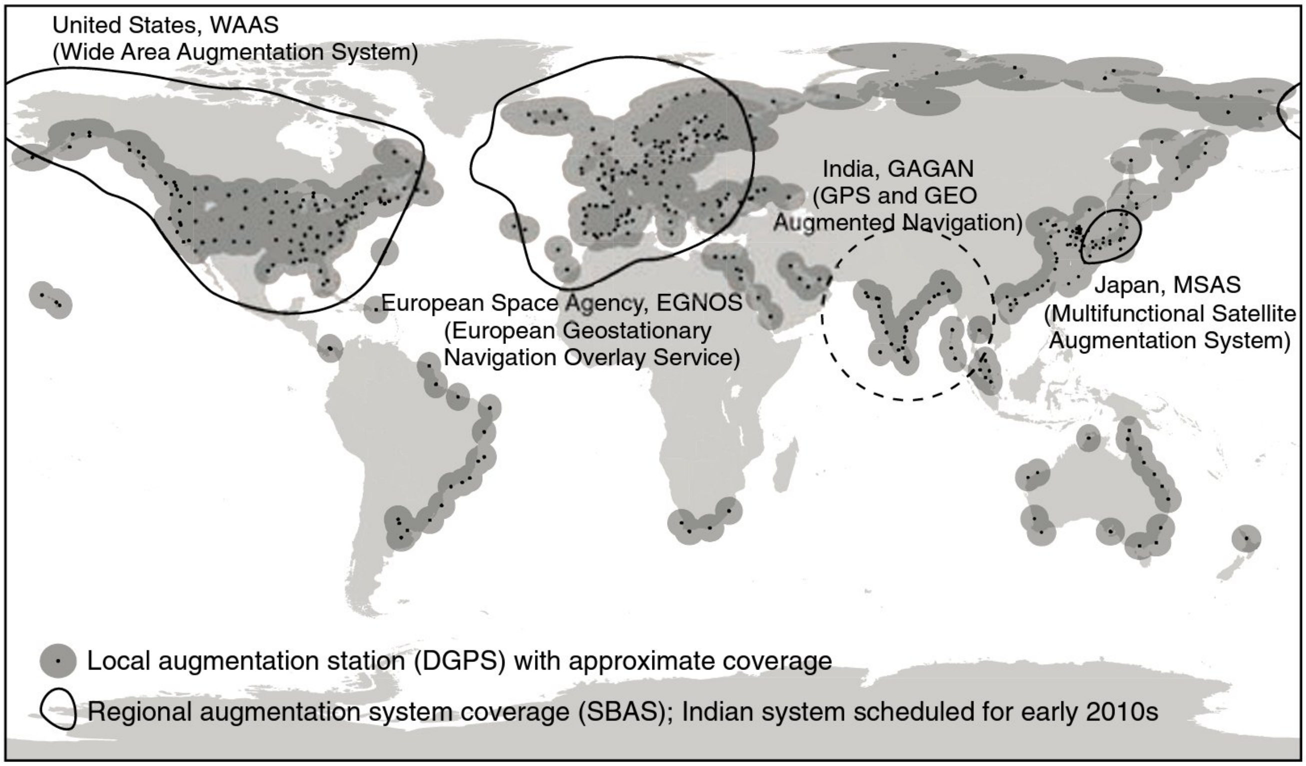


FIG. 339. MAP OF REGIONAL AND LOCAL AUGMENTATION SYSTEMS; COVERAGE AS OF 2010. In response to military degradation of civilian GPS signals, competing government agencies and companies (especially the U.S. Coast Guard, NASA, Federal Aviation Authority, Fugro, and John Deere) began providing Differential GPS (DGPS) and Satellite-Based Augmentation System (SBAS) services in the 1990s; these systems increase accuracy by monitoring raw GPS signals and broadcasting real-time corrections.
Image courtesy of William J. Rankin.

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