One infrastructure, many global visions: The commercialization and diversification of Argos, a satellite-based environmental surveillance system

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One infrastructure, many global visions: The commercialization and diversification of Argos, a satellite-based environmental surveillance system

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Abstract

Argos is a satellite-based data collection and location system that has been in operation since the late 1970s; it is the only such system to be dedicated solely to environmental applications. This paper shows how multiple and sometimes conflicting ways of envisioning and studying the global environment have been embodied in the Argos system. In particular, it shows how the system's initial focus on meeting the needs of meteorologists and oceanographers made it difficult for wildlife biologists, who were interested in tracking the long-distance movements of animals, to use Argos tags. Physical environmental scientists' vision of the global environment as a 'volume of flows' dictated their need for regular, precise, standardized sampling stations distributed in a grid across and above the Earth's surface. Biologists interested in the interactions of individual animals and populations in a 'web of life', in contrast, demanded a flexible system of global access to the movements of individual bodies. Until the mid-1980s, the unit of the French space agency responsible for Argos resisted changes to the system that would have made it easier for biologists to deploy lightweight, low-reliability tags. It was only after the quasi-commercialization of the system in 1986 that it began to make significant concessions to the needs of biologists. The history of Argos suggests that individual infrastructures of environmental observation can host multiple and conflicting global environmental visions and that commercialization, at least within certain constraints, has provided opportunities for such visions to proliferate.

Keywords

environmental sciences, infrastructure, meteorology, neoliberal science, oceanography, satellites, wildlife biology

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'Argos' is the name of a satellite-based environmental data collection and location system that was launched in the late 1970s under an agreement between the French and US governments and has operated since then with the support of US, French, European, Indian and Japanese space and weather agencies (Kramer, 2001: 311–313; Martin, 2000: 150–151; Ortega, 2003; Swenson and Shaw, 1990). As an infrastructure, it is not particularly well known. Even some of the scientists who rely on data generated from it are only vaguely aware of its existence. It is nonetheless widely used and uniquely well suited for some applications. Today the Argos system includes instruments carried aboard American and European satellites, a global network of receiving stations, and two centralized data processing and analysis centres located in the vicinity of Toulouse and Washington, DC (Collecte Localisation Satellites, 2011: 2–6).[1]

The name of the Argos system is not an acronym.[2] It was inspired by a figure of Greek and Roman myth: Argos (or Argus), the many-eyed servant of Hera who guards over Io, one of Zeus's romantic conquests, after she has been transformed into a white heifer. In John Dryden's 1717 translation of Ovid's *Metamorphoses*, Argos's head is described as being 'compass'd round' with a 'constellation' of eyes, 'as with stars the skies' (Ovid, 1717). Argos is thus a symbol of watchfulness, and for that reason the French designers of the satellite system gave it his name. Argos was to be a set of eyes in the sky, sleeplessly watching over the Earth.[3]

Though the metaphor of 'an eye in the sky' is evocative, it is also misleading. The satellite-based environmental observation systems with which we are most familiar, such as those that generate landscape images (DeNicola, 2007; Mack, 1990), carry environmental sensors in orbit. In contrast, Argos works as a tracking service and telecommunications hub, collecting environmental data from sensors located on so-called 'platform transmitter terminals' (PTTs) and retransmitting them to ground stations for processing and redistribution. Argos's eyes, in a sense, are distributed across the surface of the Earth; only its visual nuclei, relaying data from its distributed retinas to several ground-based brains where the data are processed and further distributed, lie in space. Even this elaborated metaphor continues to mislead, however, inasmuch as very little of the data collected by Argos are visual in nature. The short messages that Argos is capable of transmitting usually consist of numerical measurements of single variables, such as temperature or pressure, or, increasingly, summaries of location records acquired through the Global Positioning System, which are more precise than Argos's own Doppler-effect-based location method can produce (see for example Schwartz and Arthur, 1999). Often, the only data collected by Argos are the locations of the PTTs. Rather than an eye in the sky, it is perhaps better to think of Argos as a set of very sensitive ears that monitor the positions and collect the reports of an army of observers on the ground (see Figure 1).

Argos is not the only satellite-based data collection and location system in existence, but it is the only one dedicated almost entirely to environmental applications. It is also technically simpler than most other such systems, which means that its platforms or tags are comparatively light, robust and inexpensive, although a single Argos PTT can still cost thousands of dollars, even before the costs of processing and distributing data are included. Today the more than 21,000 PTTs to which Argos is listening at any given moment (Vassal and Woodward, 2010) allow oceanographers and meteorologists to collect data from drifting buoys and automatic weather stations. They also allow wildlife

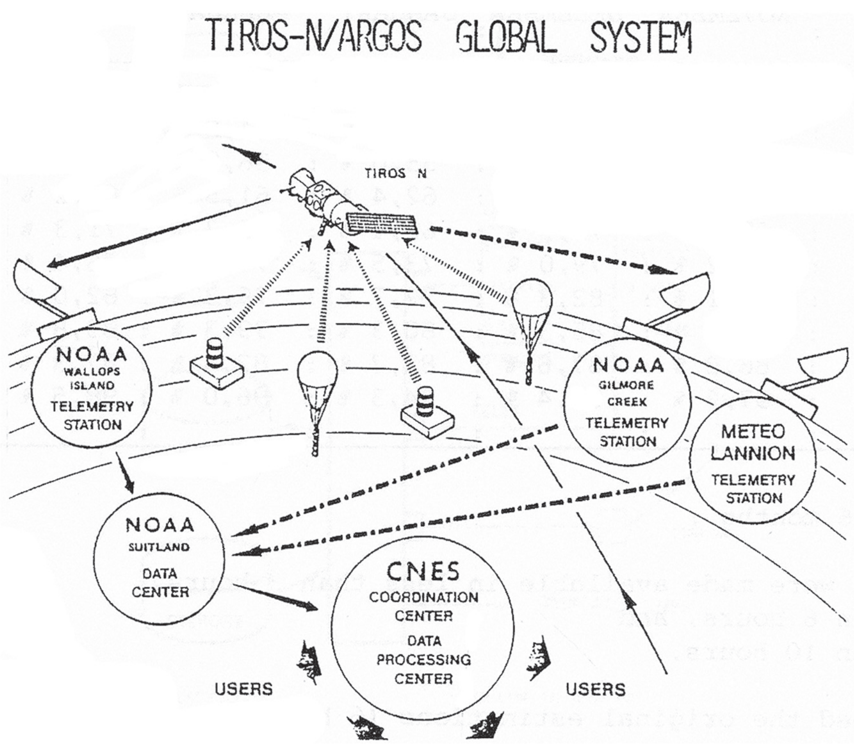

Figure 1. A schematic diagram of the operation of the Argos data collection and location system showing the transmission of data from balloons and buoys to the satellite instrument, ground-based telemetry stations in France and the US, NOAA's processing centre in Suitland, Maryland, the CNES coordination centre in Toulouse and, finally, users (source: Taillade, 1981: 105). Republished from *Advances in Space Research* with permission of the Committee on Space Research (COSPAR).

biologists and ecologists to follow the movements of whales, albatrosses, sea turtles and other far-ranging creatures, and allow governments to track foreign fishing vessels, monitor the transport of hazardous materials and verify the delivery of humanitarian aid.[4] For some of these applications, there are other ways of acquiring the same information. The data collected by oceanographic buoys, for example, can also be collected by ship-based expeditions, albeit at a greatly elevated cost. For other applications, such as high-precision studies of the migration paths of birds, Argos remains the only feasible method (see Burger and Schaffer, 2008).

Argos is thus a small but critical component of the space-based infrastructure of environmental and ecological surveillance that has emerged since the 1960s. It is through this infrastructure that much of what we know today about the global environment, from the status of endangered species to the rate of climate change, is produced. Writing about biodiversity and climate science, respectively, Geoffrey Bowker (2006) and Paul Edwards (2010) have argued that infrastructures of data collection, classification, distribution, analysis and modelling critically shape our understandings of the global environment. This study builds on their work and that of others who study the history of environmental observation systems (e.g. Aronova et al., 2010; Conway, 2006, 2008; Miller and Edwards, 2001; Millerand and Bowker, 2008). It does so in two ways. First, it makes explicit a point that has remained implicit in most such studies: the fact that multiple visions of the global environment can be and often are implemented within a single infrastructure.[5] In particular, it shows how physical environmental scientists and biologists have shaped the Argos system to suit their divergent visions of the global environment since the 1970s – visions I describe in more detail below as a 'volume of flows' and a 'web of life', respectively. As a result of their efforts and those of the administrators of the system, Argos today provides global environmental data to all of its users, but not all in the same way. There may be only one Earth, but there are many ways, both scientific and popular, of imagining and encountering it in global terms (Jasanoff, 2001; Jasanoff and Martello, 2004; Kwa, 2005; Slotten, 2002).

Second, this paper argues that the growing importance of biologists and ecologists in the design, operation, and use of Argos beginning in the mid-1980s was due in large part to the qualified neoliberalization of the French space programme, which spurred the managers of Argos to expand and diversify their system's user base beyond the meteorologists and oceanographers who had dominated its initial use and continued to rely heavily upon it. The development of the Argos system was shaped by the convergence of several factors in France: the persistence of cold war-era Gaullist technopolitics (Hecht, 1998; Hecht and Edwards, 2010; cf. Zaidi, 2008); a growing societal commitment to a 'light-green' environmentalism (Bess, 2003); and a limited but nonetheless significant set of neoliberal reforms in the 1980s (Hancké, 2002; Prasad, 2005; see also Lave et al., 2010). One result of Argos's quasi-privatization was that the system became more useful and accessible to a wider range of scientists than it had been when its development and operation were driven by scientific and programmatic interests alone, as it had been from the early 1970s to the mid-1980s. The trajectory of the Argos system suggests that we should be prepared to find multiple global visions embodied in any given environmental research infrastructure, and that commercialization, at least in certain forms and under certain conditions, can play and has played an important role in allowing such visions to proliferate.

Argos and the meteorological volume of flows

The origins of Argos lie in the 1960s, when meteorologists' ambitions for a global infrastructure of weather monitoring converged with the aspirations of the American and French space programmes. Argos's immediate predecessor was Eole, a short-lived experimental system designed to locate and collect data from sensors carried aboard meteorological balloons (Morakis and Cote, 1973; Sitbon, 1975). Eole was the result of collaboration between the US National Aeronautics and Space Administration (NASA) and its French equivalent, the Centre National d'Etudes Spatiales (CNES), at a time when the latter was still largely dependent on NASA for technical expertise and for basic satellite launch and operation services (Krige et al., 1987a). As it later would with Argos, the French agency named the system after a figure of Greek myth: Aeolus, ruler of the winds. Eole proved sufficiently useful to the meteorological community after its launch

Table 1. Successive generations of Argos instruments have brought more sensitive receivers, greater bandwith, longer messages, and two-way communications (sources: Kappas, 2009: 43; NASA Goddard Space Flight Center, 2011; Collecte Localisation Satellites, 2002, 2009, 2010). Abbreviations: NOAA, US National Oceanic and Atmospheric Administration; NASDA, National Space Development Agency of Japan; Eumetsat, European Organisation for the Exploitation of Meteorological Satellites; ISRO, Indian Space Research Organisation.

Satellite	Agency	Launch date	End date	Instrument
Tiros-N	NOAA	13 October 1978	27 February 1981	Argos 1
NOAA-6	NOAA	27 June 1979	31 March 1987	Argos 1
NOAA-7	NOAA	23 June, 1981	7 June 1986	Argos 1
NOAA-8	NOAA	28 March 1983	29 December 1985	Argos 1
NOAA-9	NOAA	12 December 1984	13 February 1998	Argos 1
NOAA-10	NOAA	17 September 1986	30 August 2001	Argos 1
NOAA-11	NOAA	24 September 1988	16 June 2004	Argos 1
NOAA-12	NOAA	14 May 1991	10 August 2007	Argos 1
NOAA-13	NOAA	9 August 1993	21 August 1993	Argos 1
NOAA-14	NOAA	30 December 1994	23 May 2007	Argos 1
NOAA-15	NOAA	13 May 1998		Argos 2
NOAA-16	NOAA	21 September 2000		Argos 2
NOAA-17	NOAA	24 June 2002		Argos 2
ADEOS II	NASDA	14 December 2002	25 October 2003	Argos 2+
NOAA-18	NOAA	20 May 2005		Argos 2
METOP-A	Eumetsat	19 October 2006		Argos 3
NOAA-19	NOAA	6 February 2009		Argos 3
SARAL	ISRO	2012 (planned)		Argos 3

in 1971 that NASA and CNES began discussing the construction of an operational system that would provide similar services with more reliability and a guaranteed term of service. In 1974, an agreement to develop such a system under the name 'Argos' was signed by NASA, CNES and the recently established US National Oceanic and Atmospheric Administration (NOAA) (Collecte Localisation Satellites, 1987a; Service Argos, 1978a). NASA and NOAA would be responsible for the construction, launch and operation of the polar-orbiting satellites on which the Argos instrument was to be carried, while the design and operation of the Argos system would be left largely in the hands of CNES and its industrial partners. Between 1978 and 2009, NOAA would successfully launch 15 satellites carrying three generations of Argos instruments (see Table 1).

Although Argos was promoted from the beginning as a tool that would be useful to a broad range of scientists, the government agencies spearheading its development in France and the US gave highest priority to the interests of the meteorological and oceanographic communities. This was partly because those areas seem to hold out the most promising applications for Argos, and partly because these scientific communities were better organized and more influential than other groups interested in space-based observation of the Earth (Lambright, 1994).[6] Their interests were represented both by national scientific and professional societies and by the World Meteorological Organization

(WMO). In the 1960s, the WMO responded to advances in satellite and telecommunications technologies by establishing the World Weather Watch (WWW) (Edwards, 2010: 229–250; Leese et al., 1989; Rasmussen, 2003). The goal of the WWW and its research arm, the Global Atmospheric Research Program (GARP), was to create a unified global weather observation system in an era of space-based environmental surveillance and telecommunications. In this unified system, data collection and location systems such as Argos would play an important role by gathering in situ weather data from hard-to-reach places such as the southern oceans. Such data were important both for basic science and for predictive purposes. In the late 1960s, GARP began planning what it called 'global experiments': massive, coordinated observation efforts that included the construction of global observing systems, the establishment of standards and facilities for data collection, storage and retrieval, and the international coordination of modelling efforts (Edwards, 2010: 243–244; see also Krige et al., 1987b: 51–54).

The Argos system became operational in the midst of the First Global GARP Experiment (FGGE), also known as the Global Weather Experiment, which took place in 1978–1979 (Edwards 2010: 243–249; Fleming et al., 1979; *Science News*, 1978; Service Argos, 1979; Tänczer et al., 1981). As Paul Edwards has argued, FGGE was a key turning point in the development of global, space-based climate and weather observation systems. Previous large-scale weather observation 'experiments', such as the GARP Atlantic Tropical Experiment, had been limited to particular regions that could be intensively studied from a variety of platforms, including satellites, ships and aircraft (Mason, 1975). FGGE, in contrast, 'approached the global coverage dreamed of by the planners of the WWW back in the early and mid-1960s' (Rasmussen, 2003). The timing of the experiment was largely determined by the availability of satellite-based observational systems, including five satellites in geostationary orbit and several polar-orbiting satellites. Among the latter were the NOAA satellites TIROS-N and NOAA-6, which were launched in 1978 and 1979, respectively, and which carried the first Argos instruments (Fleming et al., 1979: 653–654; Yates, 1981).

The 'global' in the First Global GARP Experiment owed much to Argos, which gathered and transmitted data from high-altitude balloons and from PTT-equipped floating buoys (Edwards, 2010: 249; Taillade, 1980) (see Figure 2). These buoys and balloons demonstrated that the system could accomplish the purpose for which it had been built: the reliable collection of environmental data from instruments located around the globe. In particular, the more than 300 drifting buoys deployed in 1979 and the approximately 230,000 data points collected from them (Yates, 1981: 68) were judged by those running Argos to have been 'a major factor in the overall success of the FGGE' and to have proven the feasibility of a permanent, global system integrated into the WWW (Goasguen, 1980: 9). Others outside Argos agreed: halfway through GARP's year-long operation, a team of authors from NOAA's project office for FGGE described Argos as 'working extremely well' (Fleming et al., 1979: 563), while the British oceanographer John D. Woods later described the system as 'a crucial ingredient of FGGE' (Woods, 1983: 103).

It is important to note that the success of Argos during FGGE largely depended on infrastructures that had nothing to do with Argos per se–both infrastructures pre-existing it and those being built at the same time for broader purposes. The deployment of Argos PTTs in the southern oceans, for example, was an expensive and effortful endeavour that

Bouée australienne pour la PEMG   *Australian FGGE Buoy*

Figure 2. One of the drifting buoys tracked by Argos for the First Global GARP Experiment, also known as the Global Weather Experiment (source: De la Lande, 1979: 3). Republished from the *Argos Newsletter* with permission of CLS.

would not have been possible without an international network of meteorological collaborators (Garrett, 1979). Similarly, the usefulness of the data collected by Argos depended heavily on the WWW's infrastructure for distributing and processing weather data. Although some of Argos's first users received their data via post, the highly standardized meteorological data collected by the FGGE buoys was delivered electronically several times per day via the WWW's Global Telecommunications System (Rasmussen, 1981; Taillade, 1980, 1992). Argos was thus a vital link in FGGE's data collection system, but without auxiliary infrastructures for instrument deployment and data distribution it could not have become 'global' in any meaningful sense of the word.

The influence of meteorological organizations and of meteorological infrastructures of platform deployment and data distribution helped orient Argos toward a particularly meteorological vision of the global environment. The meteorologists who used the system conceived of the environment in terms of what one might call a 'volume of flows': a continuous atmospheric volume, circulating over a mostly spherical surface, that could be sampled at points but rarely isolated into distinct units. For these meteorologists, the phenomena of interest were 'cloud cover, cloud motion vectors, surface temperature, vertical profiles of atmospheric temperature and humidity, snow and ice cover, ozone and various radiation measurements' (Leese, 1987: 49). The infrastructural dream corresponding to this global vision was a gridded network of sensors extending over the Earth and reporting standardized data to centralized repositories at regular time intervals.

The sensors that recorded these data did not have to be arranged in an exact rectilinear grid, nor was it essential that they be fixed in place, although networks of moored buoys would eventually be established to ensure that data were reliably collected from particular points on the globe.[7] Ultimately, and in stark contrast to the needs of wildlife biologists, the trajectory of an individual buoy or Argos PTT was irrelevant. What was important was that the sensors, whether attached to moored or free-floating buoys, were distributed evenly enough that they could be used to reconstruct global flows of air and water. The 'array' of FGGE drifting buoys, for example, was intended 'to have a resolution of 1000 km, i.e. no point in the ocean was to be more than 500 km away from the nearest buoy' (Garrett, 1981: 87; Zillman, 1981). Such data served as input for models that would interpolate spatially and temporally disparate data points into a seamless whole and extrapolate the results into the future and the deep past. Although this understanding of global flows was reinforced by the postwar advent of satellite-based observation and numerical weather prediction, it was not a product of the space age. On the contrary, it had oriented the infrastructure-building efforts of meteorology, climatology and oceanography that began in the 19th century (Anderson, 2005; Burnett, 2005; Edwards, 2010; Fleming, 1990; Friedman, 1989; Harper, 2008; Rozwadowski, 2005; Weart, 2004). For meteorologists and oceanographers, satellite systems such as Argos were important because they filled out the grid (Figure 3).

Because the meteorological community was Argos's dominant user group, its priorities shaped those of the administrators at Service Argos in Toulouse, even as those administrators sought to expand the use of the system by other communities of scientists. Argos's management took several steps to meet the demands of the meteorological community for reliability, accuracy, precision and standardization, while also maintaining the stability of the system as a whole. One of them was to establish a rigorous certification process for Argos PTTs, which were mostly manufactured and sold by third parties.[8] Before PTTs of a certain model could be registered with the system, a prototype had to be tested in Service Argos's own labs, which applied stringent standards for the emitted power and frequency stability of the transmitter under a range of environmental conditions (Patenet, 1980). Manufacturers met these standards through careful engineering and testing and by setting lower bounds on the minimum weight and cost of individual PTTs. For meteorologists interested in reliable, standardized data, this certification process posed few obstacles. The PTTs used by physical environmental scientists were typically a small fraction of the total weight and bulk of the buoys upon which they were

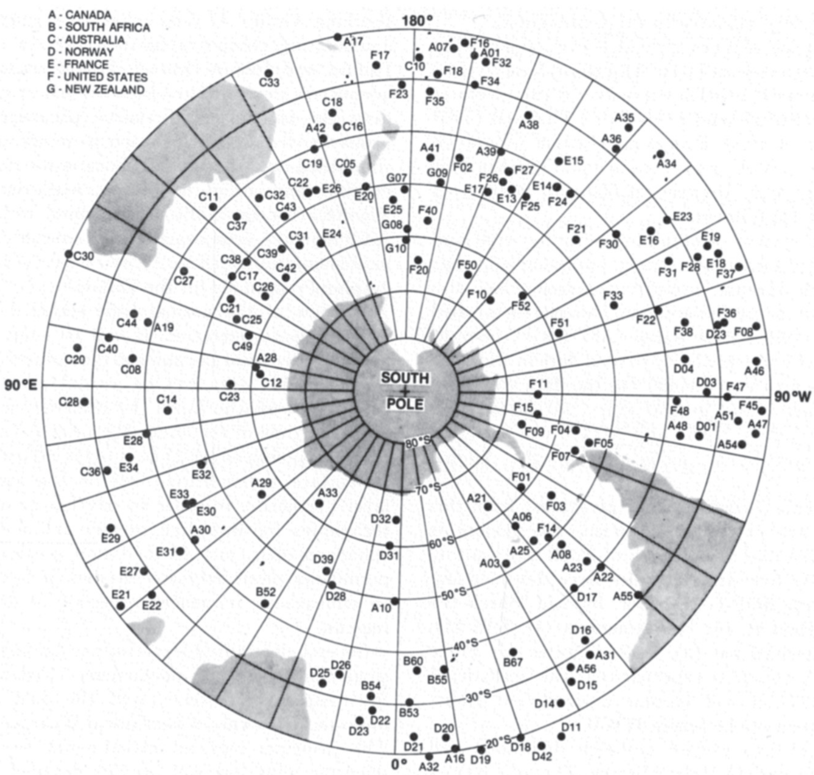

FIG. 5. Location of operational drifting buoys in the southern hemisphere on 15 February 1979.

Figure 3. An example of the meteorologist's and oceanographer's vision of satellite-based data collection and location systems as means of sampling from a 'volume of flows' via a grid of sensors. The dots represent Argos's drifting buoys deployed in the southern oceans for the First Global GARP Experiment as of 15 February 1979 (source: Fleming et al., 1979: 657). Republished from the *Bulletin of the American Meteorological Society* with the permission of the American Meteorological Society.

deployed, and there was little reason to worry that the instruments would bias the data collected.[9] Meteorologists' tolerance for large weights and sizes meant that PTTs could be heavily shielded against the elements and that large batteries could be used, thereby reducing the challenge of meeting Service Argos's requirements for frequency stability and power.[10] Certification thus served the needs both of the system and of the system's most important user group.

Argos administrators also enforced standards of reliability and accuracy in the design of their data processing and location algorithms, which suited the needs of meteorologists and oceanographers. The location method used by Argos was based on the Doppler effect – that is, the shift in apparent radio frequency detected by the satellite instrument as it moved toward or away from a given PTT – as well as on assumptions about the PTT's position and motion in relation to the Earth's surface.[11] In theory, Argos's Doppler-based method was capable of estimating a PTT's location when as few as two messages had been received during a single pass of a satellite carrying an Argos instrument. In practice, Service Argos initially refused to distribute any location estimates based on fewer than five messages received during a single satellite pass (Rosso, 1985). By doing so, it raised the overall reliability and accuracy of the system but reduced the user's range of options. This constraint was hardly perceived as such by physical environmental scientists, since it was congruent with their vision of the global environment as a volume to be reconstructed through regular, reliable, precise sampling over a uniform grid. For these researchers, non-standardized data were little better than no data at all (Edwards, 2010: 252–253). Other potential users had different research practices and visions of the global environment, however, and for them the standards established to suit Argos's system administrators and its meteorological and oceanographic users proved to be major obstacles.

Argos and the ecological web of life

As early as the beginning of the 1960s, wildlife biologists had speculated about the possibility of using satellite-based systems to observe animals that migrated over long distances or lived in remote, inaccessible environments. One of the first published proposals for a satellite-based animal tracking system appeared under the title 'Space Tracks' in a 1963 issue of the magazine *Natural History* (Warner, 1963). The article was based on a proposal that University of Minnesota ornithologist Dwain Warner had developed with engineer William W. Cochran and submitted to NASA the previous year. It suggested using a Doppler-effect-based algorithm similar to the one that would eventually be used by Argos to monitor the migratory flights of North American waterfowl and other animals. NASA had rejected the proposal, but many more like it were to come. In 1966, the Smithsonian Institution organized a meeting of ecologists and engineers to discuss animal tracking using the experimental Interrogation, Recording, and Location System (IRLS) that NASA had announced would soon be launched aboard one of its experimental Nimbus weather satellites.[12] As an interrogation-based system, IRLS required two-way communication between the tag and the satellite instrument, in contrast to the one-way communication from tag to satellite that had been proposed by Warner and Cochran. The tags it required were both extraordinarily expensive by the standards of wildlife biologists and too heavy and bulky to be used with most wild animals (Benson, 2010: 80–82; Buechner et al., 1971).[13]

Even before the limits of IRLS were completely evident, much of the discussion among wildlife biologists was therefore focused on finding or developing a satellite surveillance system more suited to their needs. In some ways, the desiderata of biologists coincided with those of physical environmental scientists. Both wanted to be able to locate and to collect data from platforms located anywhere on the Earth's surface at regular temporal intervals. Both valued data that were reliable, accurate and precise, and both desired a system that would allow platforms to be small, rugged, efficient and affordable. But the balance of priorities differed between the two groups. As noted above, meteorologists and oceanographers privileged reliability, accuracy and standardization and were willing to tolerate relatively large and heavy transmitters to achieve those goals.

For wildlife biologists the balance of concerns was quite different. Rather than seeking regular samples from a volume of flows spread across the Earth's surface, they sought to trace the trajectory of individual organisms as they moved through a 'web of life' – a complex network of ecological interactions that could, in some cases, reach global scales (see Wilcove, 2007; Wilson, 2002, 2010). The migrations of birds, whales and other far-ranging animals were the threads that linked disparate ecosystems together into a cohesive whole. In 1970, a team of biologists and an engineer who had participated in the 1966 Smithsonian meeting argued that studies of migration – 'this process through which large numbers of animals play significant roles annually in remote, different ecosystems of the earth' – were among the most promising applications of animal tracking by satellite (Buechner et al., 1970: 3–4).[14] Biologists were interested in tracing paths rather than sampling from volumes; their global network was a patchwork of highly diverse ecosystems linked by individual animals in motion, rather than a set of continuous flows of energy, gases and fluids (Figure 4).

In practical terms, although they shared the meteorologists' desire for accuracy and reliability, the wildlife biologists' overriding need was for Argos PTTs that were small enough not to interfere with the behaviour of the animals they studied. To obtain such tags they were willing to compromise on virtually every other factor. In the late 1980s,

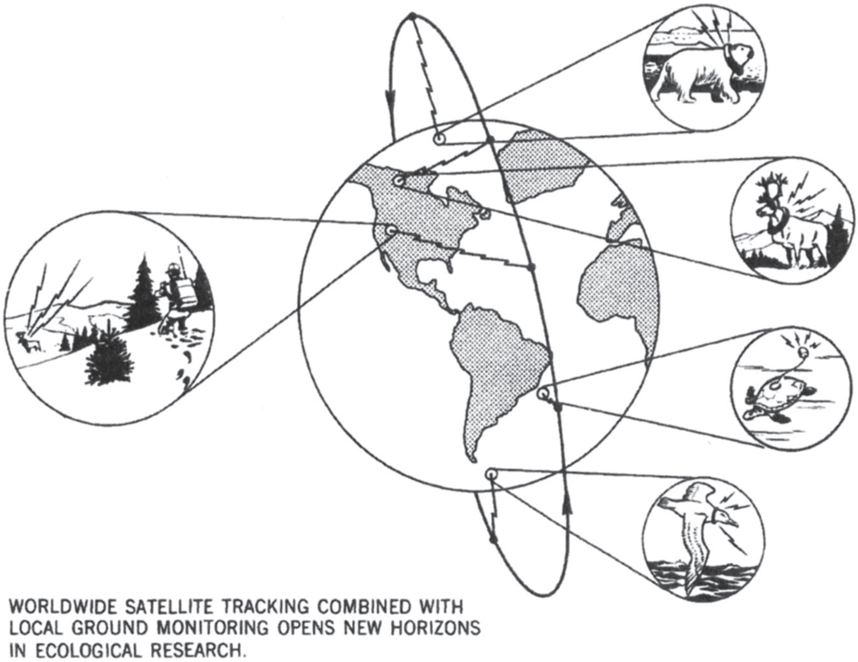

Figure 4. An example of the wildlife biologist's vision of satellite-based data collection and location systems as means of tracing the movements of individual animals from diverse species through a 'web of life' (source: Buechner et al., 1971: 1202). Republished from *BioScience* with permission of the American Institute of Biological Sciences.

assessing the state of the field, the lead engineers of one of the largest US manufacturers of wildlife radiotracking equipment noted that, for biologists, 'it may be preferable to know gross information, such as in which ocean a whale is located, as opposed to not knowing anything at all' (Tomkiewicz and Beaty, 1988: 9). A tag might be unreliable, underpowered and expensive, but if it could provide unbiased data on the movements of migrating birds or whales – however irregular or imprecise those data might be and however difficult it might be to compare them with other sources of data – it would count as a major breakthrough. Moreover, unlike meteorologists, wildlife biologists did not place a particularly high value on standardization. Studies of migrating birds might well demand different instruments and collect different sorts of information from studies of migrating whales; even studies of a single species might have radically different data collection needs depending on the research questions that were being pursued. Location data might be needed once an hour or once a month; environmental measurements might be essential or irrelevant. The difference between meteorologists' and wildlife biologists' methods and goals corresponded with the relative value they placed on reliability, precision and standardization, on one hand, and flexibility and miniaturization, on the other. Abstract differences in global vision were concretized in technical choices about the construction of environmental surveillance infrastructures.

It is important to note that the difference between wildlife biologists' and meteorologists' visions was not primarily that the former were stubbornly 'local' and the latter truly 'global', although this characterization contains a grain of truth. Chunglin Kwa has argued that many ecologists had become suspicious by the 1980s of the kinds of large-scale, coordinated projects advocated by their colleagues in the physical environmental sciences, in part because of the apparent failure of that approach in the International Biological Program of the 1960s and 1970s (Kwa 1987, 2005; see also Aronova et al., 2010). But the wildlife biologists who were most interested in using Argos did not reject the global in favour of the local, nor did they seek, as some ecologists did, to reach a compromise by focusing on regional or mesoscale phenomena. On the contrary, they eagerly embraced both global rhetoric and research practices with global reach, such as the construction of quantitative measures of biodiversity (Raven and Wilson, 1992; Takacs, 1996). What they opposed was the idea that study of the global environment could be reduced to the standardized measurement of a few key variables – whether those variables were the temperature and pressure of the meteorologists or the photosynthetic activity indexes of some ecologists – which could then be processed by global models. They clung not to a mythologized 'local field site', a concept that has been deployed both to praise ecology as a practice of place and to pillory it as scientific stamp-collecting (Kohler, 2002), but to the ability to pursue diverse research subjects across a global stage.

The question, then, was not whether the wildlife biologists who were interested in satellite tracking would accept a global vision but whether their vision of the global would be accepted. A major obstacle in the way of acceptance of this vision within Argos was the institutional weakness of wildlife biologists and their lack of experience with global-scale projects. This is not to say that there were no precedents. In addition to the International Biological Program, ornithologists had coordinated bird banding across international borders since the early 20th century (Barrow, 1998: 172; Vaughan, 2009), systematists had developed international taxonomic nomenclatures (Bowker, 2006), and ecologists and biologists had established conservation organizations with global scope (Adams, 2004; Holdgate, 1999). But there was no 'World Zoological Organization' coordinating 'global experiments' to collect standardized observations of animal movement and to improve simulations of global animal behaviour.[15] Partly as a result of this institutional weakness, animal tracking was definitely a second priority for Service Argos. One comprehensive overview of the Argos system written in 1979 omitted biology entirely, mentioning only atmospheric, oceanographic and earth sciences applications (Bessis, 1981). Only after Argos had been operational for more than a year did the Argos Operations Committee, which was responsible for setting the system's general policies, grant permission for animal tracking studies (Service Argos, 1980).

Despite their second-class status, a number of wildlife biologists remained interested in using the Argos system and devoted significant time and effort to overcoming its limitations. Some participated in the user conferences that Argos organized beginning in the late 1970s and partnered with engineers to develop PTTs that were small and robust enough for use on animals (Service Argos, 1984b). By the early 1980s, several had managed to test their tags on living animals in the field (e.g. Duron and Duron, 1984; Fedak et al., 1984; French, 1984; Mate, 1984; Priede, 1984), but their efforts were hindered by the Argos administrators' commitment to preserving high standards of reliability and precision for physical environmental science applications. This commitment placed constraints on PTT design that were difficult for engineers to satisfy while also producing tags that could be used on animals. Partly as a result of these requirements, and partly as a result of inherent engineering challenges and the difficulty of attaching tags to living creatures without drastically altering their behaviour, wildlife biologists had little success with Argos during the system's first decade of operation. The costs were daunting, the amount of useful data collected before the tags failed was negligible, and the impact of the tag on the behaviour of the animal was almost always in question.

This situation changed in the late 1980s, when a number of animal tracking studies began to collect significant amounts of usable data with Argos, including a groundbreaking study by French biologists Henri Weimerskirch and Pierre Jouventin. Weimerskirch and Jouventin used a Japanese-made miniature Argos PTT to track albatrosses as they travelled on foraging trips away from nesting sites on one of the French possessions in the southern Indian Ocean (Jouventin and Weimerskirch, 1990; Weimerskirch, 1990). Multiple factors contributed to their success, including the accumulated expertise of wildlife biologists and engineers in developing small PTTs and effective attachment methods, the progressive miniaturization of electronics components and batteries, and Weimerskirch's and Jouventin's familiarity with the animals and environments of the Southern Indian Ocean. But among the most important factors was a newly open attitude at Service Argos toward biological and ecological applications.

Between 1986 and 1989, Argos administrators implemented several changes to the system that made it more welcoming to animal trackers. One was the creation in 1987 of a stratified scheme of 'quality indexes' for location estimates (Le Traon and Liabet, 1987). With this new scheme, Argos users could specify that they only wanted to receive location estimates that satisfied a certain minimum level of quality, where the minimum was well below what Argos had previously made available. A category of extremely low-quality estimates was introduced at the end of 1987 under the rubric of the ‘Wildlife Service’, with the explicit admission that wildlife researchers sometimes wanted data that other Argos users would reject out of hand (Courrouyan, 1987). The so-called ‘Category 0’ locations were delivered by Argos even when only two messages had been received by the satellite and a variety of previously mandatory data-quality standards had not been met. Two messages was the bare minimum required for a location estimate and, in combination with the other relaxed standards, often resulted in errors of tens or even hundreds of kilometres, but it was sufficient for the study of far-ranging creatures such as albatrosses or whales. These changes in Argos’s location algorithm, together with advances in PTT miniaturization and attachment techniques, finally made Argos viable for animal tracking. By the summer of 1988, there were about 100 wildlife PTTs in active use, representing between 10 and 15 percent of the total number of deployed Argos PTTs (Tomkiewicz and Beaty, 1988; see also Fancy et al., 1988; French, 1994).

During Argos’s first decade, its administrators had adamantly resisted making concessions on system performance to suit the needs of wildlife biologists and researchers in other fields for smaller and more flexible, if less reliable, PTTs. They did not change their minds simply because Argos was so well established that they could afford to take more risks with system reliability, although that was a contributing factor. More important was an institutional reorganization that took place at Service Argos in 1986, when CNES and its American partners committed themselves to supporting Argos over the long term. In that year CNES, in partnership with the French oceans and fisheries agency (L’Institut Français de Recherche pour l’Exploitation de la Mer (IFREMER)) and a number of private French banks, spun off Service Argos as a *société anonyme*, just as it had with the SPOT satellite imaging service several years earlier. Under the name Collecte Localisation Satellites (CLS), the unit remained under the direction of the French government and continued to be bound by the intergovernmental agreement under which Argos had initially been launched, but it was run as a for-profit corporation (Collect Localisation Satellites, 1986).

According to Michel Taillade, one of the leaders of Service Argos and then of CLS, the idea of creating a separate quasi-commercial unit for Argos had been non-existent at the time of the system’s design in the early 1970s. Only when it became apparent that Argos had the potential to endure longer than the period established in the initial agreement between NOAA, NASA and CNES, did CNES began to consider setting the system on a commercial basis. It ultimately did so not because of programmatic concerns, such as the promotion of biology or of interdisciplinary research, but in order to relieve itself of the financial and administrative burden of managing an operational system.[16] Combining, as it did, an embrace of market incentives with the maintenance of close governmental control, this arrangement was characteristic of French economic reforms of the mid-1980s (Hancké, 2002; McDougall, 1985; Prasad, 2005), but it also reflected international trends toward the privatization of government-supported research and development (Lave et al., 2010). The result was a ‘hybrid’ civilian space organization halfway between public and private (Withee et al., 2001: 124).

Following its reorganization, CLS aggressively expanded its ground facilities, user services, and marketing efforts, initially focusing its efforts on North America (Bessis, 1986; Collecte Localisation Satellites, 1987a). Argos's former marketing manager, Jean-Luc Bessis, became the head of its new subsidiary outside of Washington, DC (Bessis, 1986; Service Argos, 1986a). Taillade, general manager and head of promotional development at CLS in Toulouse (Service Argos, 1986b), recognized that the new *société anonyme* needed to market its service directly to scientific users as well as to the representatives of government agencies.[17] While reliability, accuracy and standardization remained important motifs, 'service', 'flexibility', 'diversification' and 'decentralization' became the dominant themes of Argos's corporate rhetoric after 1986 (Bessis, 1986; Cazenave and Taillade, 1986; Taillade, 1987).

This turn toward the market did not make CNES's American collaborators entirely comfortable. Privatization of space applications and other domains of government activity had been a recurrent theme of the Reagan presidency and led to NASA's establishment of an Office of Commercial Programs in 1984 (Rumerman, 1999: 355–379) and the attempted commercialization of the US satellite-imaging programme, Landsat (Mack, 1990). When the French government took steps toward privatizing a service upon which American scientists and government agencies had become dependent, and in which the US government had invested significant funds, however, it raised significant concerns. In 1988, Robert O. Masters of NOAA's National Environmental Satellite, Data, and Information Service stressed in an article in the Argos newsletter that the system remained a 'government service' and that charges for use should be understood as cost recovery for a 'public service' (Masters, 1989). The implication was clear: user fees collected under CLS's new corporate structure were not to be understood as a mechanism for enriching the *societé anonyme* or its investors.[18]

As the single largest user of Argos, both directly through the activities of its own agencies and indirectly through grants to nongovernmental researchers, the US government had negotiated for a reduced bulk rate for 'PTT-years' of data collection service since 1980. Effectively, it bought the service at wholesale rates and then 'resold' it to agencies such as NOAA and the US Fish and Wildlife Service, and to the extra-governmental grantees of the National Science Foundation and other agencies (Collecte Localisation Satellites, 1987b). This arrangement did not change immediately with the establishment of CLS, but the quasi-privatization of the system did have consequences. In particular, it paved the way for the creation of a more flexible infrastructure and new standards that were amenable to users other than meteorologists and oceanographers, as well as a broadened sense of what the term 'environmental' could mean. According to the memorandum of agreement signed by CNES, NOAA and NASA in 1974 and renewed at regular intervals thereafter, Argos could only be used to collect 'environmental data'. During Argos's first decade, the collection of environmental data had been understood as 'the observation and measurement of physical, chemical, and biological properties of land masses, rivers, lakes, oceans and the atmosphere (including space)', with a de facto emphasis on physical measurements (Service Argos, 1978b). Such research often had practical implications, but it was not necessarily environmentalist in nature. After 1986, in its quest to maximize users and income, CLS increasingly opened the Argos system up to explicitly environmentalist applications. As Taillade wrote of Argos in 1994: 'For a long time its major task was monitoring, and most international research into the ocean and climate has benefited from it. Since the late 1980s, users have also found Argos useful in applications to *protect* the environment' (Taillade, 1993).

Taillade's examples of 'protective' applications included tracking the movements of oil spills and shipments of hazardous waste, but the more strictly scientific applications of the Argos system also took on an increasingly environmentalist tone. These included efforts to track wild animals, which were almost always intimately tied to questions of conservation. The many studies of albatrosses by Weimerskirch and his colleagues that followed his initial work, for example, were driven as much by concerns about the impact of longline fisheries on albatross populations as they were by an interest in subarctic ecology or mechanisms of seabird evolution (BirdLife International, 2004; Weimerskirch, 1990). Studies of the foraging routes of albatrosses answered basic evolutionary and ecological questions, but they also developed preliminary maps of areas where environmentalists hoped to establish new fisheries reserves and regulations. Another novel environmentalist application of Argos was the tracking of fishing vessels, which allowed governments to verify that foreign nations were complying with fishing treaties.[19] Of course, as climate change became a significant political and scientific issue (Edwards, 2010; Oreskes and Conway, 2010; Weart, 2004), many studies of the physical environment and related infrastructure-building efforts involving Argos became increasingly environmentalist in tone rather than simply environmental (see for example Nowlin et al., 1996). The goal of improved weather forecasting that drove Argos's initial development was largely replaced by a concern with protecting a natural world under threat. This shift in focus cannot be disentangled from Argos's reorientation after 1986 toward the market. It was admittedly a market still largely defined by scientific and government priorities, but it was a market nonetheless, in which Argos viewed itself as competing for scientific 'customers' in order to grow its own revenue.

Conclusion

I have argued that the global environmental visions of meteorologists and wildlife biologists differed and that these differences led to distinct requirements for a satellite-based environmental data collection and location system. This argument builds on recent studies of the ways that environmental observation infrastructures shape how scientific questions are posed and answered (e.g. Bowker, 2006; Edwards, 2010), but it also highlights the potential diversity of and potential for conflict between alternative global visions instantiated within a particular infrastructure. In the 1970s, when Argos was being designed and implemented, meteorologists were better organized, better funded and more influential with the relevant government agencies than wildlife biologists or ecologists were. Because those government agencies were the ones making the key decisions, meteorologists were able to shape the system to meet their needs, which centred on the acquisition of standardized, reliable samples from a global grid of sensors. While the infrastructure that resulted was well suited to the study of the atmosphere and oceans as volumes of flows, it was less suited to the purposes to which wildlife biologists hoped to put it and for which they had been seeking a satellite-based tool since the early 1960s: tracking the movements and interactions of diverse animal species in a web of life. The latter purpose demanded not a standardized global grid but a flexible system of global access for tracking individual bodies in motion.

The quasi-privatization of CLS in 1986 and the creation of subsidiary companies in the US was soon followed by the establishment of similar subsidiaries in Australia, Japan and other countries (Collecte Localization Satellites, 1988, 1989). At the same time, the administrators of Argos increasingly sought to attract users from scientific domains besides meteorology, notably wildlife biologists and others with explicitly environmentalist concerns. 'Diversification' became their key word. CLS pursued diversification by offering special services to communities of new users and by loosening standards that had originally been established to win the confidence of physical environmental scientists. In addition to the Wildlife Service, established in 1987, under which CLS delivered location estimates even when a number of quality assurance standards had not been met, the system was also rendered more useful to wildlife biologists and other users by the addition in 1998 of the first of the second generation of Argos orbiting instruments. These instruments were more sensitive than the first generation and could receive signals in a broader range of frequencies, thus reducing competition between the underpowered tags of animal trackers and those of meteorologists, oceanographers, and other users (Goasguen and Guigue, 2002; Lafuma and Ruiz, 1996; Tomkiewicz, 1997).

In combination with these technical changes, CLS's aggressive marketing efforts and advances in transmitter design by independent engineering firms and academic laboratories resulted in significant growth in Argos's user base. Between 1986 and 2010, the number of Argos PTTs actively tracked at any given time underwent a nearly 25-fold increase, from about 850 to more than 21,000 (Cazenave and Taillade, 1986; Vassal and Woodward, 2010). The system also became more diverse, hosting multiple and sometimes conflicting user groups, research practices and visions of the global environment. As new and more sophisticated commercial satellite systems such as Iridium and Globalstar increasingly competed with Argos for scientific and environmental applications, ultralight PTTs for wildlife tracking remained one area where Argos continued to provide a unique service.[20]

The history of the development of the Argos system shows that limits on the usefulness of a satellite system to scientific 'user groups' cannot simply be attributed to the failure of the relevant government agencies to understand or meet those user groups' needs or, conversely, to 'user resistance' to the adoption of new technologies (cf. Krige, 2000; Mack, 1990). On the contrary, it was sometimes precisely the agencies' understanding of and desire to satisfy the needs of one user group that kept it from meeting the needs of other groups that were eager to adopt the technology. There were some aspects of the Argos system, such as the sensitivity of the orbiting instruments, that could not easily be changed to meet wildlife biologists' needs, but there were others that required only relatively minor technical or policy changes. The Argos administrators' failure to make these changes in the system's first years of operation reflected, in large part, their desire to satisfy their best-organized and most influential user group.

By tracing the impact of commercialization on the scientific use of a space-based environmental observation system, this account also builds on the recent historiography of the post-Second World War environmental sciences, which has revealed the central role played by national security concerns in the development of global environmental surveillance systems and of the environmental sciences (e.g. Bocking, 1997; Cloud, 2001; Doel, 2003; Hamblin, 2005; Hounshell, 2001; Masco, 2010; Mukerji, 1989; Oreskes, 2003; Solovey, 2001; Warner, 2000; Worster, 1994). The development of Argos, which was launched in the late 1970s, but whose period of most dramatic growth began a decade later, just as the cold war was coming to an end, was less influenced by such concerns than by the turn toward privatization of research and development in the 1980s (Lave et al., 2010; Randalls, 2010). During this period, national space programmes outside the US and the Soviet Union achieved their first independent successes, neoliberal approaches to governance gained in popularity, and technocratic varieties of environmentalism became institutionalized in most developed countries (see Beck, 1992). One result of these shifts was the transformation of Argos from a fairly small system, serving a well-defined constituency of physical environmental scientists, to a much larger system serving a diversity of users with different needs, including, prominently, wildlife biologists. Limited commercialization of the infrastructure of environmental observation opened doors that previously had been closed because of a tight alliance between certain particularly well-organized and influential scientific communities and government agencies. New difficulties undoubtedly arose as a consequence of this shift, but the highly negative consequences of the neoliberalization of research and development described by Rebecca Lave and her colleagues (2010) seem to have been largely avoided. This may be due to the fact that CLS, however commercial in orientation it may have become in its day-to-day operations, ultimately remained under the control of CNES and bound by its international agreements.

This paper has emphasized the differences between the global environmental visions of meteorologists and wildlife biologists as they were instantiated in one satellite-based environmental surveillance system, but it is important to note that the divide was not absolute, and it has grown more porous over time. Even though the promotion of interdisciplinary research was at best a distant second in importance to the institutional and financial considerations that led CLS to embrace non-meteorological and non-oceanographic users in the late 1980s, the Argos infrastructure has had the unintended result of facilitating a rapprochement between visions of the global environment as a volume of flows and as a web of life. As the links between climate change and biodiversity loss have become more apparent (Intergovernmental Panel on Climate Change, 2007) and as Argos PTTs for wildlife tracking have grown smaller, more robust and more capable of collecting and transmitting environmental data, biologists have begun using them to acquire data of direct use to climate scientists. Organisms as diverse as albatrosses, whales and seals have been deployed as autonomous biological sampling platforms capable of collecting measurements of temperature, pressure, salinity and other physical properties from regions of the oceans and atmosphere not regularly visited by human observers or by buoys and balloons (e.g. Boehlert et al., 2001; Fedak, 2004; Laidre et al., 2010). Biologists continue to conceptualize the far-ranging animals they study as living links between ecosystems, but they also see them as components of a global grid of sampling stations. At the same time, they have begun to recognize the importance of large-scale oceanic and atmospheric flows for interpreting the movements of individual animals (e.g. Gaspar et al., 2006; Luschi et al., 2003). Just as global environmental visions have shaped the development of infrastructures of environmental surveillance, so have those infrastructures, in turn, shaped scientists' global visions.

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Notes

1. The best source for technical information about the Argos system is the Argos User's Manual available at http://www.argos-system.org/manual/index.html (accessed 12 July 2012). In addition to published and archival sources, the arguments in this paper are based on interviews with participants in the development of satellite data collection and location systems and animal tracking by satellite. Specific interviews are cited below.
2. The Argos system under discussion here should not be confused with the Advanced Research and Global Observation Satellite (ARGOS), a US military satellite launched in 1999 (Boeing, 1999).
3. The mythical 'shepherd with many eyes' is mentioned in an official Argos publication in 1980 (Goasguen, 1980).
4. This list was derived from the 'Applications' page of website of the Argos system, http://www.argos-system.org/web/en/44-applications.php (accessed 15 November 2011). Oceanographic and animal tracking applications of the Argos system are summarized in special issues of the Argos newsletter that were published to commemorate the system's 30th anniversary in 2009 (*Argos Forum*, 2009, 2010).
5. Compare Park Doing's (2009) account of the use of the Cornell University synchrotron by solid state physicists and protein crystallographers, which shows how biologists effectively took control of technical infrastructure and epistemic standards previously dominated by physicists.
6. Biologists' relative lack of coordination in comparison to meteorologists was stressed to me as a factor in their delayed use of the Argos system, during an interview with William E. Woodward, president and CEO of CLS America (a company formed in 2006 by the merger of Service Argos, Inc., and North American CLS). The interview occurred on 30 October 2007; recording in possession of the author. Charles E. Cote, a NASA engineer who collaborated on the first study involving animal tracking by satellite in 1970, made a similar point in an interview on 24 October 2007; recording in possession of the author.
7. One important example is the Tropic Atmosphere Ocean/Triangle Trans Ocean Buoy Network (TAO/TRITON) array, which since its completion in 1994 has consisted of about 70 moored buoys that feed data into global climate and El Niño/La Niña models. Available at: http://www.pmel.noaa.gov/tao/proj_over/taohis.html (accessed 1 April 2012).
8. By 1984, there were 10 institutions offering certified PTTs for use with Argos: Bristol Aerospace Limited (Canada), Ceis Espace (France), Eidsvoll Electronics (Norway), Hermes Electronics Limited (Canada), Instituto de Pesquisas Espacias (Brazil), Johns Hopkins University Applied Physics Laboratory (USA), National Center for Atmospheric Research (USA), Polar Research Laboratory, Inc. (USA), Toyo Communication Equipment Co. Ltd. (Japan) and Wood Ivey System Corporation (USA) (Service Argos, 1984a).
9. Researchers interested in tracking ocean currents *did* worry that the shape of the buoys might bias their movements, but size and weight of the Argos PTTs were insignificant factors (Johnson, 1989: 697).

10. By way of example, the FGGE buoys deployed by Australian Bureau of Meteorology in 1979 were 5.3 m long and weighed 105 kg, not including the weight of a ballast chain and drogue assembly (De la Lande, 1979).
11. This is very different from the method used by the Global Positioning System, in which each receiver calculates its own location based on the timing of signals received from multiple satellites (see Samama, 2008: 114–117; Taillade, 1981).
12. The proceedings of the 1966 Smithsonian meeting were never published, but brief descriptions can be found in Craighead and Dunstan (1976) and Bird (1966). Details about the Smithsonian's involvement in the development of animal tracking by satellite in the 1960s and early 1970s can be found in Boxes 20–23 of the Helmut Karl Buechner Papers, 1939–1975, Record Unit 7279, Smithsonian Institution Archives, Washington, DC.
13. Several participants in the early development of wildlife tracking – including Dwain Warner, George Swenson, and William Cochran – told me of their frustration with NASA policy during this period: according to them, the agency seemed eager to expand its reach but unwilling to invest the resources necessary to make satellite instruments useful to wildlife biologists.
14. The manuscript from which this quote is drawn was later published in revised form (Buechner et al., 1971).
15. Recently this has changed somewhat; see, for example, the Census of Marine Life, which ran from 2000 to 2010 (O'Dor, 2004). An online presentation of the Census of Marine Life is available at: http://www.coml.org (accessed 12 July 2012).
16. Interview with Michel Taillade on 25 July 2007; recording in possession of the author.
17. Ibid.
18. Unease on the part of Argos's American collaborators about the French decision to commercialize the system was described to me by Michel Taillade, former general manager of CLS (ibid.). Taillade also emphasized the importance of the creation of CLS in injecting a newly entrepreneurial spirit into the management of the Argos system, which included experimenting with new products and reaching out to new user groups.
19. As of April 2011, the 'ArgoNet' website for fishing vessel tracking applications of Argos claimed that more than 8,000 fishing vessels were equipped with Argos PTTs. Available at: http://www.argonet-vms.com/ (accessed 12 July 2012).
20. In an interview on 30 October 2007, William Woodward of CLS America speculated that in 20 years, 90 percent of active Argos tags might be used for animal tracking, since this is the one area in which newer and often more technologically sophisticated satellite-based data collection and location systems are at a disadvantage; recording in possession of the author.

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