Section IV

Applications Satellites, the Environment, and National Security

Chapter 14

Satellites and Security: Space in Service to Humanity

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In his classic political history of the early Space Age, Walter McDougall explained the cold war competition between the Soviet Union and the United States as a competition between two increasingly technocratic states.[1] In the American case, his narrative represents a cry for restraint. The technocratic imperative is not a democratic one. He saw in the coming of technocracy the rise of a narrow, technologically focused elite to power. He apparently did not like the technocratic vision of the future this gave him; not surprising, I think, given his experiences in one of American technocracy's great Apollo-era disasters, the Vietnam War.

But one of the key traits of technocracy is the state's effort to use "technology," often defined very amorphously, to improve lives. This is, I think, what Steve Dick meant when he asked me to discuss the societal impact of military, applications, and science satellites. The United States government has financed these in the general belief that they would result in progress of some sort. In many cases, the hoped-for outcomes were obvious. Everyone thought weather satellites would result in longer-range weather forecasts, an economic, as well as a social, good. Military satellites, too, had obvious uses. The earliest military satellites were oriented toward surveillance and intelligence gathering, developed to supplement intelligence aircraft.

The same can be said about the literature on applications satellites. To date, only communications satellites have a significant literature, as David Whalen will discuss in his paper. Only military satellites, my first topic, have received extensive study, although to date imaging satellites have drawn most attention, leaving several areas untouched. It is also the case that many "big picture" questions about the impact of these vehicles on the military, and on our political culture, have yet to be asked.

Even scientific satellites were often utilitarian in nature. Asif Siddiqi wrote in his essay for the 2005 Critical Issues conference that "[T]he literature on the history

1. Walter A. McDougall, *. . . the Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985).

of space-based science has, however, not been significant."[2] Indeed it has not! Very few efforts in space science have drawn scholarly attention. But scientific satellites and solar system probes have had profound impacts on the scientific community and, as is the case with military satellites, on our national politics.

SATELLITES AND THE MILITARY

One of the fundamental historical realities exposed in all of the papers in this session is that satellites have been seen, since Sputnik, as militarily useful. The first weather satellite, TIROS, started its road to existence as an Army reconnaissance satellite project at Fort Monmouth, New Jersey, a couple of years prior to Sputnik's launch. Army leaders thought, quite rightly, that just as airborne reconnaissance had transformed knowledge of the battlefield in World War II, spaceborne reconnaissance would cement that tactical advantage and make it a global, and strategic, asset. It would also place that asset under Army control, relieving the institution's dependence on its chief rival, the U.S. Air Force, for intelligence. They were thwarted by President Eisenhower, who gave imaging reconnaissance to the Central Intelligence Agency and the Air Force, weather satellites to NASA and the Weather Bureau in an unsuccessful partnership arrangement, and to his own former service, the Army, communications.

There is already some good literature on reconnaissance satellites and their impact on the cold war. Jeffrey Richelson has examined two important systems in a pair of books, the Defense Support Satellite Series, which served to provide early warning of Soviet ballistic missile launches, and the Keyhole series of imagery satellites (also known as Corona and Discoverer.) The Corona satellites have also drawn attention from Dwayne Day, from a policy and technology perspective. There is also at least one popular treatment of space surveillance.[3]

2. Asif A. Siddiqi, "American Space History: Legacies, Questions, and Opportunities for Future Research," *Critical Issues in the History of Spaceflight*, Steven J. Dick and Roger D. Launius, ed. (Washington, DC: NASA SP-2006-4702, 2006), p. 440.

3. Jeffrey Richelson, *America's Secret Eyes in Space: The U.S. Keyhole Spy Satellite Program* (New York: Harper & Row, 1990); Richelson, *America's Space Sentinels: DSP Satellites and National Security*, Modern War Studies (Lawrence, KS: University Press of Kansas, 1999); Dwayne A. Day, "A Strategy for Reconnaissance: Dwight D. Eisenhower and Freedom of Space," in *Eye in the Sky: The Story of the Corona Spy Satellites*, Dwayne A. Day, John M. Logsdon, and Brian Latell, ed. (Washington, DC: Smithsonian Institution Press, 1998), pp. 119–142; William Burrows, *Deep Black: Space Espionage and National Security* (New York: Random House, 1986). Also see R. Cargill Hall, "Missile Defense Alarm: The Genesis of Space-Based Infrared Early Warning," *Quest: The History of Spaceflight Quarterly* 7, no. 1 (Spring 1999): pp. 5–17.

A thorough overview of what's often called "MILSPACE" can be found in Stephen Johnson's article in the *Critical Issues in the History of Spaceflight* volume, so instead of repeating his work I want to highlight a few areas that seem particularly interesting.[4]

From a technological standpoint, several types of intelligence satellites have existed since the late 1960s that haven't been examined. Since the early 1980s, the United States has flown a series of synthetic aperture radar satellites known as Lacrosse (and sometimes Onyx). These satellites are intended to detect vehicles of all types and can also detect motion and change. The first civilian synthetic aperture radar (SAR) flew in 1977 and, as far as I can determine, the first intelligence SAR was initiated in 1976. The Jet Propulsion Laboratory (JPL) built the first civilian SAR but does not seem to have been the source for the military version.[5] Are these truly independent developments? Or is there a relationship between the two? Our current understanding of space history would pretty strongly suggest that there must have been a relationship between the two. John Cloud has described the relationship between classified imaging satellites built for intelligence purposes and their unclassified counterparts (i.e., Landsat) as a shuttered lamp—a relationship controlled by the intelligence community.[6] The radar case might show us that the relationship between civilian and military technology is more complex than this model.

There are also other kinds of intelligence satellites. As was revealed at least as far back as the early 1980s, the United States operates "signals intelligence" (sigint) satellites. These satellites capture millions of electronic signals every day that are analyzed by an ever-changing array of supercomputers. There are many possible stories to tell buried in this topic. As Stephen Johnson also pointed out, the technologies underlying sigint are in need of historical exegesis.[7] The political, military, and intelligence utility of these kinds of systems is in need of study, too. In the early 1990s, the U.S. National Security Agency apparently considered using it for industrial espionage against our European allies. This briefly produced diplomatic problems for the United States (whose governmental allies were, apparently, quite content with the system's existence until their publics found out about it).[8]

4. Stephen Johnson, "The History and Historiography of National Security Space," in *Critical Issues in the History of Spaceflight*, Steven J. Dick and Roger D. Launius, ed. (Washington, DC: NASA SP-2006-4702, 2006), pp. 481–548.

5. The Jet Propulsion Lab's SAR flew on Seasat-A; see Peter Westwick, *Into the Black: A History of the Jet Propulsion Laboratory* (New Haven, CT: Yale University Press, forthcoming); for Lacrosse, see *http://www.fas.org/spp/military/program/imint/lacrosse.htm* (accessed 5 September 2006).

6. John Cloud, "Imaging the World in a Barrel: CORONA and the Clandestine Convergence of the Earth Sciences," *Social Studies of Science* 31:2 (April 2001): pp. 231–251.

7. Johnson, "History and Historiography," note 4.

8. Ron Suskind, *The One Percent Doctrine: Inside America's Pursuit of its Enemies Since 9/11* (New York: Simon and Schuster, 2006), p. 85.

The history of this technical capability is also directly relevant to the current administration's attempts to discredit revelations that it is using signals intelligence to spy on terrorists (and everyone else, too.)[9] The historical fact of the matter is that this is old news.[10] The technical capacity to do this has been a matter of public record since the public unmasking of the National Security Agency in the Ford administration and its role in illegal domestic surveillance; wise leaders should assume enemies have a basic awareness of our capabilities—particularly old, well established ones. The subject of signals intelligence and its use and abuse deserves further historical exegesis.

Better covered historically than signals intelligence has been the development of military communications satellites. So far, the literature suggests that although the military saw the utility of surveillance satellites well before the ability to build them existed, the armed services rather missed the boat with communications satellites. The first communications satellites that we're aware of were commercial. AT&T immediately sought a monopoly in this new business and was denied by government policy; the Department of Defense (DOD) seems to have bought access to the technology in the early years. It became an innovator later in the Space Age. One author places responsibility for this in the decision to place communications satellite development in the Army and in the Advanced Research Projects Agency, delaying development until after private companies had already flown their satellites. NASA also played a significant role in communications satellite development in the 1960s and early 1970s, although apparently not after that.[11] To make this picture of innovation still more complicated, I was recently told by a retired NASA manager that the Air Force paid for a significant fraction of the last of NASA's Advanced Technology Satellite comsat series, ATS-6, launched in 1974.

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9. Liberal columnist Paul Krugman discusses the treason charge in Paul Krugman, "The Treason Card," *The New York Times*, 7 July 2006; also see Frank Rich, "Will the Real Traitors Please Stand Up," *The New York Times*, 14 May 2006.

10. The technical capability to carry out large-scale eavesdropping on electronic communication was revealed in the 1970s, when the National Security Agency's illegal activities in spying on Americans was investigated by Congress. See James Bamford, *The Puzzle Palace: A Report on America's Most Secret Agency* (Boston: Houghton Mifflin, 1982), esp. pp. 280–308. The role of satellites in this system is not clear; much of what was revealed during the 1970s involved wiretapping and interception of radio communications from ground-based "listening stations." As Dwayne Day has shown recently, signals intelligence satellites first flew in 1960, although these seem to have been radar intercept satellites for characterizing air defenses, not communications intercept satellites. See Dwayne A. Day, "Early American Ferret and Radar Satellites," *Spaceflight* (July 2001): pp. 288–293.

11. See David N. Spires and Rick W. Sturdevant, "From Advent to Milstar: The U.S. Air Force and the Challenges of Military Satellite Communications," in *Beyond the Ionosphere: Fifty Years of Satellite Communication*, ed. Andrew Butrica, (Washington, DC: NASA SP-4217, 1997), pp. 65–70; David Whalen, *The Origins of Satellite Communications, 1945–1965* (Washington, DC: Smithsonian Institution Press, 2002).

Communications satellites have had a profound impact on the armed services. My own former service, the U.S. Navy, evolved command traditions over 200 years that were based on the unreliability and often non-existence of communications with the National Command Authority back in Washington. Even radio did not fundamentally change this reality, because the high-frequency radios that were the basis of World War II communications were "environmentally unreliable." As radio engineers all knew, sometimes one could get global range from a radio set—and sometimes you couldn't reach a ship 50 miles away. The Navy continued to operate under the expectation that senior commanders were unlikely to be immediately available.

Satellite communications changed that. Essentially instantaneous communications were possible from virtually any spot on Earth or in the air above it after the mid-1960s. In addition to the culture shock this imposed on the Navy (and which it is still dealing with), I rather suspect it accounts for some of the severe cultural differences between the relatively new Air Force—which has only existed in the era of electronic communications—and the Navy. But in any case, buried in the history of military communications satellites are stories of cultural change as well as technological change, deserving of documentation and analysis. There are also, of course, changes in operations and in operational capacity due to this capability in need of examination.

Although there is at least some literature on communications satellites, largely missing from the historical record is an examination of the first military navigation satellite series, Transit. Operational in 1962, Transit was a Navy project implemented by the Applied Physics Laboratory of the Johns Hopkins University. Transit operated until 1996. The technical literature contains articles on its genesis, but I can identify no examination of its impact on Navy operations, capabilities, etc.[12] Yet Transit was simple and inexpensive, and it was part of the justification for belief in "faster, better, cheaper" in the 1990s within NASA. It also paved the way for the NAVSTAR Global Positioning System, which one paper in this book addresses. So it had important ramifications but it hasn't found its historian yet.

The last kind of military space technology that I want to discuss is weather satellites. The United States has maintained a civilian weather satellite series since 1960 and a military weather satellite series since 1961.[13] President Eisenhower had intended that there be a single system operated by the Weather Bureau, but the resulting agreement collapsed very quickly. The prime justification for splitting into two satellite systems was that the DOD and the Weather Bureau wanted different overpass times, with DOD officials wanting an early morning orbit that would

12. See, for example, Robert J. Danchik, "An Overview of Transit Development," *Johns Hopkins APL Technical Digest*, vol. 19, no. 1 (1998): pp. 18–26.

13. See the essay by Purdom and Menzel in James R. Fleming, *Historical Essays on Meteorology, 1919–1955* (Boston: American Meteorological Society, 1996), for basic information on the civilian weather satellite program.

permit planning of reconnaissance and aerial refueling missions. One source also states that the civilian system would not overfly Moscow, increasing the Pentagon's desire for a different orbit choice.[14] I rather suspect that the Pentagon's desire for control also had a lot to do with this decision.

Initially, the two organizations used two variants of the TIROS satellite, with very similar instrumentation. This changed over time and, although the current civilian and military satellites use the same "bus," they have different instrumentation. It is the military weather satellites that have provided strong evidence that the Arctic ice cap is shrinking rapidly, for example—a capacity the civilian satellites do not have. Other than R. Cargill Hall's recent short, and very technically oriented, history of the Defense Meteorological Satellite Program, however, there are no studies of DOD's weather satellite system or its evolution.[15] My own forthcoming work deals only with the civilian system.

A Larger View of Military Impacts

Paul Edwards expounded a thesis a few years ago that in constructing its network of surveillance and communications assets, the DOD sought nothing less than a "closed world"—an Earth in which nothing could happen without the Pentagon's knowledge. His argument is more sociocultural than historical, and I am not convinced. The sheer arrogance of such a goal (not to mention its technological unlikelihood!) gives me pause. Yet he might be right. The very name of the DOD's communications architecture, The World Wide Military Command and Control System, certainly suggests that he is right.[16] Rigorous investigation of his claim would tell us a great deal about the DOD and its leaders' faith in technology if someone were willing to dig into it.

All in all, the extant historical literature on military use of space pretty strongly suggests that surveillance and communications have been stabilizing influences in terms of the strategic deterrence and the cold war contest with the Soviet Union. That's the point made by Glenn Hastedt in his paper in this book. It's far less clear that this is true in terms of the myriad "small wars," "regional conflicts," and "operations short of war" that the United States has engaged in since 1945. It's likely true that these space assets have expanded the United States' ability to engage in so-called conventional war, the sort fought by large formations of men and machinery.

14. Dwayne Day comments on an earlier draft of this paper, September 2006.

15. R. Cargill Hall, "A History of the Military Polar Orbiting Meteorological Satellite Program," (Washington, DC: National Reconnaissance Office, 2001).

16. Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, MA: MIT Press, 1996), pp. 1–42. On WMMCS, see David E. Person, *The World Wide Military Command and Control System: Evolution and Effectiveness* (Maxwell AFB, AL: Air University Press, 2000).

One recent analysis describes the very conventional first Gulf War as the first "space war."[17] Yet satellites have not similarly improved the nation's capability to wage "guerilla war"—we remain poor at it, as the current wars in Iraq and Afghanistan show, and as was also true in Vietnam. The impact of space technology has been profound, in other words, but not limitless.

Further, one should wonder whether the global view offered by our space assets have encouraged the belief prevalent among neoconservatives that we can construct and maintain a perpetual Pax Americana. Based on a presumed "Revolution in Military Affairs" that derives from the integration of space-based communications, intelligence, and space- and airborne weapons, they contend that America can maintain and expand its dominion over Earth forever. In their 1998 program for America, for example, the movement's leaders called for the development of "global missile defenses to defend the American homeland and American allies, and to provide a secure basis for U. S. power projection around the world," and for establishment of control over "the new 'international commons' of space and cyberspace."[18] Their faith in technology and the utility of the space weaponry seems to me founded directly on a heavily distorted view of space capabilities.[19]

In fact, they seem to believe in exactly what Edwards claims the Pentagon did in the 1960s—that a closed world is possible and desirable. There is a great subject here for someone to dig into. Satellites may very well have encouraged the rapid rise of militarism in the United States as well as encouraging our political classes to undertake global wars of choice.[20]

Civilian Applications Satellites

So, I claim, military satellites of many descriptions and functions have had significant impacts on the American military, and may have had far larger impacts on American political culture. What about their civilian twins?

NASA launched the first civilian weather satellite in April 1960. This was TIROS 1, the direct descendant of the U.S. Army's work toward an imaging

17. Peter Anson and Dennis Cummings, "The First Space War: The Contribution of Satellites to the Gulf War," *RUSI Journal* 136 (1991): pp. 45–53.

18. Thomas Donnelly, et al., "Rebuilding America's Defenses: A Report of the Project for the New American Century," pp. iv, 54–64, published online at *http://www.newamericancentury.org* (accessed 5 February 2007).

19. Frances Fitzgerald, *Way Out There in the Blue: Reagan, Star Wars, and the End of the Cold War* (New York: Simon and Schuster, 2000) is the best work on Star Wars to date, although it is nontechnological. A good summary of this "Revolution in Military Affairs" thinking is Andrew Bacevich, *The New American Militarism* (New York: Oxford University Press, 2005), pp. 165–170.

20. On American militarism, see Andrew Bacevich, *The New American Militarism*. The Project for a New American Century calls such small, voluntary wars "constabulary duties." Donnelly, Rebuilding America's Defenses, p. 10.

surveillance satellite. It was hugely popular, drawing a large, front-page *New York Times* article, complete with "cloud pictures" from space. NASA officials used it to sell the agency to Congress and the public. Better weather forecasting was the first obvious and direct benefit to non-astronaut, ground-dwelling humans (i.e., 100 percent of the American population).

Yet there is no published history of the weather satellite program. The last attempt at a history was Chapman's study of the conflict between NASA and the Weather Bureau over control of the technology completed back in 1967.[21] It was rather heavily redacted due to DOD concerns. Since then, no one has found the subject worthy of historical study. Not even the Weather Bureau's descendant, NOAA, has bothered. The agency doesn't even publish data on economic benefits from weather satellites. There is a single essay touching on weather satellites in the *Exploring the Unknown* series.[22] What gives here?

My speculation on the subject goes like this: Weather satellites did not live up to the grand promises upon which they were sold. Using them, meteorologists of the 1960s thought they could produce monthly forecasts of great accuracy. As I show in my forthcoming work, however, by the late 1960s simulation studies done at the Goddard Institute for Space Studies showed that forecasts of more than a dozen days were completely impossible and forecasts of more than five days were impossible with current technologies. This was confirmed by the Global Atmospheric Research Program in 1978, a hugely demoralizing outcome to NOAA and to the meteorological profession. Satellite data emerged from this in such low regard that NOAA didn't use it in routine operational numerical forecasting until 1998.[23] So I rather suspect NOAA leaders have not wanted to undermine themselves with a historical study.

I do not want to leave the impression, however, that the weather satellites have been without impact. The geosynchronous satellites provide the hurricane and typhoon warnings and imagery and track forecasts that we've been accustomed to since the early 1980s. I suspect that they've also improved severe storm forecasting in the Midwest. Meteorologist friends of mine say this is true, anyway. Both of these are significant economic and human goods, although the lack of research on these topics available makes it impossible to make the case with any rigor. These satellites have also transformed the meteorological profession. Although operational forecasts in the United States have not used the satellite data, researchers and research-oriented forecast models have been using it routinely since the early 1980s.

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21. Richard Leroy Chapman, "A Case Study of the U.S. Weather Satellite Program: The Interaction of Science and Politics," Ph.D. dissertation, Syracuse University, 1967.

22. Pamela E. Mack and Ray A. Williamson, "Observing the Earth from Space," in *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program Volume III: Using Space*, John M. Logsdon et al., ed. (Washington, DC: NASA SP-4407, 1998), pp. 155–176.

23. National Research Council, *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death* (Washington, DC: National Academies Press, 2000).

It has led to much greater understanding of the structure of the atmosphere and its organization, particularly over the otherwise data-sparse oceans. Satellites permitted identification of the region of the Atlantic where hurricanes typically form, for example, something that hadn't been known prior to the Space Age.

There is also a policy issue to be discussed. The United States has not flown a new instrument on its civilian, polar-orbiting weather satellites since 1978. This is not a failure of innovation; NASA is flying relevant research instruments and NOAA has developed airplane-based demonstration instruments as well. But NOAA hasn't been able to get any of these instruments into space. This problem has been exacerbated by the 1994 decision to merge the civilian and military weather satellite programs into the National Polar Orbiting Environmental Satellite System, whose 1998 launch date has been "slipped" to somewhere around 2013–2014.[24] There's a gross policy failure here, and possibly several policy failures all working together to produce an exceptionally bad outcome.

Finally, in his recent movie, *An Inconvenient Truth*, former Vice President Al Gore, Jr., shows an image of Earth from space, taken by Apollo 17 astronauts from lunar orbit in 1973.[25] By showing the "Big Blue Marble" in all its beauty and fragility and free of arbitrary, human-drawn political borders, it provided a potent symbol for environmentalists to rally around.

Although I certainly agree that images have great power, I have always wondered a bit about the specifics of this story. The first Earthrise image was sent back by a robot, Lunar Orbiter 1, in 1966. The first full-disk color image of Earth was actually sent back by Vern Suomi's experimental spin-scan camera on the communications satellite ATS-3 in 1967. Yet only meteorologists talk about this image. In 1968, Apollo 8 astronauts took the first color Earthrise image. All of these images appeared in public media before the first Earth Day in 1970; the Apollo 17 images did not. The space program as a whole produced a series of stunning images that placed Earth in a context far different than Americans' daily experience. I think the steady stream of dramatic imagery mattered more to the spread of environmental consciousness than any single picture.

I have touched on some of these issues in my own forthcoming history of atmospheric science, but since my focus is on NASA science, a lot of the above ground is essentially untilled. In terms of "societal impact," I suspect that the weather satellites have been enormously important—but neither I nor any other scholar has made the case with any rigor.

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24. A bare hint of NPOESS's long, messy history is contained in Eli Kintisch, "Stormy Skies for Polar Satellite Program," *Science* 312 (2 June 2006): pp. 1296–1297.

25. Sheila Jasanoff, "Image and Imagination: The Formation of Global Environmental Consciousness," in *Changing the Atmosphere*, ed. Clark Miller and Paul N. Edwards (Cambridge, MA: MIT Press, 2001). The book companion to Gore's movie is Al Gore, *An Inconvenient Truth* (New York: Rodale Books, 2006).

Commercial communications satellites do not have quite the historical lacuna that the weather satellites do. Because David Whalen addresses them in his paper, I am not going to say much about this subject other than to reiterate what I said in the above Military Impacts section: although we have some good treatments of the evolution of comsat technology and of the policy issues surrounding them, no one has made the leap yet to societal impact. The economic value of the industry seems clear from Whalen's work but there's more to society than the pure social construct we call "money." We often believe that our technologies make our lives "better" in some meaningful way, although one should always consult Ruth Schwartz Cowen's book *More Work for Mother* before making this claim too strongly! Have communications satellites done so? I am reminded of Bruce Springsteen's lyric "57 channels and nothing on."[26] Satellites have brought me hundreds of channels; I watch two regularly.

But let me dig a bit further into this question of "impact." In one of his exploration essays, Steve Dick threw out the idea that communications satellites have brought the world "closer together."[27] The airplane was similarly touted as having the potential to "bring the world closer together" and other happy things—bring peace on Earth through greater understanding among peoples, etc. Joe Corn wrote a wonderful book on this.[28] But the airplane's legacy is far more mixed. It is true that I can take a relatively short flight to Tokyo to visit the land of sushi. It's also true that the airplane allowed us to nearly wipe Tokyo off the map two generations ago, without even bothering with nuclear weapons. The airplane's legacy is so mixed and contested that the nation's shrine to aviation, the National Air and Space Museum, is not *allowed* to construct interpretive exhibits about it. Interpreting the airplane accurately would offend powerful political and economic interests.

My personal sense is that the same will turn out to be true for communications satellites: the legacy will be heavily mixed. It is certainly true that satellites facilitate emergency communications and they provide the opportunity for vastly more programming. At the same time, we have seen the growth of targeted media—channels that exist to promote specific interests or specific politics. The same capability that enables dedicated sports networks (e.g., ESPN, NESN) also permits Al Jazeera, the first independent Arab media organization (despised by the American

26. Ruth Schwartz Cowan, *More Work for Mother: The Ironies of Household Technology from the Open Hearth to the Microwave Oven* (New York: Basic Books, 1985); Bruce Springsteen, "57 Channels (and Nothin' On)," *Human Touch*, Sony BMG Records, 1992.

27. Steven J. Dick, "Societal Impact of the Space Age," 4 April 2005, *http://www.nasa.gov/mission_pages/exploration/whyweexplore/Why_We_09.html* (accessed 11 September 2006).

28. Joseph J. Corn, *The Winged Gospel: America's Romance with Aviation, 1900–1950* (New York: Oxford University Press, 1983), esp. pp. 29–50.

political right), and News Corp's Fox News channel, derided by American liberals as "Faux News" for its blatant political bias.[29]

George Orwell feared that the end of the twentieth century would bring a perfect surveillance state into existence. Big Brother would be watching all of us, all of the time. We are not quite there yet, but we *have* achieved a world full of specialized propaganda bubbles—hidden behind the euphemisms of "targeted media" or "narrowcasting." One can go through one's daily life and never be subjected to uncomfortable or challenging ideas—or even facts. In short, we have a postmodern version of Orwell's Ministry of Truth.

This is not the fault of the technology exclusively, of course. The Reagan administration's elimination of the old Fairness Doctrine that required the airing of multiple viewpoints is another key enabler of this unfortunate outcome. It is also not new. Most major European cities have had partisan newspapers for centuries and the United States has its share of political magazines, the famous ones being *National Review* on the right and *The Nation* on the left, although there are others. But there are differences. Television is more immediate and immersive than print and has much greater emotional power. Whether these differences are sufficient to make a difference in how the newly partisan electronic media affects the nation is a subject worthy of study. To wrap up this brief discussion of communications satellites, I am not at all sure Dick's optimistic appraisal is warranted.

Finally, the last applications satellite type I'll discuss in this extended editorial essay is land use. As Pam Mack has shown in her book on Landsat, there were many possible and interested users of satellite-based land imaging during its developmental period, and their competing goals and interests made development of the system very difficult.[30] And partly because of this, and also partly due to Pentagon restrictions on allowable spatial resolution (because of ill-conceived Congressional efforts to force "privatization" of Landsat), Landsat has never achieved a large enough user base to pay for itself. Instead, its imagery has been used by researchers, not by the economic interests that might be able to afford it on a commercial basis.[31] Indeed, the primary

29. *http://www.sourcewatch.org/index.php?title=Fox_News* (accessed 22 October 2006); Steven Kull, "Misperceptions, the Media and the Iraq War," 2 October 2003, *http://65.109.167.118/pipa/pdf/oct03/IraqMedia_Oct03_rpt.pdf* (accessed 22 October 2006). Renegade conservative David Brock has written a detailed account of the creation of the right-wing media establishment in America. David Brock, *The Republican Noise Machine: Right Wing Media and How it Corrupts Democracy* (New York: Basic Books, 2004); also see Neil Hickey, "Is Fox News Fair?" *Columbia Journalism Review* 36:6 (March-April 1998): pp. 30–36. Also see Daphne Eviatar, "Murdoch's Fox News," *The Nation* (22 February 2001), online edition, *http://www.thenation.com/doc/20010312/eviatar* (accessed 5 February 2007).

30. Pamela E. Mack, *Viewing the Earth: The Social Construction of the Landsat Satellite System* (Cambridge, MA: MIT Press, 1990).

31. There is a single historical study of Landsat use for scientific purposes to date: Peter Leimgruber, Catherine A. Christen, and Alison Laborderie, "The Impact of Landsat Satellite Monitoring on Conservation Biology," *Environmental Monitoring and Assessment* 106 (2005): pp. 81–101.

buyer of the data has been the intelligence community, which apparently finds that Landsat data serves as an effective supplement to its own classified imagery sources.

The satellite series itself has lurched from one crisis to the next, with each administration since Reagan willing to commit to only one more mission prior to commercialization; with commercialization never succeeding, each new administration has had to cope with the question of how to continue the series. The fundamental policy issues of what agency should maintain the capability and who should pay for it have not been resolved. So Landsat has been a technical success, but programmatically its history has been tortured. At the very least, there's a good policy study here for someone interested in the subject.

EARTH SCIENCE FROM SPACE

This is the subject of my own recently completed history of atmospheric science at NASA, so what follows is an essay on my own findings in the context of what very little else has been done on this subject. NASA's scientific satellites, and—a very important point—its planetary probes, have revolutionized our understanding of Earth, its processes, and our place on it. They have also radically altered our beliefs about the solar system and the universe around us. Finally, they have fundamentally changed our national politics.

There is, to date, not a single history of any NASA Earth science program. The only work that even comes close is Henry Lambright's monograph.[32] Yet as several (non-NASA) studies show, the Agency's stratospheric ozone research program initiated in the early 1970s led directly to the worldwide banning of a class of highly profitable chemicals. NASA research provided the first conclusive evidence that human activity was capable of causing global-scale damage. Yet these studies are not aimed at NASA's science program. They discuss the politics and policies surrounding the 1987 Montreal Protocol.[33] The political angle is important to these studies because ozone science was politically controversial, with leaders of the American political right claiming for many years that the idea of ozone depletion was an environmentalist hoax. Congressional hearings in 1995 underscored this view. But these earlier studies leave the reader wondering how NASA wound up leading this research field.

This is particularly germane as NASA's role in the ozone wars led to repeated and long-running attacks on the agency on the editorial page of the *Wall Street Journal*, by Rush Limbaugh on his radio show and in his best-selling books, and by a

32. Henry Lambright, *NASA and the Environment: The Case of Ozone Depletion* (Washington, DC: NASA SP-2005-4538, 2005).

33. The best of these works is Edward A. Parson, *Protecting the Ozone Layer: Science and Strategy* (New York: Oxford University Press, 2003); see also Maureen Christie, *The Ozone Layer: A Philosophy of Science Perspective* (New York: Cambridge University Press, 2000).

small constellation of other lesser actors in the right-wing political journals: *Reason, Commentary*, and *National Review*. The current administration made a brief attempt to quash NASA's James Hansen, the agency's most prominent climate modeler. But he was not the first NASA scientist to be attacked by what journalist Bill Moyers accurately terms the "radical right."[34] That honor actually belongs to Robert T. Watson, head of NASA's ozone research program in the 1980s.[35]

In *High Speed Dreams*, my history of supersonic transport research, I suggested in my conclusion that NASA's entry into political controversy came with its decision to embrace stratospheric ozone as a research program in hopes of absolving the Space Shuttle of claims that its solid rocket boosters would damage the ozone layer.[36] But in fact, the Agency's conflict with the New Right political movement that came to power with Ronald Reagan has its origins much earlier, in the Agency's planetary missions of the 1960s.[37] The JPL's Mariner Venus and Mars missions showed NASA's scientists—those employed by the Agency as well as university-based scientists involved in them—that relatively small initial differences between the three "terrestrial" planets (Venus, Earth, and Mars) had led to huge differences among these planets as they exist today. This fact, obvious by 1965, forced NASA's scientific constituency to start to come to grips with the relationship between *chemistry* and *climate*.

Probably the best known expression of this is in James Lovelock's Gaia hypothesis. Lovelock, who consulted briefly at JPL in the early 1960s, argued that biological activity regulated Earth's climate via its impact on atmospheric chemistry. But he was not the only person making chemical claims about climate by the end of the 1960s. Carl Sagan, never a NASA employee but always associated with the

34. Amanda Griscom, "Now Hear This: Bill Moyers Speaks his Mind on Bush-Brand Environmental Destruction and More," Grist Magazine (26 August 2003), online edition, *http://www.grist.org/news/maindish/2003/08/26/griscom-moyers/* (accessed 22 February 2007).

35. Andrew Revkin, "Climate Expert says NASA Tried to Silence Him," *The New York Times* (29 January 2006): p. 1; Donald Kennedy, "The New Gag Rules," *Science* (17 February 2006): p. 917; Rush Limbaugh, *The Way Things Ought to Be* (New York: Pocket Books, 1993), pp. 154–157. A few citations from the ozone depletion denial effort will suffice: Robert W. Pease, "Ozone Chicken Littles Are at It Again," *Wall Street Journal* (23 March 1989): p. 24; S. F. Singer, "My Adventures in the Ozone Layer," *National Review* 41 (1989): pp. 34–38; R. Bailey, "The Hole Story: The Science Behind the Scare," *Reason* 24 (1992): pp. 24–31; R. S. Bennett, and Robert W. Clack, "Ozone, CFCs and Science Fiction," *Wall Street Journal* (24 March 1993): p. 15; Kent Jeffreys, "Too Many Holes," *Wall Street Journal* (11 February 1993): p. 15.

36. Erik M. Conway, *High Speed Dreams: The Technopolitics of Supersonic Transportation* (Baltimore, MD: Johns Hopkins University Press, 2005), p. 303.

37. There is already a substantial body of literature on the New Right political movement. For examples, see Sara Diamond, *Roads to Dominion: Right Wing Movements and Political Power in the United States* (New York: Guildford Press, 1995), esp. pp. 108–128 and 205–227; for surveys placing the New Right in the context of the New Left of the 1960s, see Maurice Isserman and Michael Kazin, *America Divided: The Civil War of the 1960s* (New York: Oxford University Press, 2000), esp. pp. 205–220, and Rebecca E. Klatch, *A Generation Divided: the New Left, the New Right, and the 1960s* (Berkeley, CA: University of California Press, 1999).

Agency anyway, did a relatively speculative study for JPL on Venus's climate in 1960 and did a series of comparative studies between Earth, Mars, and Venus over the course of his career. His first graduate student, James Pollack, built NASA's planetary climate modeling program at the NASA Ames Research Center. [38]

It was also Pollack's group at Ames that produced the "nuclear winter" hypothesis in 1984, bringing down right-wing opprobrium on NASA while also stimulating tropospheric aerosol research.[39] The nuclear winter hypothesis helped trigger the foundation of the George C. Marshall Institute by Robert Jastrow. Jastrow, horrified by what he saw as a deliberate political attack on the Reagan administration disguised as science by Sagan, Pollack, and other scientists (including Donald Kennedy, the current editor of *Science*), appealed to conservative foundations for funds to finance a pro-nuclear "scientific" organization. He envisioned it as the conservative response to the Union of Concerned Scientists.[40]

Planetary climate studies also landed on the East coast, NASA's Goddard Institute for Space Studies (GISS). This organization, founded (somewhat ironically) by Jastrow in 1960, was intended to be the Agency's center for theoretical study of planetary atmospheres. That's still what it does. Unlike Goddard, Ames, and JPL (all of which also retain experimental and hardware programs), GISS is primarily theoretical. In modern space science, theory and data are both examined through the use of models. GISS actually performed the simulation studies that suggested weather satellites of the 1970s would not produce a great improvement in daily weather forecasts, for example.

GISS, of course, is also the home of NASA climate modeler James E. Hansen. Hired there in the early 1970s, Hansen initially worked on a scattering model for Venus' planetary cloud layers. Jule Charney, founder of numerical weather forecasting, performed some regional (Earth) climate studies using a GISS weather model in the middle of the decade; these, and Pollack's comparative planetary studies, triggered Hansen's interest in Earth's climate. Hansen and his colleague at GISS, Andrew Lacis,

38. Carl Sagan, "The Radiation Balance of Venus," *JPL Technical Report* no. 32-34 (15 September 1960); D. R. Hitchcock and J. E. Lovelock, "Life Detection by Atmospheric Analysis," *Icarus* 7:2 (1967): pp. 149+; Lynn Margulis and J. E. Lovelock, "Biological Regulation of the Earth's Atmosphere," *Icarus* 21 (1974): pp. 471–489; James Lovelock, *Gaia: A New Look at Life on Earth* (New York: Oxford University Press, 1974); Carl Sagan and George Mullen, "Earth and Mars: Evolution of Atmospheres and Surface Temperatures," *Science* 177 (7 July 1972): pp. 52–56.

39. Paul Ehrlich et al., *The Cold and the Dark: The World after Nuclear War* (New York: W. W. Norton, 1984); Lawrence Badash, "Nuclear Winter: Scientists in the Political Arena," *Physics in Perspective* (2001): pp. 76–105.

40. On the Marshall Institute's founding, see Robert Jastrow to Robert Walker, 1 December 1986, box 21 file "George C. Marshall Institute, accession 20001-01, William Aaron Nierenberg papers, Scripps Institution of Oceanography Archives, University of California–San Diego; Draft Proposal for the George C. Marshall Institute, sent to Bill Nierenberg, 12 December 1984, MC 13, William Aaron Nierenberg Papers box 75, folder 6, Scripps Institution of Oceanography Archives, University of California–San Diego.

came from the University of Iowa. Hansen considers his intellectual forebears to be the late James van Allen of Iowa and Jule Charney.[41] He began building GISS's climate modeling capabilities in mid-decade.

Hansen's climate model was one of two that formed the basis of the first declarative study by the National Academy of Science on the subject of global warming, the 1979 "Charney Report." In its preface, the University of Wisconsin's Verner Suomi stated that there was "no reason to doubt that climate changes will result and no reason to believe that these changes will be negligible."[42] Every study by the National Academy of Science since has ratified its conclusions, as has the Intergovernmental Panel on Climate Change in each of its three assessments of climate science since its foundation in 1988.[43]

Global warming is caused by human emissions of carbon dioxide, which exceed volcanic output by more than 150 times. Carbon dioxide is a chemical, of course, although one that is currently difficult to measure accurately from space. Sagan was the first to blame Venus's extremely hot climate on a surplus of this gas; Venus, American and Soviet robotic spacecraft found in the 1960s and 1970s, has about 300 times as much atmospheric carbon dioxide as Earth. And these facts bring us back to my claims about chemistry, climate, and NASA's role in fostering political controversy.

To be blunt about it: NASA has shown conclusively that humans cannot continue to change the chemistry of Earth's atmosphere without enormous, and negative, consequences. One of these consequences is ozone depletion, a cancer risk. The larger consequence is global warming. A 1983 National Academy study laid out some of the problems for the United States: much of the irrigated area of the southwest would have to be abandoned unless sufficient additional water could be imported. The highest forecasts of sea level rise would leave most of coastal America underwater unless defended by dikes of 15 to 20 feet (5 to 6 meters)—quite an expensive undertaking along several thousand miles of coast.[44] Further, this committee pointed out, "[I]ncreasing carbon dioxide is expected to produce changes in global mean temperature that, in both magnitude and rate of change, have few or no precedents in the Earth's recent history."[45] This had led much of the

41. Author interview with Hansen, January 2006; J. Hansen et al., "Climate Modeling in the Global Warming Debate," *General Circulation Model Development* (New York: Academic Press, 2000), pp. 127–164.

42. National Research Council, *Carbon Dioxide and Climate* (Washington, DC: National Academies Press, 1979), p. vii.

43. Naomi Oreskes, "The Scientific Consensus on Climate Change," *Science* (3 December 2004): 1686, DOI 10.1126/science.1103618; also see Oreskes, "The Scientific Consensus on Climate Change: How Do We Know We're Not Wrong?" in *Climate Change: What It Means for You, Your Children, and Your Grandchildren*, Joseph DiMento and Pamela Doughman, ed. (Cambridge, MA: MIT Press, 2007), forthcoming.

44. NRC, Carbon Dioxide and Climate, 1983, p. 46.

45. NRC, Carbon Dioxide and Climate, 1983, p. 51.

committee to a state of "unease," as they put it, because they could not assume that the effects would appear in a gradual, linear fashion.

Yet these facts are a direct affront to the belief system that dominates the American political right. Beginning with the popular work of famed economist Milton Friedman, the American right has adopted a worldview that equates economic freedom with political freedom.[46] Although this is historical fantasy—we have never been a free-market nation—this belief system forces its adherents to deny the reality of the scientific community's fact claims. True believers seek to protect their faith by denying inconvenient facts, and they believe that no scientific agency of our government has done more to undermine what George Soros has called "free market fundamentalism" than NASA has.[47] The accepted facts are that unregulated carbon dioxide emissions are the cause of global warming; solving the problem will require regulation of some kind. Such regulations would violate fundamental precepts of free-market theology, so the rightists have decided to reject the facts. Instead, they have formulated a convenient set of conspiracies. And, perhaps further reinforcing my point about "targeted media" above, a recent Pew Research Center for the People and the Press poll indicates that 43 percent of college-educated Republicans reject the fact of global warming, whereas only 25 percent of Democrats do.[48]

Hence, if one reads what's published in the rightist political literature mentioned above, one will find environmentalism equated with communism throughout the 1980s and 1990s, and with terrorism after 2001. One will also see scientists, including NASA scientists, derided as dupes and frauds for promoting "environmentalist nonsense." The "hidden agenda" of these scientists, in the words of one writer, is "against business, the free market, and the capitalistic system."[49] In the words of

46. Milton Friedman, *Capitalism and Freedom* (Chicago: University of Chicago Press, 1962). In his obituary of Friedman, economist Paul Krugman delineates carefully between Friedman's careful and meticulous academic work and his role as a public intellectual, promoting free markets with not entirely honest zeal. See Krugman, "Who Was Milton Friedman? *The New York Review of Books* 54/2 (15 February 2007).

47. George Soros, "The Capitalist Threat," *The Atlantic Monthly* 279 (February 1997): pp. 45–58; Myanna Lahsen has done signal work in digging up some of this material; see "Climate Rhetoric: Constructions of Climate Science in the Age of Environmentalism," Ph.D. dissertation, Rice University, 1998). The clearest expression of the belief that environmentalism is merely a plot to destroy capitalism I have found to date is in S. Fred Singer, "Global Warming: Do We Know Enough to Act?" in *Environmental Protection: Regulating for Results*, ed. Kenneth Chilton and Melinda Warren (Boulder, CO: Westview Press, 1991), pp. 29–50. My favorite exegesis of the behavior of fanatics is Eric Hoffer, *The True Believer: Thoughts on the Nature of Mass Movements* (New York: Harper and Row, 1951; Perennial Classic reprint, 2002), esp. pp. 79–80.

48. Pew Research Center for People and the Press, "Global Warming: A Divide on Causes and Solutions," 24 January 2007, *http://people-press.org/reports/display.php3?ReportID=303* (accessed 9 April 2007).

49. S. Fred Singer, "Global Warming: Do We Know Enough to Act?," p. 45. For a larger discussion of the political affiliations of the global warming denial effort see Lahsen, "Climate Rhetoric: Constructions of Climate Science in the Age of Environmentalism."

another, global warming is merely "a means of achieving an egalitarian society."[50] It is this literature that Senator James Inhofe (R-Oklahoma) and his colleagues draw on when they denounce global warming as "the greatest fraud ever perpetrated on the American people."[51] A new book from the Competitive Enterprise Institute puts it still more bluntly, calling them anti-American, anti-capitalist, and anti-human; to make clear their linkage to communism, they are "green on the outside, red to the core."[52] "Commies," as it were, in green makeup. To be clear, these political actors are not merely attacking leftist politicians. They attack practicing scientists for the results of their research—the very content of science. One journalist has labeled this assault "The Republican War on Science."[53]

One can argue, as physicist William Nierenberg did in the National Academy of Science's 1983 study of global warming, that the phenomenon is real and is likely to have severe consequences, but we don't need to do anything about it. Human civilizations have come and gone as climate changed around them; survivors simply migrate and rebuild elsewhere.[54] This is scientifically, and historically, entirely correct. One can argue about the ethics of such an approach—I would not subscribe to it—but it is correct and honest. One does not have to deny the legitimacy of a science to defend capitalists' right to pollute; in a pluralist, democratic society, one can simply accept Nierenberg's argument that we adapt to the new, warmer world. Yet this not the argument being made by the global warming deniers. Instead, they have chosen to demonize working scientists by applying the McCarthyite tactic of linking them to communism and accusing them of a global conspiracy.

This extreme reaction against climate science by the American right is not merely a quibble over interpretations of data. And it is not happening simply because ExxonMobil has spent millions of dollars a year supporting the denial industry.[55]

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50. Aaron Wildavsky, "Global Warming as a Means of Achieving an Egalitarian Society: An Introduction," in Robert C. Balling, *The Heated Debate: Greenhouse Predictions versus Climate Reality* (San Francisco: Pacific Research Institute for Public Policy, 1992), p. xv.

51. Inhofe's speech is available at *http://inhofe.senate.gov/pressreleases/climateupdate.htm* (accessed 10 July 2005); also see Chris C. Mooney, *The Republican War on Science* (New York: Basic Books, 2005), p. 78.

52. Christopher C. Horner, *The Politically Incorrect Guide to Global Warming* (and Environmentalism) (New York: Regnery Publishing, 2007).

53. Chris Mooney, *The Republican War on Science* (New York: Basic Books, 2005), esp. pp. 78–101. Mooney attributes this "war" to the business interests of the afflicted corporations and their ability to buy political protection, ignoring the ideological issues at the root of the conflict.

54. See Carbon Dioxide Assessment Committee, *Changing Climate* (Washington, DC: National Academies Press, 1983), pp. 48–55, 61–63; and physicist Alvin Weinberg's review, "Comments on NRC Draft Report of the Carbon Dioxide Assessment Committee," folder 7, box 86, William Aaron Nierenberg Collection, MC 13, Scripps Institution of Oceanography Archives, University of California–San Diego.

55. Union of Concerned Scientists, *Smoke, Mirrors and Hot Air: How ExxonMobil Uses Big Tobacco's Tactics to Manufacture Uncertainty on Climate Science* (Washington, DC: Union of Concerned Scientists, 2007), pp. 3–6.

It is a defense of a political ideology. Nothing else adequately explains the rightists' reaction to a half-century of scientific research.

I do not wish to make too much of NASA's role in the science of global warming. As Spencer Weart's recent history of global warming shows, there are many other threads to that story. But since the late 1970s, NASA funding for climate science has overwhelmed all other sources. It is by far the dominant funder of the current Climate Change Research Program, a fact in need of explication. Of the $1.86 billion dollars spent on climate science in fiscal year 2005, NASA spent $1.24 billion. The next largest funder, the National Science Foundation, spent $198 million that year.[56] NASA's interest in planetary climates stemming from the Mariner missions of the 1960s, and the seeming need for a global view of global warming, made its entry into this research field an obvious choice.

It's also true that these controversial fields were not originally as politically charged as they are now. During the 1970s, both American political parties accepted the reality of environmental damage and argued over policy details: the most efficient form of regulation, standards of evidence, how to determine when a sufficiency of evidence existed to base regulation upon. The modern anti-environmental movement—often it is called "pro-business" to disguise its true nature—started in the Western states at the same time and achieved its first national expression with Reagan's election.[57] When NASA officials decided to enter these fields, the technocratic impulse still ruled: once one understood the science, science-based regulation would follow. It made sense to them to try to lead in fields relevant to the agency's technological capacities. As technocratic managers, they also didn't expect that anti-environmentalism would wind up dominant 20 years later. The magnitude of the controversy they entered came as a surprise.

Inside the scientific community, the intersection of space science and Earth science also engendered controversy. Lovelock's Gaia hypothesis was widely criticized for its depiction of Earth as a self-regulating *organism*. In one paper he used a metaphor of a planetary engineer to describe how the integrated Earth system worked. This had obvious metaphysical implications that he later regretted. In short, he was attacked for Gaia's religious implications. But his view of planetary climate as a system of

56. Spencer Weart, *The Discovery of Global Warming* (Cambridge, MA: Harvard University Press, 2003); also see the expanded online edition at *http://www.aip.org/history/climate* (accessed 3 July 2006). Current funding for the Climate Change Science Program is given in CCSP-4Budget14Jan2006.pdf, available at *http://www.climatescience.gov/infosheets/factsheet4/default.htm* (accessed 12 September 2006).

57. On the anti-environmental policies of the Reagan administration, see Samuel P. Hays, *Beauty, Health and Permanence: Environmental Politics in the United States 1945–1985* (New York: Cambridge University Press, 1985), pp. 490–526; on the origin of anti-environmentalism in the West, see Hal K. Rothman, *The Greening of a Nation? Environmentalism since 1945* (San Diego: Harcourt Brace Publishers, 1998), pp. 169–181.

nested feedback-control systems involving what came in the 1980s to be called "biogeochemistry" was ultimately highly influential. In 1986, a group of scientists working under a NASA charter created a new, less offensive label for this integrated view of Earth, "Earth Systems Science." One can find textbooks bearing this name in university bookstores now and some universities have integrated their separate geology/geophysics/atmospheric/ocean science programs into a single department. The California Institute of Technology's integrated department is Earth and Planetary Sciences, while the University of California, Irvine called its program Earth System Science (it was organized and named by a former NASA scientist, Michael Prather). Earth sciences are in the midst of a sea change in organization and, I think, their intellectual structure, inspired by the availability of planetary-scale data.

Satellites seem to have disappeared from my narrative, so let me bring some back in. I have ignored solar physics and the tightly linked field of space weather. Our friendly local star's radiation and particulate output affects Earth's upper atmosphere, and solar radiation trapped by Earth's magnetic field does as well. These also affect satellites in Earth orbit and deep space probes. Because satellites have significant economic and military value, NASA, the DOD, and NOAA have all spent quite a bit of money over the last several decades on satellites and model studies aimed at understanding and predicting these effects. Scientists are also interested for the intrinsic scientific questions involved, of course—the motivation isn't solely utilitarian!

Three recent works discuss the evolution of solar science and space weather—the border between these two issues being, like space itself, rather tenuous. Karl Hufbauer's book *Exploring the Sun* focuses exclusively on the history of solar physics and the solar wind. He does not discuss their influence on Earth. Two other works make attempts at this. In *Storms from the Sun*, Michael Carlowicz and Ramon Lopez focus on the impact of solar eruptions on telecommunications and electrical power distribution networks. But their work is weak on the science and on the historical evolution of the field.[58]

A more useful treatment of the subject is Barbara Poppe's and Kristen P. Jorden's *Sentinels of the Sun*. Written largely from NOAA's perspective, this work focuses on the evolution of space weather forecasting with that agency. It gives the reader a good sense of the bureaucratic politics of the issue. Unfortunately, it is completely undocumented and, while it leaves the reader with the understanding that NASA and the Air Force have always been parallel actors in the field of space weather, it tells us little about their respective roles.[59] There is plenty of room left for new research in this area.

58. Karl Hufbauer, *Exploring the Sun: Solar Science since Galileo* (Baltimore, MD: Johns Hopkins University Press, 1991); Michael J. Carlowicz and Ramon E. Lopez, *Storms from the Sun: The Emerging Science of Space Weather* (Washington, DC: Joseph Henry Press, 2002).

59. Barbara Poppe and Kristen P. Jorden, *Sentinels of the Sun: Forecasting Space Weather* (Boulder, CO: Johnson Books, 2006).

The second type of satellite to discuss is oceanographic. NASA has flown satellite sensors aimed at both physical and biological oceanography. Neither type has been addressed in an historical study. The most significant of these has probably been TOPEX/Poseidon, a joint US-France mission that performed sea surface altimetry. Altimetry directly measures the height of the ocean surface; indirectly, it can tell us a great many other things about the oceans. Its most public outcomes have probably been in El Niño forecasting and in measuring sea level rise.

Scientifically, however, it may turn out to be revolutionary for its impact on ocean modeling. JPL and several other institutions are involved in a joint modeling effort aimed at transforming data from TOPEX/Poseidon and NOAA's Argo buoy network into a new, four-dimensional view of the world ocean. They are not done yet but, from what this group has published so far, they're building a radically new interpretation of how the ocean absorbs and distributes heat.[60] In turn, this will affect scientific understanding of how the geographic distribution of heat and precipitation will change under global warming.

The final type of satellite I will discuss is geodetic. These measure the shape of Earth and its gravity field. They were among the first kinds of scientific satellites flown, as they are very simple by their nature and militarily useful. Earth's gravity field is not perfectly spherical—it has "bumps" due to local concentrations of higher-density material within Earth—and the DOD wished to know where these were for more accurate targeting of nuclear missiles. Dwayne Day has published a set of articles on military geodetic satellites, the first historical studies on this subject.[61]

At NASA, the Goddard Space Flight Center has led the development of this technology until very recently. In collaboration with the DOD, NASA has flown a series of these satellites. These haven't been part of the Agency's "controversy portfolio," however, perhaps because most of the public has no idea what they do. But that's likely to change because the latest geodetic satellite, the JPL's GRACE mission, is accurate enough to produce mass estimates for ice sheets and aquifers. Recently, the mission scientists have pronounced that their data shows mass loss from both Greenland and Antarctic ice sheets, thus sticking themselves directly into

60. Carl Wunsch and Detelef Stammer, "Satellite Altimetry, the Marine Geoid, and the Oceanic General Circulation," *Annual Review of the Earth and Planetary Sciences* 26 (1998):219–253; D. Stammer et al., "The Global Ocean State during 1992–1997, Estimated from Ocean Observations and a General Circulation Model. Part III: Volume, Heat and Freshwater Transports," ECCO Report no. 6, 24 August 2001, *http://www.ecco-group.org* (accessed 1 July 2006).

61. Dwayne Day, "Mapping the Dark Side of the World, Part 1: The KH-5 ARGON Geodetic Satellite," *Spaceflight* 40/7 (July 1998): pp. 264–269; Dwayne A. Day, "Mapping the Dark Side of the World, Part 2: Secret Geodetic Programmes after ARGON," *Spaceflight* 40/8 (August 1998): pp. 303–310.

the climate wars.[62] There is a lot more historical work on the subject of geodetic satellites and their impacts on science, however. To date, very little examination or interpretation of this field has been done.

Space science, then—not merely Earth science but aspects of planetary science as well—has radically altered our beliefs about Earth and its processes. It has forced scientists, often against their own political preferences, to come to grips with the very uncomfortable notion that humans have become geological agents. We humans have the ability to change the basic conditions of life on Earth. The dominant belief from the nineteenth century—that humans were too puny to have any significant impact on Earth—can no longer be sustained in the face of NASA's research. This is the root of the political problems faced by Earth scientists in the 2000s.

Conclusion

Much of the historical literature on the Space Age to date has focused on human spaceflight. To borrow the analytical terminology of feminist history of science, this privileges the narrative of a handful of transient males—the professional space tourists we call astronauts—over that of most of the species. But the largest impacts of space technologies to nonastronaut humans have come from robotic spaceflight. These impacts have been positive and negative, economic, political, scientific, military, and ideological.

Unlike humans (to date, at any rate), robot spacecraft can be engineered to live in space, providing routine data for sometimes decades. They can also be sent to places inhospitable or deadly to humans. This has been the source of their success as scientific explorers, routine storm monitors, communications facilitators, and intelligence gatherers. It is also probably why they have virtually no place in the narrative of space history to date. As nonhumans, they're ignored. It's far easier to write a compelling heroic narrative about human actors than robotic ones, and space history has often been little more than advocacy written in heroic prose.[63]

62. I. Velicogna and J. Wahr, "Greenland Mass Balance from GRACE," *Geophysical Research Letters* 32/18 (30 September 2005); I. Velicogna and J. Wahr, "Measurements of Time-Variable Gravity Show Mass Loss in Antarctica" *Science* 311 (24 March 2006): pp. 1754–1756; J. L. Chen et al., "Antarctic Mass Rates from GRACE," *Geophysical Research Letters* 33 (9 June 2006). On geodesy more generally, see Paul D. Lowman, *Exploring space, Exploring Earth: New Understanding of the Earth from Space Research* (New York: Cambridge University Press, 2002). The title of this book is deceptive. It deals only with geodesy from space, ignoring all other fields of Earth remote sensing.

63. Roger D. Launius, "The Historical Dimension of Space Exploration: Reflections and Possibilities," *Space Policy* 16 (2000): pp. 23–38, esp. pp. 24–26.

But engineering is a human endeavor as well. As the above discussion should suggest, spacecraft engineering is wrapped up in the politics of science and government—both human enterprises. The New Space History, as Roger Launius has called it, has plenty of room in it for this narrative as well.[64] Precisely because there is so little already written, it's also a rich area for research.

64. Launius, "Historical Dimension of Space Exploration."