Data Crunching in the International Geophysical Year (1957-1958)

*Robert A. James**

The International Geophysical Year (IGY) was perhaps the greatest peacetime confluence of institutional, government and private initiative in history. It was a milestone in the development of synoptic science—advanced not over time in one individual's laboratory or even by a small community of scholars, but simultaneously across disciplines on a global scale. Scientists scored a host of achievements, including discovery of radiation belts beyond the Earth's atmosphere; compelling evidence for plate tectonics; and a sophisticated understanding of the past, present and future of Antarctica.

IGY by and large was proof of cooperation amid conflict. It was a political and social artifact of its times. Cold War tensions in 1957 were never far away. The United States (U.S.) and the Union of Soviet Socialist Republics (USSR) were the obvious adversaries in this climate, the rivalry most acutely showing in the deployment of satellites and their launches and transmission frequencies. There were other tensions, including zero-sum ultimatums hurled between the People's Republic of China on the mainland and the Republic of China on the island of Taiwan. Seven countries had staked territorial claims on the Antarctic, joined by others with interest in the allocation of resources there.

Despite the challenges, IGY was an oasis of optimism for humankind. It revealed that even during such periods of barely concealed strife, countries and scientists could work together for the advancement of learning.

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The era was a time in which data were generated on an unheard-of scale and scope. Individual pieces of information were recorded at thousands of points—from scientific installations and military sources to homemakers and children monitoring the progress of satellites across the sky. To be useful, that information needed to be transmitted, received, and gathered. Once the data were gathered, detailed operations needed to be performed on them. And the records needed to be preserved and made available to the scientific community. Exercises in cooperative science prior to IGY faced severe problems on all these counts, but IGY surmounted them.

There was often no time to process the data centrally for short-term purposes. For many of the investigations, calculations needed to be performed on live data and in real time. Data on satellites were coming in so fast that with every wobbly orbit, formulae needed to change. Mathematical operations had to be quickly performed to an acceptable tolerance aboard dogsleds, snowmobiles, balloons, and ships at sea, far from any mechanical or electrical device. How could numerous diverse points engage in sophisticated calculations, in an era before the widespread distribution of computers or similar resources? The IGY field participants in 1957 employed tools that would have been familiar centuries earlier—slide rules, logarithm and trigonometry tables, nautical almanacs, theodolites, and astrolabes.

The purpose of this article is to summarize selected aspects of IGY, and along the way to examine both the manner in which data were gathered and preserved and the innovative means by which the numbers were crunched in a live and often hostile environment. It is hoped that the cooperative spirit of IGY, and the parties' resourcefulness in harnessing and managing sudden influxes of big data, are instructive for how we structure international cooperation tomorrow.

A. The Road to IGY.

Thinkers have long dreamed of cooperative scientific engagements. Francis Bacon spoke of "experiments in concert," in which observers at multiple points would make observations free of any preconceptions and report the outcomes to see if what apparently were unrelated phenomena in fact were connected. French thinkers including Laplace, Lavoisier and Lamarck advocated the accumulation of weather data across the country, and the practice spread to Europe as a whole. On the high seas, United States, Navy Commander Matthew Maury throughout his career championed the collection of maritime weather data. International observations were correlated on the 1761 and 1769 transits of Venus across the sun. Alexander von Humboldt studied the varying magnetic orientation of the Earth and identified brief global disruptions he termed "magnetic storms." [1]

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[1] The best single reference work on the IGY and its antecedents is Walter Sullivan, *Assault on the Unknown: The International Geophysical Year* (1961).

The idea of cooperative science in particular disciplines was thus in front of the scientific community. The great leaps forward in rapid communications, including steam-powered vessels and especially telegraphy and radiotelegraphy, provided the means for an expansion and formalization of the concept.

In the 1870s, Karl Weyprecht, an Austrian scientist, proposed the first International Polar Year; IPY-1 was held 1882-83, the delay owing to a Russo-Turkish war. Weyprecht and scholars at Göttingen University conceived rings of stations around the Arctic and Antarctic Circles measuring auroras in the skies and polar ice at sea to identify commonality and distinctions in the phenomena. IPY-1 was marred by disaster on ice-blocked Lady Franklin Bay on Canada's Ellesmere Island, where nearly twenty U.S. personnel lost their lives. Despite the tragedy, magnetic studies during IPY-1 helped to debug the undersea cables across the Atlantic and from England to India. Twenty volumes of data were published and proved useful over the years. Those books would not fill even a single shelf of a research library, and could hardly be called big data.

The second International Polar Year (IPY-2) was held 1932-33. The date was remarkable as the fiftieth anniversary of the first endeavor, but otherwise was ill chosen, since it occurred during the global Great Depression, limiting funding, and since the year featured an absence of enhanced solar activity. While IPY-1 was confined to sea-level observations, IPY-2 employed balloons that rose some six miles above the Earth's surface.

It was well known that Marconi's radio waves in the high frequency range (below the U.S. AM band) reflected off the ionosphere sixty miles up, bouncing back-and-forth with the Earth's surface to reach distant places. Short-wave radio waves at higher frequencies clearly penetrated that ionosphere layer, but still bounced to facilitate long-distance communication. How could this be? IPY-2 revealed or solidified the evidence for the delineation of multiple ion layers, against which waves of different frequencies could bounce. That advance enriched global telecommunications.

Soon after IPY-2, the world plunged into conflict, preventing collective exploitation of the discoveries. Much of the data resided with solitary sources in either the Allied Powers or the Axis Powers. Access to the information was largely suspended, and stacks of data were lost altogether as a result of World War II.

The stage was set postwar for a third try. In April 1950, famed British geophysicist Sydney Chapman, who had made use of IPY-1 data in his research, traveled to the U.S. for a conference and was invited to a dinner with American Lloyd V. Berkner and other geophysicists at the Silver Spring, Maryland suburban home of radiation researcher James Van Allen.[2] In the course of this dinner, two reasons were offered to support 1957-58 as an auspicious time for global research: it was a tidy 25 years after IPY-2, and it opened a period of elevated sunspot activity, generating large yet variable impacts that would influence phenomena in a relatively compressed period of time.[3] The attendees started to muster the concept of a Third Polar Year (IPY-3).

B. The Launch of IGY.

The IPY-3 proposal had to run a daunting gauntlet of approvals through scientific societies, some of which had been dispersed or reorganized in the postwar and Cold War environment. I will not unpack the acronyms, but suffice it to record that the proposal went through IUCG, IAU, URSI, IGU and IUPAP. It finally arrived at the doorstep of the International Congress of Scientific Unions (ICSU, pronounced to rhyme with "fix you"). ICSU referred the matter to yet another committee, JCI, and in 1951 ICSU recommended the launch of IPY-3.[4]

By 1952, the ambitions of the geophysicists were running far beyond the polar regions. As a result, the period was renamed the International Geophysical Year or IGY. The curious duration of the "year," July 1, 1957 through December 31, 1958, captured more of the solar activity. The period was extended again, into 1959 and later into 1960. Recognizing that the term "year" was stretched beyond recognition, the entire undertaking was redubbed the period of "International Geophysical Cooperation."

An ICSU committee was formed in 1953 to steer the activity, with the ungainly acronym CSAGI (Comité Speciale de l'Année Géophysique Internationale). Chapman was president, Berkner the vice president, and the Belgian Marcel Nicolet the Secretary-General. The world headquarters of CSAGI was nothing more than Nicolet's office in the suburb of Uccles on the outskirts of Brussels.

The arduous process began of engaging societies, governments, and funding sources. The USSR was at first wary of consorting with the West. Although Andrei Zhdanov had died in 1948, the spirit of his insistence on separate or "chauvinist" Soviet science remained strong. Geophysicist Valery Beloussov was chastised for citing more Western than Russian research in his papers. Czechoslovakia and Yugoslavia

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[2] See Fae L. Korsmo, *The Birth of the IGY,* Leading Edge (2007); Sullivan. No mention of this party in the IGY literature is complete without mentioning Abigail Van Allen's chocolate layer cake, said to be the catalyst for the inspired after-dinner conversation.
[3] Sunspot intensity varies on an approximately 11-year cycle. It has been correlated with crop growth, meningitis outbreaks, wine vintage quality, and even rabbit and salmon breeding.
[4] See International Astronautical Federation, *International Geophysical Year: Initiating International Scientific Space Cooperation* (2012).

nonetheless joined the IGY effort early on. The death of Stalin in 1953 led to a rapprochement and the USSR entered in 1954, with Beloussov himself joining CSAGI along with Jean Coulomb of France.[5]

Eventually 67 countries answered the call, with about 60,000 scientists and countless civilians engaged in the effort.[6] The major national contretemps in the formation of the IGY involved the Chinese. The Republic of China (Taiwan) was invited to join but did not respond for four years. The People's Republic of China offered to participate, expressly conditioned on the Taiwanese not participating. At this point Taiwan lurched into action and asserted its dormant interest. To make a long story short, mainland China sat out the IGY itself—though it engaged in a great deal of research that was ultimately shared. CSAGI was disappointed, as the mainland Chinese efforts were far better supported, but no one appears to have had the stomach to endure extended diplomatic battles.

The organizations participating in IGY were supported by grants from national organizations, such as the National Science Foundation in the United States, and by the United Nations. The UN Educational, Scientific and Cultural Organization (UNESCO) used the opportunity to tout global cooperation well beyond geophysics.

IGY was ushered in with audacious promises of human capabilities and brotherhood. It was "History's greatest science research project." "A new age [has been] opened." It was "the single most significant peaceful activity of mankind since the Renaissance and the Copernican Revolution." UNESCO exuded, "For the first time the peoples of the Earth have joined to study their common and fundamental scientific problems together."[7]

The year's distinctive hexagonal emblem attempted to capture many of the research interests. A hypothetical single new satellite encircled the planet. The globe was oriented toward the south pole and ocean to showcase the focuses on Antarctica and

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[5] See Rip Bulkeley, *Aspects of the Soviet IGY,* 10 Russian Journal of Earth Sciences ES1003 (2008).

[6] See Christy Collis & Klaus Dodds, *Assault on the Unknown: The Historical and Political Geographies of the International Geophysical Year* (1957-8), 34 Journal of Historical Geography 555 (2008).

[7] See UNESCO Courier, *International Geophysical Year* (September 1957); Werner Buedeler, *The International Geophysical Year,* UNESCO (1957); Hugh Odishaw, *Science Explores Our World: An IGY Report for Students* (1959); Mark O'Connell, *The Year Science Changed Everything: 1957's International Geophysical Year and the Future of Our Planet* ix (2025).

the deep blue sea. Creatively, even the terminator line between night and day highlighted the interest in solar activities of all types.[8]

C. IGY and Popular Culture.

Before getting into the science of IGY, it is entertaining to survey the popular culture aspects. Why not start with the funny papers?

Walt Kelly's popular comic strip *Pogo* had great fun satirizing the scientists as representative of the folly of mankind. In his panels, collected in a work called *G.O. Fizzicle Pogo* (1958), Kelly's sardonic swamp critters (including the eponymous possum, an alligator, an owl, and a cockroach) started by ridiculing the humans' definition of an eighteen-month "year." The animals discussed their desire to shoot men to the moon (without any plan to bring them back), and darkly joked about nuclear war and the advancement opportunities such an apocalypse would present for the cockroaches.

IGY was covered in several popular books, magazines, and articles, including *My Weekly Reader,* a publication distributed to schoolchildren across the United States. The National Academy of Sciences provided more classroom materials in *Planet Earth: The Mystery with 100,000 Clues,* along with six colorful posters with learned quotations about the oceans, the sky, and the sun. At the conclusion of IGY, *Life* magazine ran four issues reporting on its outcomes. Of particular interest is a November 7, 1960 map of the seafloors, clearly showing the newly mapped mid-ocean ridges that would help establish plate tectonics.[9]

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[8] See Roger D. Launius, James Rodger Fleming & David H. DeVorkin, *Globalizing Polar Science: Reconsidering the International Polar and Geophysical Years* (2010).
[9] Other introductions include Sydney Chapman, *IGY: Year of Discovery* (1959), and the gasoline service station handout of Esso and Mobil, *The Story of IGY: IGY and the Earth Satellites* (1958).

IGY was a philatelist's dream. Almost all the participating countries issued postage stamps, either commemorating the overall global initiative or parochially taking pride on the achievements of their respective side. Sputnik and Explorer satellites thus graced many of these issues. The stamps along with their first day covers now flood eBay searches when one looks for materials of any type relating to IGY.[10]

Walt Disney was already under way in the mid-1950s with Wernher von Braun - narrated documentaries on space travel and rockets, and the beginnings of Tomorrowland at the original Disneyland. IGY proved an accelerant. The 1964 New York World 's Fair channeled the achievements and spirit of the era, as did the evolution of Tomorrowland across all the Disney resorts. Donald Fagen, the songwriter behind Steely Dan who grew up in New Jersey reading *My Weekly Reader*, wrote the song "I.G.Y." (released in 1982). Its lyrics paint a future—"What a beautiful world this will be/What a glorious time to be free"—run by "A just machine to make big decisions/Programmed by fellows with compassion and vision." [11]

D. Prioritizing IGY Research.

Back to the science of IGY. The six-mile altitude of the IPY-2 weather balloons was impressive then, but only attained the equivalent of the width of a heavy coat of paint on a basketball-sized Earth. In contrast, IGY would receive data from one hundred miles or more above the Earth, via balloons and satellites.

CSAGI prioritized synoptic observations and experiments, conducted simultaneously and evaluated in real time. Leaders focused on activities that would benefit the most from scientists studying the same transient phenomenon at the

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[10] See Don Hilger & Garry Toth, *A Philatelic Look at IGY and the Dawn of the Space Age,* Astrophile (July/August 2007),

[11] Steely Dan Database, lyrics of "I.G.Y." available at http://www.steelydan.nl:80/lyrics/IGY.txt.

same time but in separate places or conditions. An example was global meteorology, as opposed to local historical geology. An associated priority, thanks to the advanced funding and widespread participation, was to “access the inaccessible”—to plumb at long last the mysteries of Antarctica and the deep ocean.

The era was also a propitious time to establish baselines for more slowly moving phenomena. A Caltech postdoctoral student named Charles David Keeling had begun measuring atmospheric carbon dioxide concentrations in 1956. He was described as “a fanatic who does only one thing” and is “never wrong.”[12] His work took off with the accumulation of IGY data. That evolved into the famous Keeling curve, with the Northern Hemisphere winter-summer sawtooth and steady upward incline evidencing the ominous increase in greenhouse gases.

Industrial CO2 emission and its contribution to warming were well understood at the time. Ronald Fraser wrote in 1958, “Mankind is quite unwittingly altering the overall climate of the earth, by spewing CO2 into the atmosphere.”[13] It was incorrectly thought that the CO2 was overwhelmingly absorbed by the oceans instead of remaining in the atmosphere (at a 50-to-one ratio). We now know the oceans carry less of that load, so more CO2 remains in the sky to contribute to climate change.

To avoid the IPY-2 data problems, with critical data being held only in a single potentially partisan country in wartime, the principle of dispersed data storage and free data exchange was fixed in 1957. Three World Data Centers were created. Center A was the United States, distributed among widespread organizations; Center B was the USSR, split between Moscow and an eastern location; and Center C was scattered across Europe and Japan. Weather data were accumulated in the World Meteorological Organization in Geneva.

CSAGI had fourteen Divisions, each anchored by a Reporter. They consisted of world days (concentrated opportunities to gather and report data); rockets and satellites; solar activity; aurora and airglow; cosmic rays; geomagnetism; glaciology; gravity; ionospheric physics; longitude and latitude determination; meteorology; oceanography; psychology; and nuclear radiation. The geographic focuses of IGY were largely on Antarctica, as the new object of interest, and on the open ocean. Interest also extended to outer space, the Arctic, the Equator, and three selected meridians running through populated continents.

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[12] O’Connell 130.

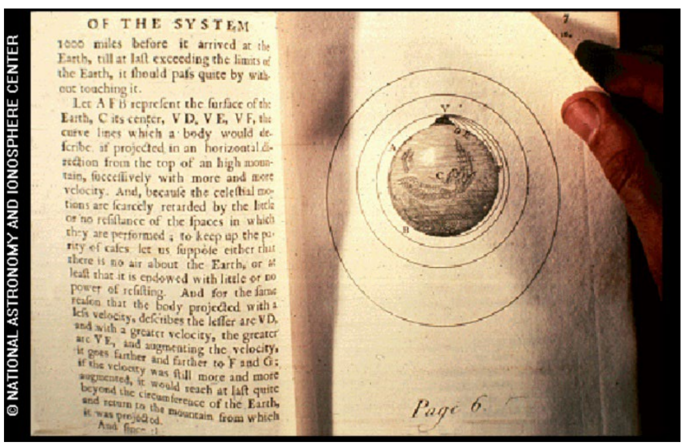
[13] Ronald Fraser, *Once Round the Sun: The Story of the International Geophysical Year* (1958); Sullivan 240. The CO2 molecule absorbs infrared radiation at 4.3 and 15 micrometer wavelengths, preventing energy reflected from Earth from returning to space. In modest doses it makes the Earth inhabitable, but in larger concentrations it modifies the global climate to our overall detriment.

Of the fourteen Divisions and their subsidiary investigations, this article will focus on the fields in which I found information about the gathering of data and the performance of calculations *in extremis*. Accordingly, the discussion concentrates on satellites, the ionosphere, and the Antarctic.

E. Satellites.

It is no hyperbole to say that the postwar world changed at 1928 hours Zulu or universal time (GMT) on October 4, 1957. [14] It was at that moment that *Sputnik 1* detached from its third rocket stage and began transmitting a steady beep at frequencies of 20.005 MHz and 40.002 MHz.

The idea of an "endlessly falling object" had been known at least since the publication of Sir Isaac Newton's posthumous papers, including the engraving of his famous "cannonball" thought-experiment. Newton could not fulfill his dream as he lacked means of achieving the altitude and velocity needed for an object to orbit the globe. That step had to await the developments in rocketry advanced in the late 1800s and early 1900s by Tsiolkovsky, Goddard and Oberth.



Launch vehicles entered a new phase with the German rocket facility at Peenemunde, where were deployed the V-1 and V-2 guided ballistic missiles (the *V* standing for "vengeance"). Oberth's protégé Wernher von Braun was the architect of this program which rained some 3600 V-2s down on London and Antwerp toward the end of the war. In the U.S. Operation Paperclip, about 70 V-2s and 120

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[14] See Paul Dickson, *Sputnik: The Shock of the Century* (2001); Asif A. Siddiqi, *Sputnik and the Soviet Space Challenge* (2003); Homer E. Newell, Jr. & J.W. Townsend, Jr., *IGY Conference in Moscow,* Science 129 (Jan. 9, 1959) 79; Homer H. Hickam, Jr., *Rocket Boys* (1998).

scientists were patriated stateside. The USSR secured the facility itself and some technicians, but not the scientists or the rockets. This asymmetry was thought at the time to put the Soviets years behind the Americans—a comforting belief that perhaps contributed to U.S. complacency.

Both the U.S. and the USSR were known to be active in rocketry research since the 1940s. Twin public statements about their efforts were made in 1955. The Soviets commented vaguely that they were making significant progress, although details were not forthcoming and the comments garnered little press coverage. In contrast, a July announcement of upcoming U.S. efforts was widely reported. The Americans seemed very sure of their superiority, even though the Russians signaled they were getting close. It is no surprise that *Sputnik 1* came to the U.S. public as a surprise.

In the summer of 1957, a Russian amateur radio magazine asked ham operators to get ready to listen for a satellite, and to report signal strength by cable to MOSKVA-SPUTNIK (*sputnik* meaning something akin to "fellow traveler"). This periodical was available in the West, but apparently no heed was paid. The Soviets breached protocol by withholding scientific details on the flights, in particular not disclosing the date of upcoming launches. The Soviet scientists justified their silence (obviously directed by the Kremlin) by saying they wished to avoid "boasting." It turns out the USSR had its share of launchpad disasters; only theirs were kept secret, while the American failures happened in broad daylight directly visible by thousands and broadcast on television.

The U.S. was riven by dilemmas both internal and external on the development of a space program. On the external side, President Dwight Eisenhower was concerned that space not become a field for warfare. He did not want to start a space race, and he was troubled by the idea of the various militaries of the world taking charge of such endeavors.

On the internal side, each of the U.S. armed forces had its own ballistics program and was touting its own version. The Army had von Braun and the Jupiter-C (a modified Redstone inter-regional ballistic missile (IRBM)) that might fairly or unfairly be described as the "V-3." The Air Force had its longer-range Atlas intercontinental ballistic missile (ICBM), also a purely military device. In contrast, the Naval Research Laboratory was planning a Vanguard satellite that would be used to gauge ocean depths and polar conditions, ostensibly matters of science. The same research would help to establish clear paths for submarine and war vessels, but at least the Navy program had the advantage of having a dual-use civilian purpose.

Ultimately, the decision was made to let the Navy go first. Unfortunately, the Vanguard was to be launched by the Viking rocket, a problematic contraption to be sure. The rocket cylinder was only 47 inches in diameter, with no stabilizing fins, so there was little room for error in launch. Its three stages were manufactured by three different vendors. Despite being given the green light at the outset of 1957, Viking and Vanguard fell back into the armed service pack on actual successful launches.

The October 4, 1957 launch of *Sputnik 1* appears to have caught flat-footed not only Western journalists but perhaps some of the Western military as well. Inter-service rivalries inhibited exchange of information about each branch's programs. Eisenhower tried to simply congratulate the Soviets and move on with the American program, but the public could not be so easily appeased.


FINAL

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SIGHT RED BABY MOON OVER U.S.

Cambridge, Mass., Oct. 4 (UP).—The Russian satellite was seen for the first time in the U. S. tonight at Columbus, Ohio, where Larry Ochs, manning a Moonwatch observation station, reported sighting a steady light that crossed his telescope. It definitely was not a meteor, he said.

Ochs, stationed at one of the 150 Moonwatch observatories set up throughout the world, told the Smithsonian Astrophysical Observatory here that he first noticed the light at 11:28 P. M. It was traveling from west to east. Ninety-five minutes later it was sighted again.

Also Seen in Indiana

At Terre Haute, Ind., farther west, another watcher, Nunz Addabbo, reported sighting the satellite at approximately the same time.

Meanwhile, American scientists disagreed on whether the satellite, which circles the globe every 95 minutes will be visible in the U. S. to the casual observer, but all agreed that if it is, the best viewing time will be at dawn and dusk.

Dr. Fred L. Whipple, director of the Smithsonian observatory, said Americans might be able to see the satellite at twilight hours, but Prof. W. J. Luyten of the University of Minnesota said viewing the sphere would be "extremely difficult if not impossible."

Astronomer J. Allen Hynek and his staff prepared to receive at the Smithsonian observatory reports from the specially equipped observation points around the world.

More than 40 Operation Moonwatch observatories west of the Mississippi River were activated first because they were the nearest U. S. stations in the band of twilight.

If the moon is in a north-south orbit—as the Russians once said they planned—it will pass over various points in the U. S. because the earth will be rotating under the satellite from west to east.

Moscow Moon—around the world in 95 minutes

Other stories of the Soviet moon on pages 3 and 4; pictures of U. S. satellite progress on page 34.

Citizens tended to believe such an achievement by the Russians could only have been accomplished via espionage (as with the atomic bomb), and worried that World War III could begin by a satellite dropping nuclear weapons from overhead. Soviet Premier Nikita Khrushchev took full public-relations advantage of the launch to tout the virtues of socialist science, promising underdeveloped countries that they were better off to be aligned with advanced Soviet technology than with the decadent and backward West. [15]

People the world over listened to the transmission from *Sputnik 1* as it crossed the sky. The 22-pound object orbited at 18,000 miles per hour at an angle of 65° to the equatorial plane, swerving from Fairbanks, Alaska, to below Cape Horn every 95 minutes. The 20 and 40 MHz frequencies were adjacent to commercial or amateur

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[15] See Walter A. McDougall, …*The Heavens and The Earth: A Political History of the Space Age* (1985).

radio bands, so that the beeps could be heard by citizens, not just scientists. At the time, CSAGI had set 108 MHz as the satellite transmission frequency, and receiving stations had been specifically constructed for that specification. The expensive stations sat unused while the Russian satellite transmitted to the public. This in itself was a scandal ("Russians Tricked U.S. Scientists on Megacycle Band," blared the headline in the *Washington Evening Star*).[16]

Some people thought they spotted *Sputnik 1* racing across the heavens, but they were probably seeing the much larger third stage of its launch rocket. Other listeners imagined the beeps were transmitting secret code, but the pulse had no purpose other than to signal its presence and perhaps something about its temperature.

As Americans were reeling from *Sputnik 1*, a month later on November 3 they saw the launch of *Sputnik 2*, which even packed aboard a passenger, a dog named Laika. That was it for 1957. Launched in 1958, *Sputnik 3* had the weight of a small sports car, much larger than the "grapefruits" launched by the Americans.[17]

The U.S. lurched into action with an immediate order to launch Viking and Vanguard. There were spectacular failures in December 1957 and again in February 1958. Khrushchev gleefully called it "Rearguard," while Germans dubbed it *Spätnik* (the "tardy" satellite). *Vanguard 1* finally launched in March 1958 and, defying the naysayers, remarkably is still going strong—unique among the IGY satellites. Still, only three out of the eleven Viking launches were successful.

Meanwhile, the Army stepped in with von Braun's Jupiter-C and successfully launched *Explorer 1* in January 1958. Significantly, this launch was the first to do actual science. The Explorer had Van Allen's Geiger tube apparatus on board, and detected a radiation belt some 2500 miles above the Earth's surface. *Explorer 3* confirmed the result. U.S. Pioneer space probes, along with Russian probes, detected the outer Van Allen belt a short while later.

What about data crunching? Ingenious methods were used to cope with the lack of information provided by the USSR. Westerners were able, from the velocity of the satellite and third stage and the assumed air resistance, to calculate that stage's laden weight as 2690 kilograms.

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[16] See Veronica della Doza, *From the Radio Shack to the Cosmos: Listening to Sputnik During the International Geophysical Year (1957-1958),* 114 History of Science 123 (2023); Siddiqi, *Korolev, Sputnik and the IGY,* NASA History (February 2, 2005).
[17] See Sullivan.

When *Sputnik 1* started to fall from orbit, its path left a trail of increased ionization. The briefly thicker ion layer increased the strength of terrestrial transmissions such as that from WWV, the National Bureau of Standards (now NIST) radio station broadcasting frequency and time from Fort Collins, Colorado. Ohio State University professor John D. Krause was able to calculate the time of *Sputnik 1's* disintegration from the change in WWV signal strength. Krause detected multiple changes in the signal, suggesting that the stage broke into several parts as it descended.[18]

Computers were remote from observation locales, in any event were slow, and with the data input conditions of the time could not have handled the need for rapid evaluation. The orbits of the IGY satellites were increasingly irregular, so the calculations as to the time and place of its reappearance on every orbit needed to be recalibrated at least weekly, often daily, and sometimes on each revolution.

For this purpose, a Cold War-era program (the Ground Observer Corps established to spot Soviet bombers) was repurposed by Fred Whipple of the Smithsonian and Harvard into Operation Moonwatch. This was especially critical when the Sputniks transmitted at 20 and 40 MHz (though some hams at those fancy new stations must have tuned in with their personal equipment). Thousands of amateur observers (including "housewives and children"), equipped with simple 12-inch telescopes, were teamed up to track the approach and passing of the satellite, noting the location and apparent speed. They used ink or pencil to fill in "mark sure" cards readable by a primitive optical scanner at Cornell University.[19]

For the more professional calculations, complex tables were commissioned to integrate the data. The variables included time, longitude, current altitude, azimuth, observer elevations, and observer slant range. This information was not easily digestible in real time, so "close enough" calculations needed to be made. In 1957, as it had been for centuries, the basic instrument of "close enough" was the slide rule.

Simple guides were given for converting the Babylonian system of degrees and minutes and seconds to decimal parts of a degree of latitude or longitude. Then the operations could be performed to "close enough" tolerance:

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[18] See Sullivan 73; Leonard N. Cornier, Norton Goodwin & Reginald K. Squires, *Simplified Satellite Prediction from Modified Orbital Elements,* IGY Satellite Report series, No. 7 (1 January 1959).
[19] See O 'Connell 107; W. Patrick McRae, *Keep Watching the Skies! The Story of Operation Moonwatch and the Dawn of the Space Age* (2008).

> Where a desk calculator is not available, the long divisions indicated in schedule B and in schedule C item 4 can be reduced to slide rule problems of sufficient accuracy. [20]

An interesting artifact is a slide rule constructed for calculations based on a single wavelength. The "minitrack ambiguity resolver" was a circular slide rule premised on 136 MHz. In other words, it took what normally is a variable, frequency, and converted it to a constant—so that one fewer remaining variable could be input and results quickly generated. By the time of this rule, CSAGI's desired frequency for satellite communications had changed from 108 MHz. If it ever changed again from 136 MHz to a different figure, one would toss this slide rule aside and get a new slide rule based on the *new* constant frequency. [21]

[20] Cornier et al., Appendix 3.
[21] See Goddard Space Flight Center, *Final Report for Minitrack Tracking Function Description* (1973). It is reminiscent of the composer Giacomo Rossini, who composed an operatic aria for a singer with a voice so horrible that only one note was tolerable. The melody is that single note, repeatedly endlessly, while the orchestra runs through harmonies and chord changes behind her.

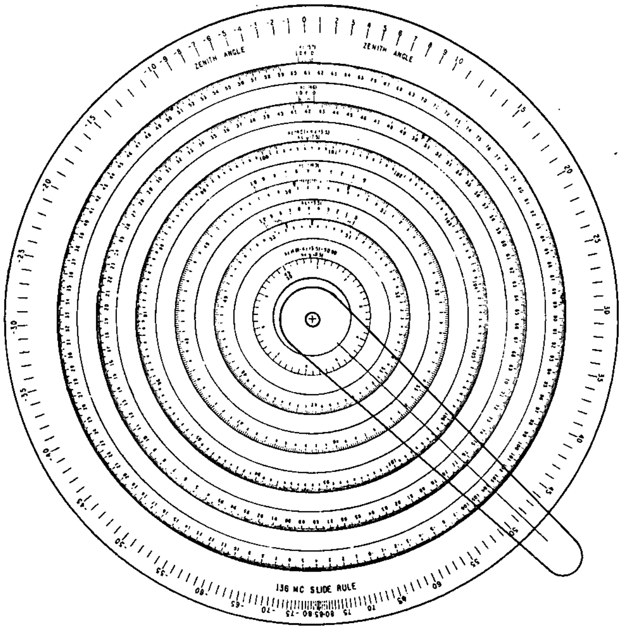

Figure 2-14.—Minitrack ambiguity resolver: 136-MHz circular slide rule.

RESETTING INSTRUCTIONS

NORTH—SOUTH

A. Lay cursor arm hairline along 0.5 on the drift scales.

B. Rotate 57 λ equatorial scale until NSF(E) K_c from new calibration lies under hairline. Mark an NS arrow on equatorial scale pointing to new NSF(E) K_{s1} on equatorial drift scale.

C. Repeat Step B for the 46 λ polar scale using new NSF(P) K_c and K_{s1}, the 4.0 λ ambiguity scale using new NSM K_c and K_{s1}, and the 3.5 λ ambiguity scale using new NSC K_c and K_{s1}.

EAST—WEST

Repeat Steps A, B, and C, using EWF(E), EWF(P), EWM, and EWC K_c's and K_{s1}'s.

AMBIGUITY RESOLUTION

NORTH—SOUTH

SETUP:

A. Rotate the 57 λ, 46 λ, 4.0 λ, and 3.5 λ annular rings until the NS arrow on each ring points to current K_{s2} value on corresponding drift scale.

B. Read $K_c(4.0)$ value below arrow on 4.0 λ ring. Add 50.00 to this value. Read $K_c(3.5)$ value below arrow on 3.5 λ ring. Subtract $K_c(3.5)$ from $K_c(4.0)$ + 50.00 to compute $K_c(0.5) = K_c(4.0) - K_c(3.5) + 50.00$. Rotate 0.5 λ ring so computed $K_c(0.5)$ lies under $K_c(0.5)$ arrow.

C. Use above values of $K_c(4.0)$ and $K_c(3.5)$ to compute $K_c(7.5) = K_c(4.0) + K_c(3.5)$. Rotate 7.5 λ ring until computed $K_c(7.5)$ lies under $K_c(7.5)$ arrow.

OPERATION:

A. Using outermost scale, rotate cursor arm to zenith angle given in prediction. Hairline on cursor arm should now be near proper 3.5 λ baseline and 4.0 λ baseline Minitrack NS readings on 3.5 λ and 4.0 λ rings.

If no prediction is given, take the 4.0 λ baseline Minitrack NS reading as 00.XXX and add 50.000 to this. Then subtract from this sum the 3.5 λ baseline Minitrack NS reading as 00.YYY to obtain the hypothetical 0.5 λ baseline Minitrack NS reading as 49.ZZZ or 50.ZZZ = (50.XXX − 00.YYY). When the hairline is rotated to this computed value on the 0.5 λ ring, it should then be near the proper 3.5 λ baseline and 4.0 λ baseline Minitrack NS readings on the 3.5 λ and 4.0 λ rings.

B. Adjust hairline to fall halfway between proper 3.5 λ and 4.0 λ ring readings. This step is the mechanical analog of mathematically adding the 3.5 λ baseline Minitrack reading to the 4.0 λ baseline Minitrack reading to obtain the proper reading for the hypothetical 7.5 λ baseline. Both techniques should give the same 7.5 λ baseline reading to which the hairline should be adjusted.

C. The hairline should now be adjusted to the nearest 46 λ or 57 λ ring reading having the same value as the corresponding Minitrack 46 λ or 57 λ baseline NS reading. The correct lobe number for this reading may now be read directly off the proper ring scale.

EAST—WEST

Repeat above using EW readings and arrows.

Figure 2-15.—Ambiguity resolver instructions printed on rear of slide rule.

on-the-spot correlations with satellite prediction data that may be at hand. A reduced illustration of the slide rule and a reproduction of the instructions printed on its reverse side are shown in figures 2-14 and 2-15, respectively.

By the end of 1961, the "satellite score" was the U.S. over the USSR, by 31 goals to 7. That would seem like a vindication of the American program, but the early psychological damage of 1957 was done in terms of resetting expectations as to Russian capabilities. The American recriminations are legion. To begin with, schools began to double science and math homework, fearing a science gap with Russian education. As one boy quipped, "It was then and there that I began to hate communism."[22]

The Soviets would not share data on their booster vehicles, considered to be military secrets. As Ronald Fraser wrote, "About every scientific discovery is a two-edged sword, and you can't blame it on God if man insists on honing the wrong edge."[23] A civilian agency named the National Advisory Council for Aeronautics (NACA) stepped into management of the U.S. space program, soon to become the National Aeronautics and Space Administration (NASA).

F. The Ionosphere.

The first-discovered ion layer, which reflected Marconi's high frequency (HF) radio waves, is called the D layer. The regions identified in IPY-2 are called the E, F1, and F2 layers, which reflect higher frequencies up to about 100 MHz, at which point transmissions pass into space without the benefit of a bounce. "Seven veils" encircle the Earth, being those four ionosphere layers, the two Van Allen belts, and the ozone layer.

The Argus Project is a curious episode in the atmospheric studies. Apparently without irony, *New York Times* reporter Walter Sullivan summarized Argus as asking the question "Why not fire a hydrogen bomb in space and see what its effect would be on the Van Allen radiation belt?"[24] Why not? This seems to modern ears a question that should have never been asked. Instead, the U.S. indeed triggered not one but three small thermonuclear explosions over the South Atlantic Ocean. An ionospheric sponder measured layers from the rebound of the shockwaves.[25]

More conventionally, combination balloons and rockets—uncreatively named "rockoons"—were elevated to a defined altitude. They then released "grenades." These grenades had a minimum of shrapnel, being absolutely safe from only five feet away, but a maximum of a sharp, crisp sound. This is where calculation in remote places came in.

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[22] See Dickson.
[23] Fraser 145.
[24] Sulivan 136.
[25] See Tuzo Wilson, *IGY: The Year of the New Moons* (1961) 122.

Observers were relayed the starting conditions—a known time of explosion and a known altitude and location. From the time that it took that sound to travel to different points on Earth, the observer could calculate the speed of sound through the air and the mean temperature of the air the sound passed through. A chart was used to demonstrate the relationship.[26]

Air-Speed of Sound vs. Temperature and Relative Humidity									
Temperature *(°C)*	Speed of Sound *(m/s)*								
	Relative Humidity *(%)*								
	10	20	30	40	50	60	70	80	90
0	331.5	331.5	331.5	331.6	331.6	331.6	331.7	331.7	331.7
5	334.5	334.6	334.6	334.7	334.7	334.7	334.8	334.8	334.9
10	337.5	337.6	337.7	337.7	337.8	337.9	337.9	338.0	338.0
15	340.5	340.6	340.7	340.8	340.9	341.0	341.1	341.2	341.2
20	343.5	343.6	343.7	343.9	344.0	344.1	344.2	344.4	344.5
25	346.4	346.6	346.8	347.0	347.1	347.3	347.5	347.6	347.8
30	349.4	349.6	349.9	350.1	350.3	350.5	350.8	351.0	351.2

Observers used slide rules and trig tables. Astrolabes and theodolites sighted the direction of the rockoons. The researchers of the 1957 IGY thus used much the same tools as were employed by ancient mariners.

The ionosphere study was connected with evaluation of the terrestrial surfaces against which the radio waves reflected. The oblate shape of the Earth was known; the bulge was such that a 200-pound man standing on the Equator weighed 201

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[26] The velocity of sound in metric units is $v=20.05(273.16 + t)^{1/2}$, increasing slightly with relative humidity.

pounds standing at a pole, there being closer to our center of mass.[27] Even daily and hourly measurements varied with the rapidly changing planet. Over longer eons, the Earth has experienced a number of flips of north and south magnetic polarity. Slight changes in the globe's precession were identified. All of these phenomena let to adjustments in the IGY calculations.

Around this time, observational personnel asked for cooking instructions atop mountains where the boiling point of water differed from that at sea level. Betty Crocker Laboratories provided alternative instructions for high-altitude cooking. It is to the IGY that we owe the alternative cake-baking recipes that residents of Denver use to this day.[28]

G. Antarctica.

Antarctica was a virtually unknown continent in 1957. The last humans to have been at the pole was the ill-fated Robert F. Scott and his valiant crew, dying on their return trip in 1912. The first permanent installation was the Mawsom Base in 1954.[29]

The apparent land mass is twice the size of Australia. Featureless plains alternate with a ridge of volcanoes rising to 15,000 feet. It is almost lifeless, but it boasts species of grass, "pink," lichen, midgets, mites, and a "wingless mosquito." It is the cleanest place on earth, where one can supposedly leave food out without fear of bacteria, and surprisingly those plains are quiet because any wind encounters no obstacles.

As of the IGY, seven countries (UK, New Zealand, Australia, Chile, Argentina, Norway, and France) had lodged territorial claims. The UK and Argentina had long tussled over the Drake Passage between South America and Antarctica, the sensitive alternative shipping route should anything happen to the Panama Canal. They also disputed the rocky outcropping known to Britain as Palmer Peninsula and Graham Land, and to the Argentinians as the Antarcandes. (It is true that geologically the Antarctic ridge is an extension of the spine of South America.)

During IGY there was a concerted effort to pursue science rather than politics. Fourteen stations were initially established, not only by the seven territorial claimants but also by the U.S., USSR, South Africa, Japan, and Belgium. The Americans, part of CSAGI from the outset, secured the South Pole. The USSR chose

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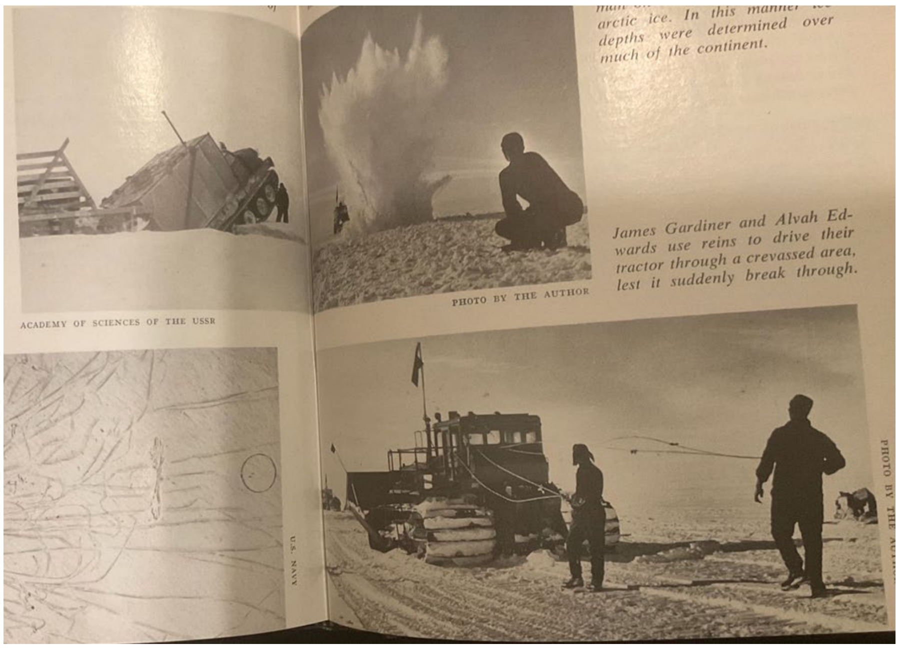
[27] See Harold Bullis, *The Political Legacy of the International Geophysical Year* (2007).
[28] See Dian Olson Belangar, *Deep Freeze* (2006) 301, 323.
[29] See Sam Marks, *The International Geophysical Year: The Greatest Science Fair of All Time,* Retrospect Journal.

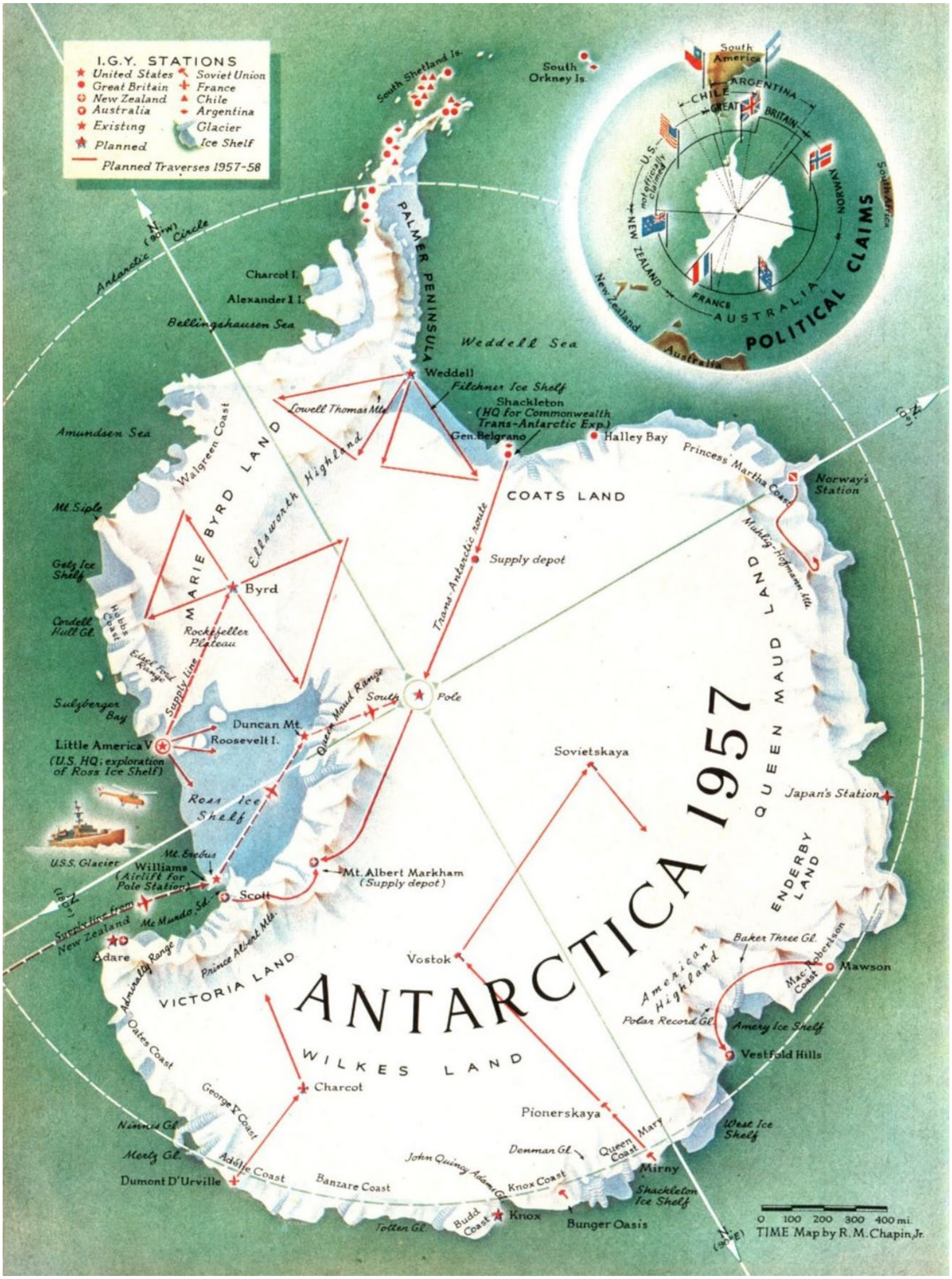
coastal locales and “The Pole of Inaccessibility,” the station most remote from any other location.

Science was a deadly serious business in Antarctica. At least 50 IGY fatalities are recorded. Planes crashed, ships sank, and tractors with drivers plunged into unseen crevasses. The “Grand Chasm” near an American base featured a 700-meter dropoff. Rather than losing more drivers and bulldozers to an abyss, men began to walk behind the vehicles holding “horse reins” connected to the throttle and brake. The rate of movement in these situations was as slow as that of Scott in 1912.



One of IGY’s major achievements was ascertaining the extent the land mass underneath the ice pack. Is Antarctica a single continent, or something else? How deep is the layer that holds so much of the world’s water? This was truly synoptic science, in that the resources of *all* the participating nations had to be brought to bear for *any* of their data to make sense. The stations launched the “Antarctic traverses”—expeditions of craft of various types on linear paths, taking soundings for depth and confirming the times and locations of their findings.[30]

[30] Wilson 163; Belangar 290.


I.G.Y. STATIONS
United States
Soviet Union
Great Britain
France
New Zealand
Chile
Australia
Argentina
Existing
Glacier
Ice Shelf
Planned
Planned Traverses 1957-58
POLITICAL CLAIMS
ANTARCTICA 1957
Antarctic Circle
South Shetland Is.
South Orkney Is.
PALMER PENINSULA
Charcot I.
Alexander I I.
Bellingshausen Sea
Weddell Sea
Weddell
Filchner Ice Shelf
Shackleton
(HQ for Commonwealth Trans-Antarctic Exp.)
Gen. Belgrano
Halley Bay
Princess Martha Coast
Norway's Station
COATS LAND
Lowell Thomas Mts.
Amundsen Sea
Walgreen Coast
MARIE BYRD LAND
Ellsworth Highland
Mt. Siple
Getz Ice Shelf
Byrd
Supply depot
Trans-Antarctic route
Hobbs Coast
Cordell Hull Gl.
Rockefeller Plateau
Edsel Ford Range
Supply line
Sulzberger Bay
South
Pole
Queen Maud Range
Duncan Mt.
Roosevelt I.
Little America V
(U.S. HQ; exploration of Ross Ice Shelf)
Ross Ice Shelf
U.S.S. Glacier
Mt. Erebus
Williams
(Airlift for Pole Station)
Scott
Mt. Albert Markham
(Supply depot)
Supply line from New Zealand
McMurdo Sd.
Adare
Admiralty Range
Prince Albert Mts.
VICTORIA LAND
Oates Coast
Sovietskaya
QUEEN MAUD LAND
Muhlig-Hofmann Mts.
Japan's Station
ENDERBY LAND
Baker Three Gl.
Mac. Robertson Coast
Mawson
American Highland
Polar Record Gl.
Amery Ice Shelf
Vestfold Hills
Vostok
WILKES LAND
Charcot
George V Coast
Ninnis Gl.
Mertz Gl.
Dumont D'Urville
Adélie Coast
Banzare Coast
John Quincy Adams Gl.
Knox Coast
Budd Coast
Knox
Totten Gl.
Pionerskaya
Denman Gl.
Queen Mary Coast
Mirny
West Ice Shelf
Shackleton Ice Shelf
Bunger Oasis
0 100 200 300 400 mi.
TIME Map by R. M. Chapin, Jr.

The U.S. made nine traverses—three from Little America, four from Byrd Station, and two from the Ellsworth Station. Other nations did their part. An American team would travel aboard snowmobiles, called Sno-Cats, only 40 to 60 kilometers in a day. They shot seismic to determine the depth and types of ice and solid material underneath their feet. They measured the position of the sun using a theodolite, akin to an astrolabe. They received the time from WWV using short-wave radio.

> [We] calculated our position using a slide rule (pocket calculators did not exist) to better than [200-meter] accuracy using a nautical amount almanac.[31]

> About every 30-40 miles, an exact position was calculated by measuring the position of the sun using theodolites, correlated with time signals from the U.S. National Bureau of Standards, and mapped using a slide-rule and a nautical almanac.[32]

The Americans only received and sent mail once a year, and fifteen months' residence were needed to squeeze out three months of useful data. Alcohol was strictly forbidden, but it was always present.[33] Not a single woman inhabited the entire continent (it is coeducational today).[34] Eagle Scout Richard Chapell joined this expedition, much as Eagle Scout Paul Siple had joined Robert Byrd's expedition decades earlier.

Three results of IGY in Antarctica are noteworthy. First, much more water was encountered than expected. The ice layer turned out to extend deeper before solid land was encountered, particularly in younger West Antarctica. The West is not so much a continent as an archipelago of islands. It features the volcanic ridge leading to Vinson Massif at 15,000 feet. East Antarctica is much older, made of Pre-Cambrian rocks, with an "IGY Valley" sequestering freshwater sources.

Second, core samples revealed coal beds and tree trunks. This certainly was evidence that the continent had moved at some point in the past from its polar location. But no theory of "continental drift" was accepted by mainstream science in 1957; indeed, graduate students were warned to stay away from such fanciful ideas.

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[31] John C. Behrendt, *IGY to IPY: The U.S. Antarctic Oversnow and Airborne Geophysical-Glaciological Research Program From 1957 to 1964 from the View of a Young Graduate Student,* USGS Short Research Paper (2007).
[32] Simon Naylor, Katrina Dean & Martin Siegert, *The IGY and the Ice Sheet: Surveying Antarctica,* 34 Journal of Historical Geography 574 (2008).
[33] See Behrendt.
[34] In 1977 Argentina shipped a pregnant woman, Silvia Morella de Palma, to its base to give birth. Emilio Palma, the first child born in Antarctica, was cited to bolster the country's territorial claim.

Alfred Wegner's 1920s theory of continental drift indeed suffered from a lack of explanation. Everyone can fit Africa into South America on the map, but no force could have dislodged a continent from the solid crust. Wegener's response was essentially "I'm Kepler not Newton, comparable to the discovery and explanation of elliptical orbits. I don't know what makes drift work, but there is drift." Indeed, evidence in his favor was accumulating. There are fossil remains of the same freshwater reptile in both South America and Africa. There are tropical plant remains in Norway as well as the Antarctic. The geologies of Africa and South America are much the same, as are those of the Appalachians of the U.S. and the Caledonians of Scotland.

Third, IGY led to a landmark treaty. The political achievement resulted from the nations collaborating on a common cause. The countries that were party to the traverses signed the Antarctic Treaty in 1959, dedicating the continent to peaceful scientific purposes and forbidding military uses. The style and form of that treaty led in no small part to the Outer Space Treaty of 1967.

The constant dangers afforded plenty of opportunities for cooperation. In December 1958, a Belgian plane broke its ski on its descent, stranding four men in the waste. The Belgians sent a distress signal to the Australian station at Mawsom, which relayed it to the USSR coastal Mirny station. A Russian hero named Victor Perov flew 1900 miles over solid whiteness and located the stranded Belgians, enabling them to be rescued. Japan was forced to evacuate its ice-bound station via helicopter, leaving thirteen dogs behind. When they returned, two of the huskies were miraculously still alive, having fed on defenseless emperor penguins. Taro and Jiro became celebrities back in Tokyo.

What about the big data? The slide rule calculations with the almanacs and astrolabes did the job, again "close enough for field work." The data were successfully integrated at the facilities with the computers needed to establish more precise conclusions.

This is not to say that there was not still a Cold War going on. Paul Siple stressed the importance of polar research by warning that the next war would be fought across the Barents Sea and Norwegian Sea. Another participant speculated that "the Russians might preempt the polar continent if the Free World did not act first." [35]

[35] See Matthew Kohut, Insight/Ask (2007); Naylor et al.

H. IGY and World Data.

Mountains of information were generated, in a multiplicity of formats. What happened to all this big data?

There were millions of feet of microfilm. There were thousands and thousands of paper records. There were photograph negatives. There were punch cards, particularly for measuring solar activity and for Project Moonwatch. None of these formats were compatible with one another. The clock was ticking, as plastic film begins to degrade in a matter of decades. The entire output of IGY would fit comfortably into a single hard disk drive today.[36]

The World Data Centers, all of A, B, and C, proved a success. With duplicates of data spread among multiple centers, the centers expertly conserved media and administered dissemination and exchange among scientists from all cultures. Eventually, the 27 initial WDC locations expanded to 50. The focus of research using these records gradually turned from East-West Cold War military tension to North-South climate change dialogue, as the implications of global warming gained relevance.[37]

The WDC was replaced by the World Data System (WDS) in 2008, and the ICSU was replaced by the International Scientific Council (ISC). Most of the data collected from IGY and later initiatives has now been digitized. The WDS mission is well summarized by the principal WDS Reporter, resident at the University of Tennessee – Oak Ridge, who said, "We don 't want another Library of Alexandria happening."[38]

I. After IGY.

Collaboration in global science has been nearly continuous since IGY. The International Geophysical Cooperation period was again extended, this time through1960. Then ensued the International Years of the Quiet Sun (1964-65), in contrast with the IGY's high solar activity period; the International Hydrological Decade (1965-1975) and International Ocean Exploration Decade (1970 -1980); and a new International Polar Year, IPY-4 (2007-2008, counting IGY as "IPY-3" of sorts). The UN facilitates the treaties and research efforts of the United Nations

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[36] See Sarah Evarts, *Information Overload* (July 25, 2016); National Academy of Sciences, *Report of the U.S. Program for the IGY* (1965); ICSU, *Guide to the World Data Center System* (1996); O'Connell 61.
[37] See Cheryl Pellerin, *International Science Council to Revamp World Data Centers* (July 23, 2009).
[38] See Belangar; O'Connell.

Framework Convention on Climate Change (UNFCCC). An IPY-5 is planned for 2032-33.

The discovery of midocean ridges helped confirm the theory of plate tectonics. The key change in understanding was that the continents were situate on giant plates residing on top of the mantle. This provided the key explanatory mechanism: if the plates moved, so would their associated land masses.

World War II submarines had already encountered alternating north and south magnetic orientation in midocean. Those "zebra stripes" were now recognized as the the result of periodic upwellings at the ridges. It had been thought that the oceans were the *oldest* part of our planet, but now we know they are new and continuously renewing. The zebra stripes were identified in the 1950s, but the old guard was reluctant to publish the first studies about them. By 1967, plate tectonics became accepted, even "obvious." Alfred Wegener would have been pleased, or at least vindicated. [39]

The IGY was a signal point for international cooperation. Beyond the Antarctic Treaty, however, it did not inspire major changes in policy. In contrast, when the hole in the ozone layer was identified in the 1970s, chlorofluorocarbons (CFCs) were flagged as the cause and they were banned by 1996. As David Victor reported, there were industrial alternatives, facilitating the international conventions leading to action. It is far from clear how one might apply that analogy to carbon emissions at scale. [40]

The IGY harnessed an unprecedented amount of data in many different forms. It was prudent to diversify the storage of this data, and the World Data Centers served their purpose well. Before the data made it to those centers, the information needed to be assembled and analyzed, often in remote locations with urgent need for real-time evaluation. Astrolabes, theodolites, nautical almanacs, trig and log tables, and slide rules were used in ways that would have made sense to navigators and mathematicians 300 years earlier. We stand on the shoulders of those who resourcefully calculated under those difficult conditions—we who now hold computing power in our coat pocket far greater than what was available worldwide in 1957.

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[39] See O'Connell 124.

[40] See David G. Victor, *Global Warming Gridlock* (2011); Valerie J. Karplus, M. Granger Morgan & David G. Victor, *Finding Safe Zones for Science,* Issues in Science & Technology (Fall 2021).