Alouette-1 – A History of The Data from Canada’s First Satellite Over 60 Years

I. Making Ionograms at the DRTE Data Processing Facility at Shirleys Bay

It is July 20, 1969, and you are a technician at Canada’s Defence Research Telecommunications Establishment (DRTE). You work at the data processing facility (called a ‘reduction centre') at the Shirleys Bay campus close to Ottawa (see Figure 1), where you process telemetry tapes from ground stations all around the world, for the Alouette-1 and Alouette-2 satellites. There are thousands of tapes, and it seems that there is a shipment coming in everyday, from Quito, Ecuador; Woomera, Australia; and Resolute Bay in the Canadian Arctic.

A system has been built to read the 7-track reel-to-reel magnetic tapes – where the primary data from Alouette’s topside sounder experiment is in the form of a video signal, that is displayed on a cathode ray

Canadian engineers at DRTE’s Ottawa reduction center check equipment used to process Alouette data.

Figure 1: Canadian engineers at DRTE’s Ottawa reduction centre check equipment used to process Alouette-I data. Credit: NASA, “Alouette: Canada’s First Satellite – NASA Facts,” 1964 (1).

tube in 'B-scan' form. The result on the screen is an **ionogram**, which depicts the reflections of radio waves emitted from the satellite off the top side of the ionosphere, across a range of frequencies from 0.5 – 12 MHz (in the case of Alouette-1). It is your job to set up and run the 35 mm camera to record the ionograms, along with their associated time codes (2). This process, called kinescope recording, is commonplace in the television industry for recording live television broadcasts for archiving purposes.

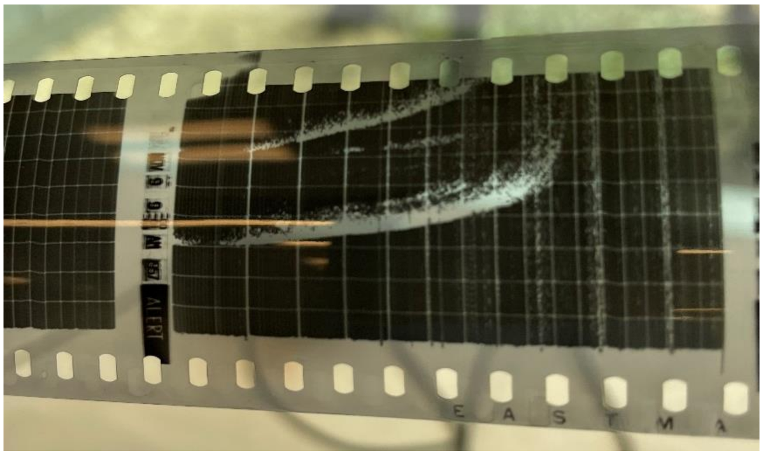

Figure 2: Ionogram recorded on 35 mm negative film.

The Ottawa DRTE data processing facility is effectively the only place in the world that can produce high-quality ionograms (other than some ionogram production that occurs at the Singapore telemetry station). In practice, most agencies who have access to copies of the telemetry tapes find it challenging to process the signal properly. The data processing facility operates 70 hours a week, producing around 200 ionograms an hour. Over the first 6 years of the facility's operation, it processed and recorded about 2.3 million ionograms, over 18,000 hours (2).

II. The Scientific Legacy of Alouette-1 In its Time

At a time when most satellites were designed for and lasted only a few months, Alouette-1 operated for ten years – from 1962-72 – outlasting any other satellite of its era. In the decade to follow its longevity was only bested by Alouette-2, and the two ISIS satellites.

Launched on September 29, 1962, Alouette-1 was the 22nd artificial satellite to be launched and work successfully, overall. However, **it is the first satellite to be completely designed and built by a country other than the USSR or USA** – it was designed and built in Canada, led by the DRTE.

Much has been written about the scientific and engineering legacy of Alouette-1 in its time. One of the most important scientific results from Alouette-1 was that it provided the first global picture of electron-density distribution in the topside ionosphere (3, p. 8). According to a NASA program summary written at the end of the multi-decade Alouette-ISIS program, "[t]he first week of topside soundings provided more information about the topside electron-density distribution than had been obtained from all sources prior to the Alouette 1 launch." (3, p. 8) By the early 1970s Alouette-1 and its data led to more scientific publications than any other satellite, resulting in over 300 publications by 1985 (4).

The principal purpose of Alouette-1 was to investigate the geographic and diurnal (day-night) variation of the topside ionosphere at altitudes up to 1000 km. To do this, it was placed into a 1000 km circular orbit with an inclination of 80 degrees prograde, which allowed for a complete coverage of all geomagnetic latitudes (4, p. 17). The primary topside sounder experiment was a 'swept frequency' experiment, radiating radio waves across a frequency range from 0.5 – 12 MHz – rather than a simpler 'fixed frequency' sounder. To transmit and receive along this frequency range Alouette-1 needed to have two extremely long antennas, one dipole at 45.7 m, and another at 22.8 m (4, p. 18; see Figure 3). Because of this additional complexity and other major reasons, Alouette-1 was meant to be a follow-on or secondary topside sounder satellite. The first satellite was supposed to be a fixed-frequency sounder built by the United States, called Explorer-20. However, due to delays it only launched about two years after Alouette-1, in 1964 (4, p. 18).

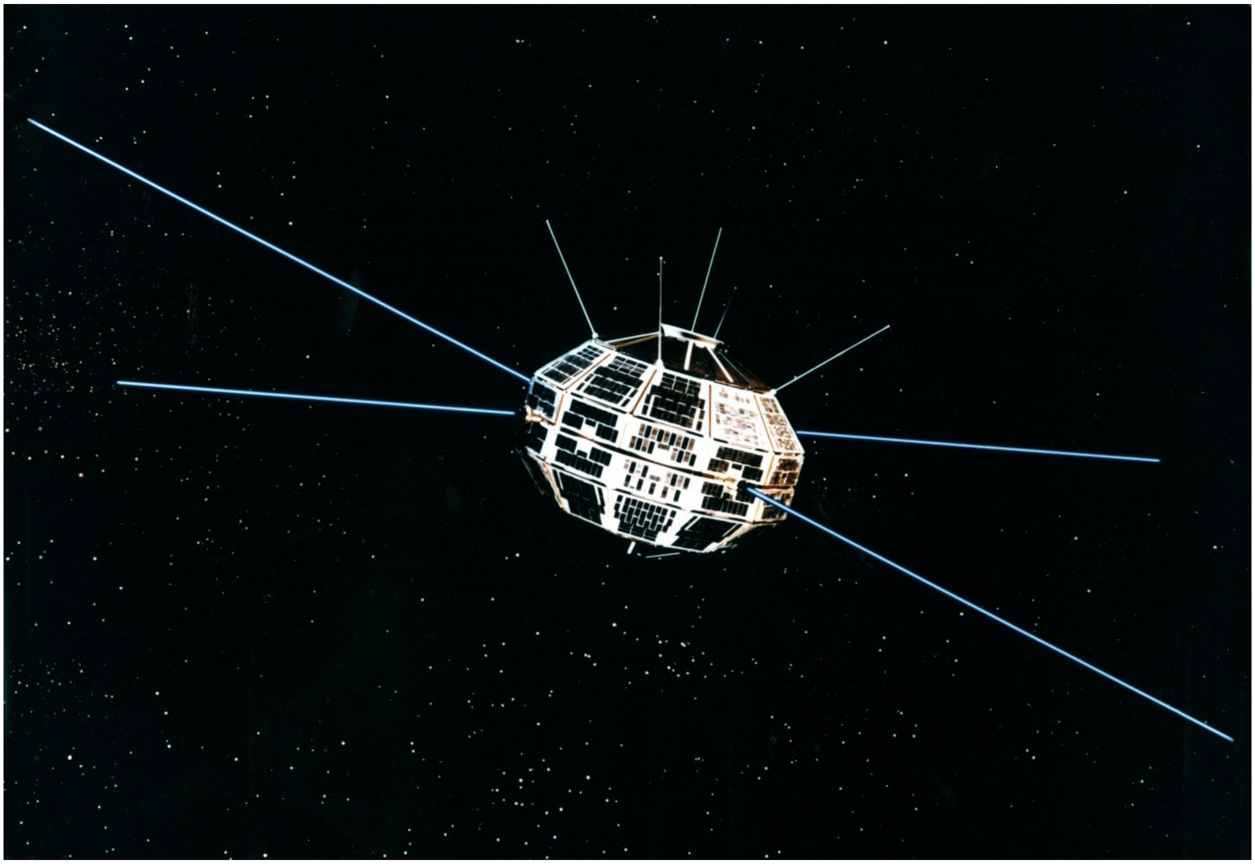

Figure 3: Artist's impression of Alouette-1 in orbit, with antennas fully extended. Credit: Canadian Space Agency.

As a result, Alouette-1 was the first ionospheric satellite and it set a precedent for space-based ionospheric research. Its initial success led Canada (by the Defence Research Board) and the United States (by NASA) to formally agree on December 23, 1963, to expand its collaboration into a program called the **International Satellites for Ionospheric Studies (ISIS)**. Canada would design and build a family of additional ionospheric satellites: **Alouette-2**, **ISIS-1**, and **ISIS-2** (4, p. 13).

To less fanfare, Alouette-1 also set a precedent for excellent data stewardship from the beginning. Starting with Alouette-1 and continuing with the subsequent satellites:

> *…the program had an outstanding record in making the data available to the scientific community. The Alouette-ISIS program was the first satellite program to make extensive and well-documented contributions of data to the international data centers… Because of its very early support of data center activities, the Alouette-ISIS Working Group also helped to develop some of the procedures and policies for submitting satellite data to the data centers. Data from the Alouette-ISIS program made available in this manner have been used by over 50 research groups and agencies." (4, p. 26)*

Because the Alouette-ISIS family of satellites produced so much data, compared to other satellites of its era, the program would have been in a unique position to be an early leader in space-related scientific data management.

Early ideas about data accessibility started in the design phase. Colin Franklin, Chief Electrical Engineer for Alouette-1 explained that "[t]o encourage the widest possible participation by outside agencies and experimenters, a major spacecraft design goal [was] to provide a telemetry signal which can be received, demodulated, and displayed by relatively inexpensive equipment. This objective was achieved in Alouette

I and every effort has been made to limit changes to the 136-MHz FM link in subsequent satellites." (2) Then, once the data were recorded onto telemetry tapes, they were further processed into ionograms, which was the most accessible and familiar form of data presentation for ionospheric researchers at the time. The ionogram (i.e: distance-frequency plots) was used since the late-1930s for ground-based bottomside ionospheric soundings. According to the 1986 NASA program summary, "[t]he use of a data presentation that was familiar to ionospheric physicists throughout the world and the rapid availability of these data to the international scientific community were additional reasons for the extraordinary success of the Alouette 1 mission." (3, p. 2)

The program summary concluded,

> *The efforts of the unusually competent and dedicated members of the Canadian team, together with the wholehearted support of their U.S. counterparts, led to Canada's spectacular entry into the space age with Alouette 1...The Canadian space program has since then maintained an unequalled record for overall excellence, in both the scientific and application areas*. (4, p. 25)

III. Why Was There So Much Data from Alouette-1?

The simple answer: *it lasted a long time*.

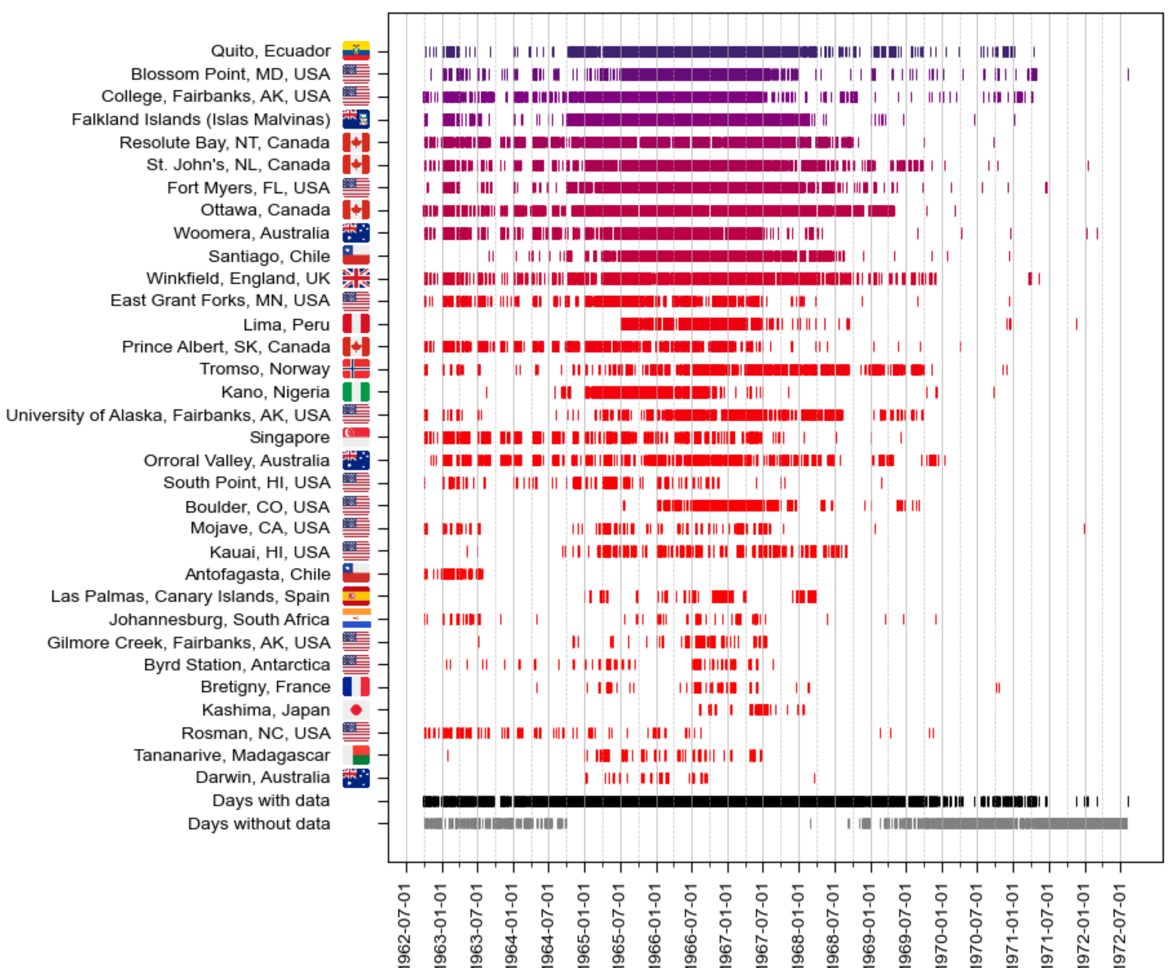

Figure 4: Current availability in days of Alouette-1 extracted data, by ground station.

First, there were important design considerations that led to the unusual longevity of Alouette-1. Fundamentally, there was an unorthodox standard of quality control. Colin Franklin and his team “insisted on a thorough understanding of semiconductor devices” (32) and realized that commercially available semiconductor transistors did not have the quality needed for space applications. Instead, the team worked closely with manufacturers to ensure that transistors and circuits would be capable of operating under much greater than expected temperature and power supply variations (5, 32). “We ended up paying the manufacturer to set up a dedicated production line in order to produce transistors…It was certainly the reason that Alouette 1 lasted ten years, rather than the industry standard lifetime of several weeks that we had experienced up to then”, according to former DRTE scientist LeRoy Nelms (6). Even on the mechanical side, the satellite’s structure and electronics units were designed for much higher-than-expected vibration levels (32).

Furthermore, the satellite’s power supply was designed with a pessimistic assumption that up to 40% of its solar cells would degrade after one year in orbit (5). And with the help of the Defence Research Chemical Laboratory in Ottawa, a major effort was made to improve the reliability of commercially available Ni-Cd batteries. This was a major difference between the Alouette-ISIS satellite batteries and those used in U.S. spacecraft (5).

There were also satellite design choices that would have directly affected the quality of the resulting ionograms. The typical approach was to keep transmitter power as low as possible for cost and reliability reasons. Yet the team chose a bolder approach of making transmitter power 10 times greater than the predicted minimum required. According to Franklin, “[t]his was a milestone decision since it greatly eased the antenna design and the mass production of high quality ionograms.” (5) Then, because the satellite needed to be spin-stabilized after its antennas extended once in orbit, the spin would have had the undesired effect of ‘drop-outs’ in telemetry, which would have severely reduced the resulting quality of the ionograms. The problem was addressed through a novel design of the satellite’s telemetry and command antenna system (5).

Despite the team’s remarkable dedication, some doubted the satellite would even work, let alone work as long as it did. Shortly after the U.S.-Canada topside sounder collaboration was announced on April 20, 1959, a technical feasibility report was completed by the Central Radio and Propagation Laboratory (CRPL) at Boulder, CO. The report perhaps reflected the skepticism of some NASA officials at the time about the feasibility of building the world’s first space-based radar (5). The report suggested that the power and antenna requirements, and the overall complexity of installing what would essentially be a bottomside sounder in a satellite was too difficult to do at the time. It recommended that a fixed-frequency and a swept-frequency topside sounder be developed concurrently – but encouraged the young DRTE team to develop the swept-frequency sounder as a ‘second-generation’ experiment (4, p. 14). According to Colin Franklin, “NASA later admitted publicly that they and CRPL were so convinced that it could not possibly function for more than an hour or two, if at all, that they had made no plans to use data from it.” (5)

Unbeknownst to the DRTE team, at one point referred to as the ‘farm team’, “at the working level we had no idea that NASA thought we couldn’t do it”, said Franklin (7). At a Canadian Space Agency event in 2023, the 95-year-old Colin Franklin continued to emphasize that “never once were we told that what we were doing was impossible…not once…I find that quite amazing. We were treated along with the U.S. fixed-frequency experiment just like one of the family” (7). Peter Forsyth, a former DRTE Defence Program Manager recalled in 2002 that:

> *"... there was this all-pervading confidence in the ability of the lab collectively to solve new problems, to come up with new approaches to old problems and at the same time to compete technologically with some of the best labs in the world…It required real audacity to believe that a small group of scientists with no previous experience in space technology could design and build a successful space satellite. Yet this is exactly what the Defence Research Telecommunication Establishment (DRTE), at Shirleys Bay undertook starting in 1958." (6)*

On the optimistic end, the DRTE team expected the satellite to last no more than a year. Therefore, the ionograms that were first produced by the Shirleys Bay data processing facility did not indicate the year, but only the day of the year and the time of the topside sounding. Once the Topside Sounder Working

Group realized that Alouette-1 could last for multiple years, they modified the metadata format to account for this before the one-year anniversary (see Figure 5).

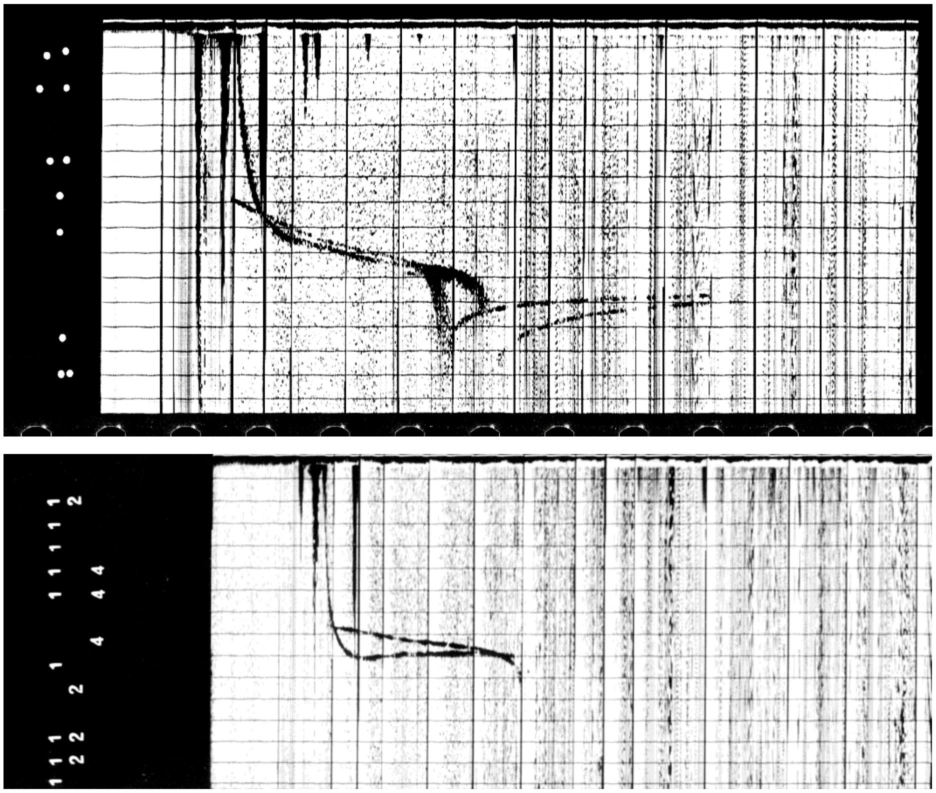

Figure 5: (top) Ionogram with dot metadata type. Early ionograms produced by DRTE encoded metadata into horizontal lanes, where each lane would represent a particular digit. The horizontal positions of dots within each horizontal lane would encode a number in binary format; (bottom) Due to the ambiguity of the relative positions of each dot in each metadata lane, dots were replaced with numbers, but they were still arranged in the binary format. Therefore, one lane with a 1, 2, and 4 would be summed and represent 7. The new metadata format also included a lane to represent the year.

It was not just that there did not exist a complete faith in the young Canadian team. A major factor was that just a few months before launch, on July 9, 1962, a 1.4-megaton high altitude nuclear detonation experiment was conducted over Johnston Atoll in the Pacific Ocean, called *Starfish Prime* (8). It was an unfortunate circumstance for the communications satellite Telstar-1 to launch just one day after, on July 10. Telstar-1 experienced a dramatic reduction in solar cell output power, determined likely due to extensive ionization damage from high-energy electrons (8). Because of this and other declines in performance observed on other satellites, there was less faith in Alouette-1's success. And yet Alouette-1 survived and outlasted its contemporaries chiefly because its power supply was designed with a tolerance for up to 40% degradation in solar cell power. Some observers at the time apparently had criticized Alouette-1 as 'over designed' (5, 8). Yet the team's focus on reliability proved to be uncannily prescient, as they did not expect that the satellite would need to withstand artificial radiation belts created by a hydrogen bomb (5).

Still Alouette-1 did incur damage from Starfish Prime radiation (8). It was power supply limited and was activated by an uplink command as it flew close to a ground station. In its early life it was able to transmit downlink telemetry for about 7 hours each day. However, because of radiation damage to its solar cells, by the end of 1968 it was only able to telemeter ionospheric data for approximately 1.5 hours per day (2). As Figure 4 depicts, the availability of extracted data decreases dramatically by 1970, likely due to the managed reduction in telemetry time.

IV. Data Was Collected from Telemetry Stations Around the World – Alouette-1 and the Ionospheric Satellites That Followed Set a Precedent for International Collaboration in Space

Because Alouette-1 did not have a data storage system, like an onboard tape recorder, it had to be activated by a command as it flew over a ground station. The uplink command was encoded in a combination of seven discrete audio tones (a command system developed by NASA) (2). Telemetry would then be transmitted by the satellite at 136.08 MHz FM to be received and recorded in real-time by the ground station, until the spacecraft either dropped below the radio horizon or was turned off by an internal timer about 9.5 minutes later (2). The output from the topside sounder was a video signal that contained the ionospheric echo pulses, but also pulses that depicted frequency markers and when a new 'frame' started. A frame is what the ionogram ultimately displays, spanning the entire frequency sweep for the experiment (2). The on-demand activation paradigm worked well. By the end of 1968, 98-99% of commands were successfully executed (2).

Therefore, Alouette-1 required a global network of telemetry stations, particularly at higher latitudes because of its 80-degree inclination orbit. Thankfully, Canada did not need to enter into bilateral agreements with various countries and build stations around the world. The United States had already begun to build such a satellite tracking system – which at first was called Minitrack in the late-1950s, and which grew and developed in capability to become NASA's **Satellite Tracking and Data Acquisition Network** (**STADAN**). For the Alouette-1 project, the United States agreed to provide tracking and telemetry support from the STADAN (4, p. 14). Canada would also provide its own telemetry stations for the mission. The master station would be at Shirleys Bay in Ottawa, along with its data processing facility that received telemetry tapes from the global network of stations, to produce the ionograms. In addition, Canada operated the Resolute Bay station in the high Arctic (opened 1947 as a weather station), and the Prince Albert Radar Laboratory in Saskatchewan (opened 1959 by Prime Minister Diefenbaker and President Eisenhower).

In building a satellite tracking network, NASA understood that proactive international collaboration was critical in getting stations established at optimal locations around the world. In fact, prior to the creation of NASA, the U.S. State Department assisted the U.S. Navy in its effort to launch and track its first artificial satellite, Vanguard-1, through the early development of the Minitrack network:

> *…the Department of State provided the much-needed assistance to the Navy as the executing agent for foreign affairs, conducting negotiations for land leases on foreign soil. The cooperation between the various departments of the U.S. government was a testament to the priority of Project Vanguard. There was with it a definite sense of urgency…"While our budget was low,…[we] had high priority which allowed us to push ahead without administration hurdles. All of us were anxious to succeed." (9, p. 16)*

As B. Harry McKeehan, Chief of International Operations at NASA's Goddard Space Flight Center (GSFC) from 1963-80 explained:

> *A major stabilizing factor in our foreign operations was our policy of maximum utilization of local people in station positions. This proved to be cost effective as well as giving the local government and population a feeling of having a stake in the NASA missions…we explored with our colleagues in NASA Headquarters and the appropriate officials of the Department of State, the country to be approached for a 'tracking partnership'. We considered the country's geographic features, accessibility, political stability and available logistic support. Also, we looked into possible sources for local employees to reduce the number of U.S. personnel. Then, we would work through the U.S. embassy, establishing contacts with representatives of the foreign governments and explaining our needs to their leaders. This approach, together with the worldwide excitement of the U.S. space effort, opened doors and usually assured us of the support needed." (9, p. 20)*

Take for instance the Chilean ground station in Antofagasta. Initially operated by the U.S. Army, it became a joint operation between NASA and the University of Chile in 1958 when NASA was formed. As greater investments into the South American stations were made, the neighbouring Santiago station underwent a

$1.2 million upgrade. By 1963 the Santiago station's staff doubled in sized from 38 (16 Americans and 22 Chileans) to 62. NASA eventually replaced half of its staff with Chileans from the university (9, p. 40).

In Madagascar, a station was required in the western Indian Ocean for tracking certain highly elliptical, high apogee orbit injections. In 1963 the U.S. entered into a 10-year agreement with the Malagasy Republic to construct a ground station in Majunga on the northwest of the island. The agreement promised to supply needed weather forecasts for the state, and the station provided about 200 jobs for residents, but largely in non-technical and maintenance roles (9, p. 54).

Figure 6: (top-left) Inauguration of the Prince Albert Radar Laboratory by Prime Minister Diefenbaker, on June 6, 1959 (10). Credit: British Pathé; (top-right) Parabolic dish installed at NASA STADAN station in Tananarive, Madagascar (11). Credit: British Pathé; (middle-right) Inauguration of Tananarive station with demonstration for Malagasy Republic and USA officials (11). Credit: British Pathé; (bottom-left) Byrd Station, Antarctica in September 1957 (12). Credit: Robert F. Benson.

By contrast, operations were different in Australia where NASA financed the construction of a variety of stations. The Australian government insisted on providing and managing its own staff. As a result, the Australian stations had the most autonomy within the STADAN, fostering a sense of ownership over local operations (9, p. 45).

The stations were highly dependent on its people, as little was automated.

> *Even though space is often associated with "high-tech," it is still the people involved who were movers of the program, who ran the day-to-day operations of the facilities, and who left behind their legacy. This emphasis on people especially characterized the early years of the Agency's tracking networks...Whether one was the head of a station or just feeding teletype printouts to the engineers, everyone had a job to do. (9, p. xxxvi)*

Figure 7: Women operators, such as Melba Roy at the Goddard Space Flight Center in a picture taken in 1964, were a big part of the tracking workforce (9). Credit: NASA (NASA Image GPN-2000-001647).

In addition to the necessity for a global network of ground stations, the Alouette-1 project was also borne out of a spirit of international collaboration in science at the time – resulting directly from the International Geophysical Year (1957-58) and occurred concurrently with the founding of NASA. The International Geophysical Year (IGY) was an "unprecedented" joint effort among 66 countries (4, p. 13) "sponsored by the International Council of Scientific Unions designed to promote and stimulate a broad, worldwide investigation of Earth and the near-Earth cosmic environment. At the time, it was quite the watershed event in terms of fostering scientific interest on an international basis when East-West tensions were [dominant]" (9, p. 3). One successful example of IGY cooperation was the Canada-U.S. sounding rocket program in Churchill, Manitoba, which in a sense was a precursor to the Alouette-ISIS program (4, p. 13).

The IGY also influenced the founding of NASA on July 29, 1958, where many have suggested that its legislation (*The National Aeronautics and Space Act of 1958*) reflects the IGY spirit of international collaboration (4, p. 13). Prior to this moment it was a matter of debate whether the United States space program should be military or civilian oriented – whereby a civilian space agency would be more able to collaborate internationally. President Eisenhower made clear his preference in a March 5, 1958 memorandum that the “long-term organization for the federal space program…should be under civilian control.” (9, p. 26)

Thereafter,

> *The initial NASA approach to space cooperation was crafted by individuals who had been involved in the U.S. activities related to the International Geophysical Year (IGY)…These included Hugh Dryden, Deputy Administrator of NASA; Homer Newell…as its first head of space science; and Arnold Frutkin, who had worked on ICY matters with the National Academy of Sciences and then became NASA’s second director of international affairs…(a position he held for almost two decades). (13, p. 2)*

NASA and the U.S. National Academy of Sciences had urged the International Council of Scientific Unions (ICSU) – the organizing body of the IGY activities – to create a venue for discussion and coordination of cooperative activities in space. The ICSU established the Committee on Space Research (COSPAR) in October 1958. However, it became clear that COSPAR was not well-suited to the actual working-level coordination of international scientific missions – and so NASA chose to take on this role on a bilateral basis with its international partners (13, p. 3).

In parallel to all of this – as another IGY activity – in July 1958 the Space Science Board of the U.S. National Academy of Sciences also issued a request for proposals for satellite experiments, that the U.S. would offer to launch into orbit. In October 1958, H.G Booker of Cornell University hosted a meeting to discuss specifically the prospect of ionospheric research satellites. This meeting stimulated a proposal from the Defence Research Telecommunications Establishment of Canada (DRTE) at the end of 1958 (4, p. 14). In fact, there were two Canadian submissions – the one from DRTE for a swept-frequency topside sounder, and one from the University of Saskatchewan to build a fixed-frequency sounder (7). NASA accepted the DRTE proposal, and the collaboration was announced on April 20, 1959.

Some have suggested (13, p. 3) that the United Kingdom was the first international collaborator for NASA. British Prime Minister Harold McMillan announced on May 12, 1959, that a British delegation would meet with NASA counterparts at the end of June 1959. However, this is months after the Alouette-1 collaboration was announced.

The nature of international collaboration from the start of the Alouette-1 mission encouraged and enabled many other countries to contribute to the project, particularly by welcoming offers to add new telemetry stations to the global network, and later in the largely manual effort of data analysis. The UK expressed an early interest in participating in the topside sounder program. By an arrangement made in 1961, the UK agreed to support Alouette-1 by operating telemetry stations in the Falkland Islands (Islas Malvinas) and Singapore. In return, the Radio Research Station in England would be given immediate access to the topside sounder data (4, p. 15), to expand its large collection of bottomside ionograms. Then, because of the success of Alouette-1 and the continuation of the Alouette-ISIS program, international participation expanded greatly:

> *The international participation was increased during 1965 and 1966 to include agencies in France, Norway, and Japan; in 1971 and 1972 to include agencies in India, New Zealand, and Australia; and in 1977 to include Finland. Specific arrangements differed in detail, but basically all these nations have supported the program by providing telemetry services and by participating in the reduction and analysis of topside ionograms. The French telemetry stations used in the Alouette-ISIS program include Brazzaville, Congo; Bretigny, France; Colomb Bechar, Algeria; Kerguelen Island; Kourou, French Guyana; Las Palmas, Canary Is.; Ouagadougou, Upper Volta; Pretoria, S. Africa; and Terre Adelie, Antarctica. Other nations have provided telemetry services at Tromso (Norway), at Kashima (Japan), at Ahmedabad and Thumba (India), at Lauder (New Zealand), at Darwin (Australia), and at Sodankyla (Finland). (4, p. 15)*

The significant international contribution of new telemetry stations to the network meant that by the early 1970s NASA was able to reduce considerably its telemetry support for the Alouette-ISIS program (4, p. 15). This was important for NASA as it could then focus on consolidating the STADAN and the Manned Space

Flight Network to form its next-generation Space Flight Tracking and Data Network (STDN), to support a variety of new missions.

It is conceivable that the United States could have made the ionospheric research satellites on their own, as U.S. contractors built the Alouette-ISIS satellites Explorer-20 and Explorer-31. Instead, the U.S. invited countries, like Canada, to propose ideas for satellite-based experiments, and offered to launch them. NASA could have stipulated in its agreement with DRTE that the STADAN would be used exclusively, such that NASA could become the exclusive owners of the data. Instead, the U.S. encouraged Canada and other countries to contribute telemetry stations, and freely shared the telemetry data received at NASA's STADAN stations with the DRTE for data processing in Ottawa.

American leadership was important for the initiation and development of Alouette-1. But Canada played its part. Alouette-1 was arguably the earliest international collaboration for NASA, and the subsequent Alouette-ISIS program as-a-whole was “probably one of the best examples of international cooperation in space research” (4, p. 13). As described thus far: Alouette-1 was founded during a period of widespread intention for international scientific collaboration; Canada already had a track record of working well with U.S. counterparts in other scientific collaborations, notably in bottomside ionospheric studies, and this continued with Alouette-1; expected satellite operations and data collection required access to and an expansion of a global network of telemetry stations, often staffed by local people; processed data in the form of ionograms were shared as openly as possible with collaborators, and were deposited in world data repositories. Then, because the DRTE team had greatly exceeded expectations, the Alouette-ISIS program attracted new contributions from many other countries that were also looking to establish their own space-related activities. The Alouette-ISIS program was clearly flexible and adaptable enough to allow more countries to collect telemetry data or assist in its interpretation. For all these interrelated factors – often involving the collection and sharing of data – it is suggested that Canada had set the tone for international collaboration in space with Alouette-1, in a formative era of space exploration.

Table 1: Interesting Details for Selected Ground Stations, in Order of Data Availability

Station	Details
Quito, Ecuador	Called Paramo de Cotopaxi (or Cotopaxi Satellite Tracking Station), it was originally built in 1957 on the side of an active volcano. Quito formed part of the original 75 W ‘picket line’ of Minitrack stations in the late-1950s, along with Blossom Point, MD; Lima, Peru; and Antofagasta and Santiago, Chile (9, p. 19). From 1960-63 Quito station was upgraded to a STADAN station and received a 12 m parabolic dish. “The South American stations, in particular, continued as a centrepiece in the evolved network, providing NASA with a tracking and data acquisition capability in the southern hemisphere.” (9, p. 42)
Blossom Point, MD, USA	Blossom Point is the ground station closest to the Goddard Space Flight Center (GSFC) in Greenbelt, MD, just northeast of Washington, D.C. It was the hub station for the entire NASA STADAN. It was also one of the original 75 W ‘picket line’ Minitrack stations. For other NASA satellites, Goddard was the main site for telemetry data processing, and where telemetry tapes from ground stations across the STADAN would have been shipped to. However, in the case of Alouette-1, the telemetry tapes were not shipped to Goddard, but directly to the DRTE facility in Ottawa.
College, Fairbanks, AK, USA	From 1960-66, the GSFC oversaw the build up of eight additional STADAN stations on four continents: Fairbanks was one of these sites. Fairbanks was the most northern station in the STADAN, where “Alaska provided crucial support for polar and high eccentricity, elliptical orbiting spacecraft such as the Nimbus weather satellites and the Alouette” (9, p. 43).
Falkland Islands (Islas Malvinas)	Operated by the United Kingdom, along with Singapore, when the UK offered its support to the Alouette program in March 1961 (4, p. 15).

Resolute Bay, NT, Canada	The Resolute Weather Station on Cornwallis Island was established in August 1947. An airfield was constructed by the U.S. Air Force and U.S. Army engineers, and two years later the Royal Canadian Air Force developed an air base and maintained facilities (14). The site developed into the 1960s for satellite tracking and other radio activities. There was a fast teletype link between Ottawa and Resolute Bay station. Whereas, for the other polar tracking station in the network, Byrd Station in Antarctica, it could take up to two days for it to receive a message (2).
St. John's, NL, Canada	Called Shoe Cove Tracking Station, it was built in 1960 as part of NASA's expansion of its STADAN stations. Financing for its construction was covered by NASA under the agreement that the National Research Council of Canada would cover its operation and maintenance. To realize the economic development potential of the station, the Newfoundland Government required that at least 75% of operators working at the site had to be a Newfoundlander, married to a Newfoundlander, or had lived in Newfoundland for a period of time (15). By 1967 the Shoe Cove Tracking Station operated full time with 24 employees, tracking up to 27 satellites in orbit (15).
Fort Myers, FL, USA	With the abrupt shut down and loss of the telemetry station in Havana, during and after the Cuban Revolution, a new station at Fort Myers, FL was needed to fill the gap in the STADAN (9, p. 42).
Ottawa, Canada	This is the master station for Alouette-1 and the subsequent Alouette-ISIS satellites, operated by DRTE (and eventually the Communications Research Centre of Canada) on the Shirleys Bay campus, just outside of Ottawa. The station monitors the engineering status of the satellite, can uplink special commands such as to switch to reserve batteries, and prepares operating schedules (2). For the first three years of Alouette-1, the Shirleys Bay station received downlink telemetry with an array of 8 cross-polarized eight-element Yagis (2). Around the launch of Alouette-2 in 1965, an 18 m parabolic dish was installed, with a substantially increased gain of 26 dB over the Yagi antenna – useful to adapt to any satellite malfunctions that could cause a drop in transmission power (2).
Woomera, Australia	Woomera in South Australia was an early Minitrack station, which began construction in 1957 for the International Geophysical Year (9, p. 44). Under an agreement with NASA, the Australian government would supply land, electricity, facilities and workers, while the U.S. would provide all of the technical equipment, installation, and training for Australian staff (9, p. 21).
Santiago, Chile	The first Chilean station was in Antofagasta, on the Pacific coast in the northern part of the country – it was an original Minitrack station built in 1957. However, a new station in the capital Santiago attracted significant investment and had a 12 m parabolic dish installed. The STADAN shifted its Chilean operations to the Santiago station in July 1963. The station operated with an agreement with the University of Chile (9, p. 40).
Winkfield, England, UK	From 1960-66, the GSFC oversaw the build up of eight additional STADAN stations on four continents: Winkfield in Berkshire, England was one of these sites (9, p. 43).
Prince Albert, SK, Canada	The Prince Albert Radar Laboratory opened on June 6, 1959 – the 15th anniversary of D-Day. The impetus for its construction originated from an initial flurry of concern over North American security following the launch of Sputnik-1 in 1957. How might one detect and track a satellite, or even an intercontinental ballistic missile over the Arctic from the USSR. Could such a missile even be detected at all due to radio interference from the aurora borealis (16). The facility was inaugurated in dramatic fashion by Prime Minister Diefenbaker, in his home riding of Prince Albert. It was to receive its first message from President Eisenhower, with the Lincoln laboratory near Boston transmitting and

	reflecting the radio signal off of the moon. "Mr. Diefenbaker pressed a button on the podium. At the press of the button, the 84 foot [26 m] parabolic antenna swung into action and pointed to what the guests doubtless thought was the location of the moon. Then the voice of the President of the United States, General Dwight D. Eisenhower, was heard congratulating Prime Minister John Diefenbaker on the establishment of this cooperative effort. The fact that the movement of the dish was being controlled by PARL staff, that the antenna was pointed nowhere in particular, and that the voice that was heard had been recorded some days before, didn't matter. The effect was the same. It was a very convincing demonstration." (16)
Kano, Nigeria	In 1965, Kano, Nigeria was a temporary site for a STADAN station to support the Alouette-ISIS program (9, p. 50).
Singapore	Operated by the United Kingdom, when the UK offered its support to the Alouette program in March 1961 (4, p. 15). However, on September 16, 1963, Singapore gained independence after 144 years of British rule. Nevertheless, the station continued to operate with likely few changes. Specific to Alouette-1, Singapore station was one of the few places where telemetry tapes were processed into ionograms – as virtually all other telemetry tapes were shipped to DRTE in Ottawa for processing (2).
Orroral Valley, Australia	Orroral Valley, 50 km southwest of Canberra, was the largest STADAN station in the Southern Hemisphere, which opened in February 1966. It had a 26 m parabolic dish. A new Australian STADAN station was needed as Woomera was no longer a cost-effective location and was closed in 1972 (9, p. 47).
Byrd Station, Antarctica	'Old Byrd' was erected by the U.S. Navy in 1957 as one of the International Geophysical Year activities, but it collapsed due to snow four years later (17). A new underground station began construction in 1960 and was used until 1972. It is the 'New Byrd' station that would have received Alouette-1's data. The site's population was about 50-60 persons in the summer, and half of that for the winter. Most of the camp occupants were civilian scientists, with the remainder as Navy personnel (18). While the station received satellite tracking tasks from the Goddard Space Flight Center, it was not technically part of the STADAN.
Rosman, NC, USA	From 1960-66, the GSFC oversaw the build up of eight additional STADAN stations on four continents: Rosman was one of these sites (9, p. 43). NASA invested over $5 M in the station in 1962, installing two 26 m parabolic dishes – making it one of the largest and most advanced stations in the STADAN (9, p. 51).
Tananarive, Madagascar	NASA realized that the Johannesburg station was too far east to be able to track highly elliptical, high apogee orbit injections in the Southern Hemisphere. In December 1963, the U.S. entered into a 10-year agreement with the Malagasy Republic for the installation of a ground station in the northwest of Madagascar. "This agreement was reached in accordance with the spirit of a United Nations resolution calling for the application of results of space research to benefit all peoples. In addition to benefiting [the western Indian Ocean region with] weather forecasts (especially during [cyclone] season), the station provided jobs for some 200 local residents in nontechnical positions for handling of day-to-day station maintenance." (9, p. 54)

V. The 1990s and NASA Goddard's Alouette-ISIS Topside Sounder Data Restoration Project

We have discussed the achievements and legacy of Alouette-1 in its time. A few decades later, Colin Franklin (Chief Electrical Engineer for Alouette-1) delivered a speech in 1993 for an IEEE International Milestone in Engineering awards ceremony. At the very end of his speech, he wondered aloud:

> *The Alouette/ISIS program produced a mountain of some 50,000 analogue tapes of topside sounder data. Is anyone going to digitize and preserve these for the archives or are they simply going to be thrown out? A question for the CSA and perhaps DOC to ponder (5)*

Dr. Franklin was referring to the original 7-track magnetic telemetry tapes, recorded at international ground stations and shipped to Ottawa for processing into ionograms. Magnetic tapes such as these were expected to last about 10 to 20 years before they would start to degrade. By 1993 many of the Alouette-ISIS tapes would have been past their shelf life; the earliest Alouette-1 tapes would have been over 30 years old. Furthermore, the early-to-mid 1990s was a period of cost-cutting for the Government of Canada. For these reasons, the National Archives of Canada, and the Communications Research Centre (CRC) were considering destroying the tapes.

By 1996, approximately 100,000 Alouette-1, Alouette-2, ISIS-1 and ISIS-2 telemetry tapes remained in storage. It was estimated that more than 80% of these were from ISIS-1 and ISIS-2 (19). It is unclear what happened to most of the Alouette-1 tapes, but it is likely that they were already destroyed by this time. The NASA Ionosphere, Thermosphere, Mesosphere (ITM) Data Evaluation Panel noted "the importance of these multisolar-cycle observations of the topside ionosphere and the danger of losing these data, gave highest priority to an Alouette/ISIS data restoration project." (19) With the help of Gordon James of the CRC in Ottawa and with funding from NASA (20), Robert Benson of the NASA Goddard Space Flight Center (GSFC) and his team initiated a digitization process. About 16,200 telemetry tapes were shipped to GSFC (13,800 in March 1996, and an additional 2,400 in July 2006), 2,500 tapes remained at the CRC, and apparently 81,000 tapes were discarded (19).

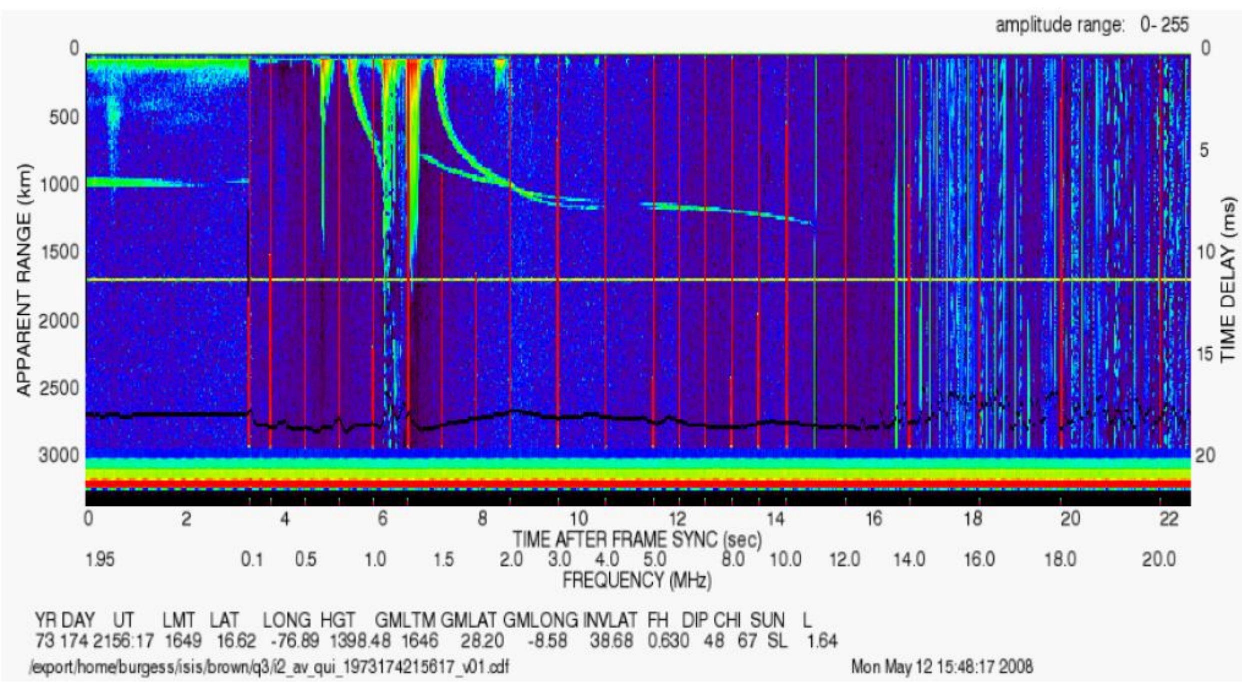

Figure 8: Digital ionogram produced from an ISIS-2 telemetry tape, recorded at Quito station in 1973 (19). Credit: Robert F. Benson and Dieter Bilitza, NASA Goddard Space Flight Center.

The aim of the digitization effort was to read the analog telemetry tapes and process the data to produce digital ionograms (see Figure 8). In the past only a small percentage of ionograms were 'manually scaled,' a tedious process to ultimately calculate a vertical electron density profile from each ionogram. However, with ionograms in a digital form, the manual scaling process (also known as 'inversion') could be automated. An algorithm was developed called TOPIST (Topside Ionogram Scalar with True Height) to process the digital ionograms and produce a rich set of topside electron density profiles (19, 20, 21).

The GSFC team chose to digitize the original telemetry tapes, rather than the 35 mm film ionograms, because it was thought to be a more accurate process. This would make sense to recover data from its most original recorded form available, rather than a processed form which could have introduced additional artifacts, noise and complications (19).

While a timely and remarkable project, the NASA Goddard data restoration effort included only 2 telemetry tapes from Alouette-1 (22), as these tapes may have been destroyed or were significantly degraded by 1996.

VI. 2010 to Today – Saving, Digitizing and Extracting Alouette-1's Data for the Future

While the magnetic telemetry tapes could last 10-20 years, the 35 mm films of ionograms that were produced by the DRTE data processing facility can last 35 years in dark storage, at ambient temperature. Each film roll was stored in a 102 mm x 44 mm metal canister. The film used was Kodak 5071 Ektachrome Duplicating film, which have a cellulose triacetate base. Such acetate-base films when they degrade produce acetic acid (vinegar). Hence this kind of film degradation is often called 'vinegaring', or 'vinegar syndrome' in the film industry, and smells as such. However, in cooler storage (such as 4°C) acetate-base films can last for over a century. While cold storage can minimize acetate production, chemical degradation of the film base is irreversible (23).

By 2010, the Alouette-1 and other Alouette-ISIS film rolls would have been in storage for over 40 years – like the magnetic tapes in the 1990s, well passed their 'best before' date. The Communications Research Centre of Canada (CRC) was the owner of about 30,000 film rolls that were stored by Library and Archives Canada (LAC) on its behalf – that would have included data from all four Canadian ionospheric satellites

Figure 9: Nearly 30,000 35 mm negative film rolls, containing ionograms from Alouette-1, Alouette-2, ISIS-1 and ISIS-2 were stored by Library and Archives Canada until 2012.

(Alouette-1, Alouette-2, ISIS-1 and ISIS-2). That year Gordon James of the CRC informed the Canadian Space Agency (Josée Saint-Marseille, Pierre Langlois) that LAC would no longer be able to store these artifacts, due to recent policy changes in the Government of Canada and concerns over long-term storage and costs.

Josée Saint-Marseille, Pierre Langlois, Louis-Paul Bédard and others began to make the argument that the CSA should take over ownership of the film rolls from the CRC. It was thought that the Alouette-ISIS data were still of value as historical context relative to new data expected from the enhanced Polar Outflow Probe (e-POP) on the upcoming CASSIOPE satellite. On March 23, 2012, a memorandum of understanding was signed between the CRC and the CSA, confirming the agreement for "transfer of approximately 28,738 35 mm film canisters containing topside and bottomside ionograms presently stored at the Library and Archives Canada site in Ottawa…to the control and custody of the Canadian Space Agency to assist in their future endeavours in space research." By taking ownership of the ionogram film rolls, it was estimated to cost the CSA about $10,000 per year.

There was an urgency to digitize the film rolls before any significant degradation could occur. Furthermore, by the 2010s firms that had expertise in the digitization of old films were already starting to shut down those operations. Faced with the prospect of potentially paying up to a million dollars, in 2015 it was proposed that Canadian schoolchildren could complete the digitization task. It was thought that students could use their smartphones to photograph each ionogram and manually record the metadata. By introducing students to new science concepts, the student could even perform the 'manual scaling' procedure that was used in the 1960s to calculate the peak electron density at the F2 region of the ionosphere. The student would then submit their results on a CSA website, with their name, their school, the photograph, the metadata, and the electron density calculation. While an interesting approach, it would have likely created several additional data quality issues.

Instead, by 2017 the CSA contracted Terra Reproductions to digitize the film rolls. Starting with Alouette-1 the mass digitization effort eventually resulted in 5054 film rolls scanned, yielding 1,612,104 images of ionograms. By compressing raw TIFF image files to PNG, that reduced the total file size by a factor of 4. This intervention still left a mammoth 1.831 TB worth of images.

By April of that year the CSA collaborated in NASA's 2017 Space Apps Challenge for the first time. Even though the digitization of the Alouette-1 film rolls was just getting started, one of the challenges posed to Canadian participants was to find a way to read the metadata associated with each ionogram, so that the images could be organized. A team of math and engineering students from the University of Waterloo (Arumuga Ganesan, Jay Soni, Milan Patel) won the award by developing a way to read the 'num' and 'dot' metadata types, by checking the relative positions of each number (or dot) in each metadata lane (24).

This approach to reading the metadata carried forward. Over the next few years, Etienne Low-Décarie and

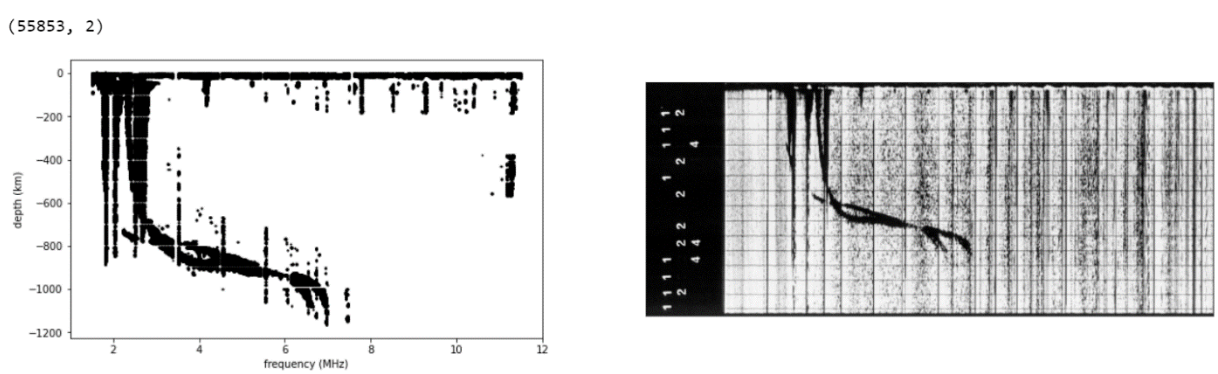

Figure 10: (left) Extracted datapoints mapped to a depth-frequency space; (right) the corresponding scanned image of the ionogram.

his team (Jenisha Patel, Wasiq Mohammad, Hansen Liu) at the CSA started to develop a data extraction algorithm, by extracting the ionogram trace from the scanned image and mapping it onto a frequency-depth space (see Figure 10). They also integrated and improved the metadata reading method.

By 2023, the current team at the CSA (Ravendra Naidoo, Roksana Sheikholmolouki, Ashley Ferreira, Jackson Cooper, Marianne Fortier, Benjamin Cannings, Émiline Filion and Natasha Fee) scaled up image processing with the data extraction algorithm to process all available Alouette-1 images (1,612,104 images). This was made possible with the use of the Agency's in-house high-performance virtual computing environment. However, by applying the algorithm to the entire set of images, it was quickly realized that there was another metadata type, referred to as 'num2'. This new, easier to read metadata format was introduced by the ISIS Working Group for Alouette-2 ionograms in 1965 – but the new format also applied to Alouette-1 ionograms which of course were still being produced that year. A machine-learned text recognition model was employed to read the numbers directly from the scanned images that had this type of metadata (see Figure 11).

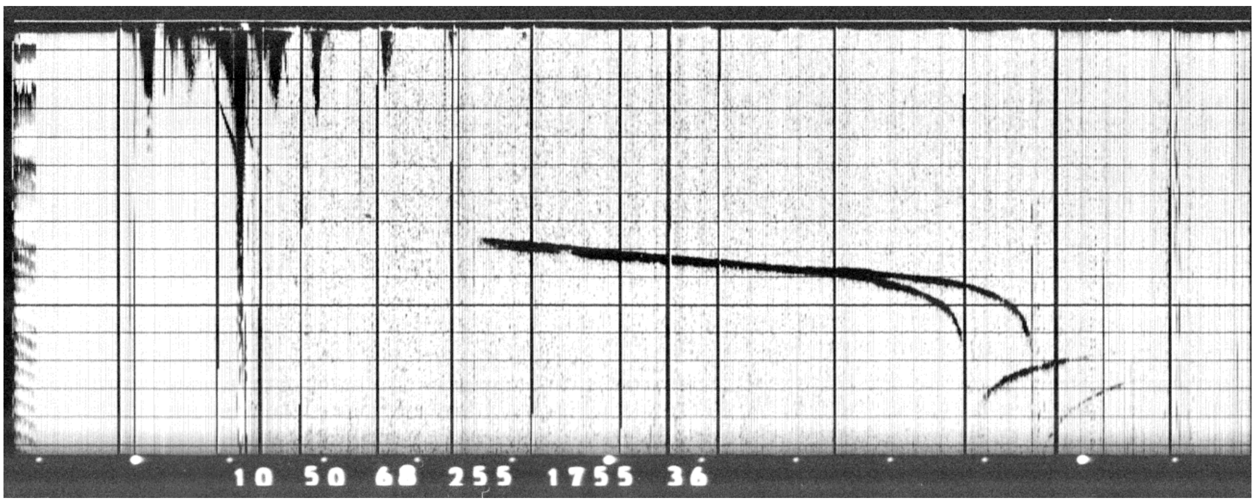

Figure 11: An easier to read numeric metadata format was introduced in 1965. A machine-learned text recognition model was used to read the metadata from ionograms with this format.

More can be done to improve the data extraction algorithm. But processing yield is also limited by scan quality issues, film quality issues, and even telemetry tape quality issues. For instance, the NASA Goddard data restoration project documented that when reading the telemetry tape, there were sometimes more frequency markers detected than expected, and the ionogram frame sync pulse (that indicates the start of the ionogram) was sometimes not detected at all (21). These telemetry tape data quality issues would have likely impacted the analog ionograms produced in the 1960s, and such issues are observed in the scanned images today.

Ultimately, 693,677 scanned images were fully processed and read – **representing a massive new dataset of Alouette-1 digitized topside ionograms.**

VII. The Scientific Value of Alouette-1 Data Today

In the 1960s and 70s a manual approach was used to interpret the data. By looking at an ionogram directly and picking a point on the reflection trace, one could calculate the electron density at a given altitude – a process called 'manual scaling'. For all Alouette-1 ionograms recorded between 1962-68, the electron densities at the satellite and at the peak of the F2 region of the ionosphere were calculated. These results have been tabulated for about 1.5 million ionograms in what “was truly a monumental data analysis task.” (3, p. 4) The results were published in 114 volumes called the ‘Alosyn’ dataset (Alouette topside sounder synoptic data).

However, by picking more data points on an ionogram (as many as 30) an entire ionogram reflection trace can be converted into a vertical electron-density profile. This would have been highly tedious and laborious work. As a result, only about 60,000 Alouette-1 ionograms have gone through this manual ‘inversion’ process. Most of that work was done at DRTE in Ottawa, as well as NASA’s Ames Research Center and the Radio Research Station in England (3, p. 6).

The NASA Goddard Alouette-ISIS data restoration project was able to pass its digital ionograms through an algorithm called TOPIST, to mass produce vertical electron-density profiles. However as discussed, their data restoration project included almost no data from Alouette-1. It is hypothesized that the new dataset of extracted Alouette-1 ionograms, from the digitization of 35 mm films, could also be processed by the TOPIST algorithm to generate vertical electron-density profiles. Nevertheless, the ‘inversion’ procedures (manual scaling, and TOPIST) require two assumptions: that there was a vertical incidence of the radio wave, and that electron density in the ionosphere is spherically stratified (as in it only varies in the vertical dimension). Nevertheless, new inversion algorithms could be developed and applied to the newly extracted Alouette-1 data.

The new Alouette-1 scanned images and extracted data, and the data extraction algorithm that was developed, will be openly available on the CSA’s Open Data Portal and the CSA’s GitHub page, respectively.

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A Canadian Space Agency scientist and engineer, who worked to save Alouette-1’s data, reflect on the scientific significance of having this data today:

Pierre Langlois (Program Lead, Sun-Earth Systems Science), Canadian Space Agency:

It is no accident that the first four Canadian satellites were aimed at understanding our ionosphere and its response to space weather. Canada lies under the auroral zone, which separates the country into three distinct magnetic zones. The auroral zone, where the aurora is visible, is magnetically connected to the nightside magnetosphere, where magnetic reconnections can trigger auroras. South of that zone, the magnetic field lines are dipolar and connect to the Southern hemisphere. North of the auroral zone, the magnetic field lines are open towards space or connect to the Sun. This complex magnetic topology brings to Canada a variety of space weather conditions, affecting our electrical grids, communications, navigation, and more. Sixty years have passed since Alouette’s first signal has begun probing the ionosphere, and space weather still has many mysteries to be revealed. The world is uniting around this challenge, understanding that such a global phenomenon requires international collaboration, be it through magnetic measurements from the ground, auroral observations, radio wave sounding, or radiation measurements.

Fifty-one years to the day after Alouette-1 launched, the Canadian CASSIOPE spacecraft was launched on September 29, 2013, to continue the pioneering work of Alouette, offering ionospheric data to a new generation of scientists. Its new measurements offer new insight into space weather processes, ***but no satellite can provide what the Alouette data contains: a glimpse into the 1960’s ionosphere, at a time where satellites were far and few. This data, once reserved to scientists, is now available to all, and can be re-analyzed using computers vastly more capable then were available at the time.***

Louis-Paul Bédard (Operations Engineer, ISS Projects Implementation and Payloads Development), Canadian Space Agency

The Alouette-1 data holds scientific, historical, and perhaps even judiciary value. Beyond its successful original purpose of measuring electron density profiles, the data holds in the form of noise, a time history of recorded events; natural and manmade that have affected the ionosphere. This is particularly true for its VLF receiver data [the satellite's secondary experiment]. The ionosphere being at the interface between the terrestrial atmosphere and the solar system environment, it contains information from both. Terrestrial, solar, perhaps even astronomical events observed elsewhere could be correlated with the events observed on the Alouette-1 dataset. If so, the Alouette-1 data could enable an independent confirmation of events that have taken place. This certainly has value scientifically, but also in other fields, for instance the presence of man-made signals that correspond to a particular conjecture of events on the ground. 10 years of well-measured, continuous data in any field of study is not to be dismissed lightly.

The Alouette-1 data has even greater value when combined with the rest of the Alouette-ISIS database, as it extends it by 3 years and increases the number of samples of the entire database by another 7 years. This is no small contribution – as 10 years represents almost an entire solar cycle – which is capital in the field of solar physics, where the ionosphere is primarily affected by the Sun. Long range predictions and observations on cyclic and event-driven phenomena are thus rendered more complete by the presence of the Alouette-1 data. This applies particularly to the swept-frequency topside sounder data for use in Space Weather statistics for extreme events (such as solar storms), similarly to the database for atmospheric data from Environment Canada that is used for extreme weather modelling. In September 2023, it will be 61 years since the start of any measurement in the ionosphere and yet the entire Alouette-ISIS database covers a continuous recording of the very first 28 years. That represents close to half. Without the Alouette-1 data, the dataset is simply not as complete and misses the first 3 years.

The study of the Ionosphere is still in its infancy. There are many phenomena in the upper atmosphere that have been discovered only recently, such as Transient Luminous Events, i.e. pixies, sprites, elves, etc. Any additional data is capital in making an inventory of how many of these events took place to understand what they are. Perhaps some of them constitute a door to new physics, not yet understood. Also, probes have been sent to other planets and satellites to acquire ionosphere data. Having Terrestrial data to compare with other planetary models is essential in the field of planetary science modelling: the more, the better. Finally, earthquakes are presumed to affect the ionosphere. Any additional data is crucial to understand the physics behind these titanic events and could help in saving lives. ***For all these reasons, the Alouette-1 data is vital and deserves to be preserved.***

VIII. Historical and Cultural Value of the Alouette-1 Data

As the 35 mm negative films continue to degrade, it is the scanned images and the extracted data that will endure. Alouette-1 still orbits the Earth at about a 1000 km altitude (25). Until the satellite can be recovered somehow, these films, these scanned images, and these extracted data, are the only real pieces of proof available that Canada did this pioneering work – that Canada was the third country to successfully build, design and operate an artificial satellite. Physical and informational artifacts as these are important to Canadians today, and for generations to come.

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