# POTENTIALS OF SATELLITE IMAGERY FOR MONITORING ARCTIC GOOSE PRODUCTIVITY



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## Introduction

The arctic breeding grounds of North America supply most of the geese available to Canadian, American, and Mexican hunters.1/ During the 1973-74 hunting season, species nesting exclusively in the arctic comprised 38 percent of the combined total Canadian and U.S. goose harvest.2/ Furthermore, the bulk of the remaining harvest consisting of Canada geese (*Branta canadensis*) was also extracted from arctic breeding populations.

Of the many factors affecting reproductive success of arctic nesting geese, perhaps none is more important than the timely disappearance of snow and ice ground cover which allows geese to nest and rear offspring before the onset of fall. Because of the vastness, inaccessibility, and severity of the North American arctic, relatively few on-site studies of nesting geese have been undertaken, and most of these have been in the Hudson and James Bay regions. Logistical problems and associated high costs clearly preclude conducting on-site appraisals of goose production throughout the arctic on an annual basis.3/ Such information, even if obtainable, would have to be readily available if it is to be considered in setting annual hunting regulations. Inability to recognize catastrophic production situations, especially in successive years, has sometimes led to overharvests and short-term population declines, some so severe that closed seasons and several years of good production have been required to restore populations to former levels.

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1/ Although the Arctic Circle circumscribes the earth at 66° 30' N. latitude, the term "arctic" as used here refers to the area beyond the northern limit of tree growth.

2/ Exclusively arctic-nesting geese include brant (*Branta bernicla hrota*), black brant (*Branta nigricans*), emperor geese (*Philacte canagica*), white-fronted geese (*Anser albifrons*), snow geese (*Chen caerulescens*), and Ross' geese (*Chen rossii*). Harvest data sources: Cooch et al. (1974); Files, Office of Migratory Bird Management, Laurel, Maryland.

3/ The Canadian Wildlife Service estimates that costs in placing a field crew in the arctic for sufficient duration to ascertain goose productivity in a limited area approaches $50,000.

This paper reports upon the exciting possibility that satellite imagery may now provide a feasible means for grossly monitoring arctic habitat conditions in a timely and economical manner. Hopefully, space-age technology will enable waterfowl biologists and administrators to recognize years of catastrophic goose production and adjust regulations accordingly. More appropriate regulations should be beneficial to the respective arctic nesting goose populations, and to the long-term interests of the hunting and non-consumptive public.

## Satellite Imagery Products

Satellite photographs and imagery are among the most fascinating by-products of our space program. New applications of space technology are being found or developed daily. Products available from the Earth Resources Observation System (EROS) located at the EROS Data Center, Sioux Falls, South Dakota, are generally familiar to the scientific community. These include imagery provided by the Earth Resources Technology Satellite (ERTS), Skylab, U.S. Geological Survey photographs, and National Aeronautical and Space Administration (NASA) aircraft. Less familiar--except as daily weather maps printed in newspapers or displayed on television--but potentially more useful for some arctic studies are products derived from National Oceanic and Atmospheric Administration (NOAA) spacecraft, particularly the series of Improved TIROS Operational Satellites. The first of these spacecraft was launched in mid-1972, and NOAA-4 is the latest of the series now in orbit.

General features and technical information on the TIROS Satellite are described elsewhere (Schwalb, 1972). These satellites, launched at Wallops Island, Virginia, by two-stage Delta launch vehicles, are orbited about 790 nautical miles (1464 kilometers) above the earth. The satellite weighs 741 lbs. (336 kg), of which 220 lbs. (100 kg) consist of sensors and tape recorders. Primary sensors include two Scanning Radiometers (SR), two Vertical Temperature Profile Radiometers (VTPR), and two Very High Resolution Radiometers (VHRR). The spacecraft measures only 40" x 40" x 49" (102 cm x 102 cm x 125 cm), plus three 65" x 36" (165 cm x 125 cm) solar panels (Figure 1).

The satellite orbits are sun-synchronous and quasi-polar with tracks converging toward the poles and diverging toward the equator. The scanning patterns of the three sensing systems are depicted in Figure 2. Twelve or thirteen orbits circle the earth daily (Figure 3). Sensor data suitable for processing are transmitted to Command and Data Acquisition (CMD) stations located near Fairbanks, Alaska; San Francisco, California; and Wallops Island, Virginia.

Operational satellite products available from NOAA's National Environmental Satellite Service (NESS), Washington, D.C., are described in an illustrated catalog (Hoppe and Ruiz, 1974). Both the SR, the basic imagery sensor, and VHRR sense visual and infrared (IR) radiance in similar spectral channels; however the latter's more rapidly revolving scanner and narrower field of view provide almost two orders of magnitude more data and greater resolution. The VTPR instrument is designed to measure IR radiance, thus it is useful for deducing the atmospheric temperature profile of the radiating column. Although all three TIROS sensing systems may eventually be found useful, the VHRR service system presently seems most applicable to our needs. This sensor produces images encompassing approximately 1 million square miles with a possible resolution of 1/2 mile. Output since 1973 is available on positive black and white photographic prints or negatives measuring 10.5 inches square. Data from the VHRR sensor can also measure sea water surface temperatures to within 1-2° Centigrade, and with slightly less precision, temperatures of the earth's land surface.

Comparative information between VHRR, and MSS (Multi-Spectral Scanner) imagery of the ERTS system, was compiled by Munro (Table 1). Obvious advantages of VHRR output for our application include: (1) more frequent coverage of a given geographical location; (2) much larger field of view; and (3) near real-time availability of output. All factors are extremely important. Storms or related weather patterns typically cover much of the arctic in late spring and early summer. Thus the loss of one or two ERTS coverages because of cloud cover or fog would essentially preclude useful observations of localized nesting areas at critical periods of the reproductive cycle. Also, delays in obtaining ERTS coverage for areas outside Canada seriously jeopardize its usefulness for regulatory purposes. ERTS coverage in Canada, however, is available on a near real-time basis from Donald Fisher and Associates, Ltd., Prince Albert, Saskatchewan, Canada, on microfiche. Migratory bird hunting regulations in the United States must be established by mid-August to fulfill legal requirements. Canadian hunting regulations must be finalized by early summer. The obvious disadvantage of VHRR imagery for our needs is the reduced resolution (1/2 mile for VHRR vs 300-400 ft. for MSS). Costs per photographic print are comparable ($2.09 for retrospective VHRR vs. $1.75 for MSS); however, on an area basis VHRR photos cost only about 1/100th as much as MSS imagery. On real-time basis, VHRR photos cost $1.50 each. Each satellite product has its advantages and disadvantages, depending upon specific needs. MSS imagery from ERTS seems better suited to situations requiring high resolution, where timely monitoring and ready availability of output are not critical considerations. In contrast, VHRR imagery seems better adapted to gross evaluations and timely applications.

Factors Affecting Productivity of Arctic Nesting Geese

Many factors influence the annual productivity of arctic geese. For a given-sized population returning to the nesting grounds, the age composition is extremely important. Depending upon species, geese normally do not breed until 2 to 3 years of age; veteran nesters presumably are

Table 1. Gross comparison of satellite imagery products which may be useful in improving forecasts of arctic nesting goose production

| Description | ERTS Multi-Spectral Scanner (MSS) | NESS Very High Resolution Radiometer (VHRR) |
|---|---|---|
| Data available back to | July 1972 | ca July 1973 1/ |
| Recycle rate | 18 days 2/ | 1 day |
| Processing and shipping time - Canada only 3/ | ca 6 days | ca 6 days |
| Processing and shipping time - other areas | 4-6 weeks | ca 6 days |
| Area of coverage per frame | $1 \times 10^4$ sq. miles | $1 \times 10^6$ sq. miles |
| Resolution, sub-satellite | 300-400 ft. | 1/2 mile |
| Sensitivity | visible + IR | visible + IR |
| Cost per frame (B/W paper print) 4/ | $1.75 5/ | ca $1.50 6/ |
| Order from | 7/ | 8/ |

1/ Some data are available back to about October 1968 from earlier weather satellites; however resolution of these images is on the order of 2 miles.

2/ Because ERTS tracks converge toward the poles, recycle rates may be only 14-15 days for areas north of about 70° N.

3/ Donald Fisher & Assoc., Ltd., P.O. Box 1630 Prince Albert, Saskatchewan, Canada, can provide on a standing order basis microfiche coverage of virtually all of Canada within about 6 days after satellite pass. Cost for 30 days (1-1/2 ERTS cycles) of imagery over Canada is $100.

4/ Other forms of data products are available at higher prices.

5/ Note cost of microfiche mentioned above.

6/ This price pertains to standing order or pre-arranged orders. Cost increases to about $2.10 for data which must be retrieved from storage.

7/ Donald Fisher & Assoc., Ltd., Prince Albert, Saskatchewan, Canada, or EROS Data Center, Sioux Falls, South Dakota.

8/ National Environmental Satellite Service, Environmental Products Group, Room 3301, Federal Office Building 4, Silver Hill and Suitland Roads, Suitland, Maryland 20233 (Phone: AC 301/763-2745).

more productive than novice breeders.

Arctic geese have a relatively short period of time available within which to build nests, lay and incubate eggs, and rear young to fledging. Also, opportunity for renesting is greatly curtailed, if not eliminated altogether. In his studies of lesser snow geese (*Chen c. caerulescens*) Cooch (1964) wrote:

> "The seasonal activity of lesser snow geese is much the same at the different colonies. In the East, the birds arrive about June 1 and begin to nest within 2 weeks. In the western Arctic nesting generally begins a week earlier, during the last week of May. Egg laying ceases 11 days after the first has been laid. Incubation takes 22 or 23 days. In mid-August, 42 days later, young birds make their first flights. Nonbreeding adults and subadults leave the breeding ground about that time. Adults, with young follow during the first week of September."

Thus, lesser snow geese require about 96 days total for these activities.

The regime for white-fronted geese requires 3 weeks for egg-laying, beginning about May 25, 23 to 28 days for incubation, and 6-7 weeks for growth and fledging of young (Dzubin, Miller, and Schildman, 1964). Other species are similarly adapted to short arctic summers by being physiologically capable of nesting shortly upon return to their breeding grounds. Also the long summer days are conducive to increased feeding activity, accelerated growth of goslings, and rapid moulting of adults.

Arctic goose production may sometimes be spectacularly successful or abysmally poor, but is more often somewhere between the extremes. Generally, good production may be anticipated during years characterized by early disappearance of snow and ice. Such a year was 1973, when exceptionally early spring conditions prevailed across the arctic. The anticipated excellent production of most species that year materialized (Anonymous, 1973) according to high age ratios of geese harvested in the United States that fall and winter (Files, Office of Migratory Bird Management, Laurel, Md.).

In contrast, brant of the Atlantic Flyway experienced negligible reproductive success during 1971 (.06 immatures per adult) and 1972 (.0008 immatures per adult). Field observations of 15,664 brant during the winter of 1972-73 included only 13 young of the year (Files, Office of Migratory Bird Management, Laurel, Md.) Thus, two successive years of production failure, harvest during the 1971-72 season, and natural attrition caused the brant population to decline from 151,000 birds in January of 1971 to 40,700 in January of 1973. Consequently, no brant hunting was allowed in the United States during 1973 and 1974. Another recent example is the poor production of greater snow geese (*Chen c. atlantica*) nesting on Bylot Island, north of Baffin, during 1974 (Heyland personal communication).

As opposed to 1973 when uniformly favorable breeding conditions prevailed across most of the arctic, regional variations occur most years. Thus species or management populations which are more extensively distributed during the nesting season probably demonstrate somewhat greater environmental resilience and population stability than those concentrated into small geographical or ecological niches where they are more susceptible to adverse factors.

Barry (1962) spent three breeding seasons on the brant colonies of Southampton Island, N.W.T., studying the effects of weather on reproductive success. He noted that the preferred brant nesting habitat, usually characterized by sedge, cleared of snow and ice 7 to 9 days later than upland nesting sites chosen by snow geese and Hutchin's geese (*B. c. hutchinsi*). During the 1956 and 1957 nesting seasons, both retarded seasons in terms of ice and snow disappearance, clutches averaged fewer eggs than in the advanced 1953 season and non-nesting adults were more numerous among flocks of non-breeding birds. Barry's physiological studies demonstrated that atresia, or resorption of maturing follicles, occurred if nesting conditions remained unfavorable. Causes suggested for atresia included: (1) snow cover which reduced the amount of available food; (2) low temperatures which forced birds to expend energy for warmth rather than egg development; (3) absence of an "environmental stimulus"; and (4) intense competition for the limited nesting sites. Barry estimated that 60 percent of the adult brant in his study area failed to nest in 1957. Because snow and Hutchin's geese nest earlier than brant, he estimated that approximately 85 percent of the breeders of these species failed to nest that year. Although atresia reduces the population in a retarded season, he speculated that it enhances the chances of adults surviving to the next nesting season. Barry concluded,

> "Because of the short arctic summer, clearance of the nesting habitat must coincide with the nesting stage of the brant's reproductive cycle. The later the thaw, the poorer the reproductive success."

Information on goose behavior under adverse arctic conditions is also available from Wrangel Island, offshore from Siberia, USSR (Uspenski,1965). Wrangel, located at 71° N. latitude, is an extremely important contributor of lesser snow geese which winter in the Central Valley of California. Uspenski quotes A. I. Mineev (1945, p. 364) as stating,

> "as had never happened before, the tundra [in 1931] was completely covered with snow during the whole of June and part of July, and there was a blizzard even in mid-June. We saw enormous numbers of geese flying around in search of nesting sites but without success."

Uspenski noted that the average clutch size of lesser snow geese in the late year of 1964 was 3.27 compared to 5-6 in normal years. Also, he stated that nests in areas where snow persisted the longest and where geese were less densely concentrated contained fewest eggs. During the same year, a large number of adults failed to nest although their gonads were normally developed. Uspenski found nonbreeders were most numerous where the snow melted late.

The foregoing examples of poor production, typical of many others on record, basically resulted from delayed disappearance of snow and ice cover. Because females of arctic nesting geese are physiologically far advanced for reproduction upon return to the nesting grounds, the availability of open ground suitable for nesting is imperative. Not any open ground will suffice as most arctic nesting geese are colonial or semi-colonial in nesting behavior. Brant remain in breeding condition only about 10 days following return to the nesting grounds. If nesting habitat remains unavailable, they and other arctic geese may forego attempts to nest. These survival adaptations, while causing a reduction or even void in annual production, enable adults to molt a month earlier and regain strong power of flight for fall migration. Arctic geese, like other geese, are biologically capable of long life. Being less vulnerable to hunting as adults, most will survive to nest when better habitat conditions exist.

Brant, although subjected to limitations imposed by presence of snow and ice cover, are sometimes confronted with an additional and related adverse factor. Forbush (1926) speculated that yearly numerical fluctuations of wintering brant denoted destruction of nests and young by arctic storms. Brant typically nest barely a foot above the high tide line on flats, islets, river deltas, and raised beaches, according to Barry (1964). Although Barry found that less than three percent of his nests under study were destroyed by high tides, the risk apparently is greater elsewhere. In Alaska, brant frequently nest below driftwood elevations (Spencer, Nelson, and Elkins, 1951). Cottam, Lynch, and Nelson (1944) stated that a rise of only 6 inches in the water level would destroy many brant nests, as happened because of a storm at the Yukon-Kuskokwim Delta in Alaska during 1963 (Barry, 1964). Hansen (1961) reported upon the potential effect of storm tides in considerable detail, noting that rhythm and height of tides in the Gulf of Alaska varies by calendar dates from year to year. Production losses in the Copper River Delta could be catastrophic if strong onshore winds coincided with a spring tide during a critical part of the nesting period. Incidentally, onshore winds have much greater influence upon tidal elevation when the sea ice is some distance offshore (Barry, 1964), as during years of early thaw.

Arctic nesting geese are subjected to a number of other decimating factors including weather and predation by parasitic jaegers (*Stercoranius parasiticus*), glaucous gulls (*Larus hyperboreus*), snowy owls (*Nyctea scandiaca*), wolves (*Canus lupus*), barren ground grizzly bears (*Ursus *arctos*), arctic foxes (*Alopex lagopus*), and red foxes (*Vulpes fulva*). These agents, although sometimes important locally, seldom are of great consequence to overall production, particularly for species or management populations having extensive breeding grounds.

Application of VHRR Imagery

The first step in assessing usefulness of VHRR imagery was to obtain a series of 1973 and 1974 photographs more or less centered over five well-distributed locations, describable by latitude and longitude degrees. These were:

| Site | N. Latitude | W. Longitude |
|---|---|---|
| 1 | 66 | 74 |
| 2 | 73 | 80 |
| 3 | 60 | 94 |
| 4 | 71 | 127 |
| 5 | 71 | 160 |

These sites provided reasonably complete coverage of the arctic from western Greenland to the extreme eastern USSR, including Wrangle Island, (Figure 3). Lacking knowledge of the historic phenology of ice breakup across the arctic expanse and goose nesting activity, a somewhat arbitrary imagery date of June 16, was selected by Munro and Reeves. Photographs for that date were ordered for each of the five areas; in addition, photographs were also ordered for June 15 and 17 to lessen chances of cloud cover or fog occulsion. Two other series of photographs were requested. The first was for the three-day period centered on June 2, and the second, a three-day period centered on June 30. Thus, nine photographs were ordered for each of five sites. A large proportion of the requested images were provided. A few were not available because the VHRR sensor does not record continuously.

Generally, the first series of VHRR images enabled us to grossly assess snow and ice conditions across the North American Arctic, including Wrangel Island and the extreme eastern USSR. These pictures support and elaborate on the generalized evaluation of arctic habitat conditions reported in The Status of Waterfowl and 1973 Fall Flight Forecast (Anonymous, 1973), and The Status of Waterfowl and 1974 Fall Flight Forecast (Anonymous, 1974). However, had the pictures been ordered on a real-time rather than retrospective basis, the imagery information would have been available 2-4 weeks earlier than the information obtained from miscellaneous sources relied upon in preparation of the status report. Also, instead of extrapolating "probable" conditions from scattered locations where habitat conditions were known, we would have had the entire arctic situation visually before us.

Among the specific conclusions which could have been drawn from the satellite images alone were the following: (1) early thaw of snow and ice throughout most of the North American arctic in 1973; (2) early to average thaw conditions in the subarctic during the summer of 1974 but delayed snow disappearance in the high Arctic; (3) retarded disappearance of snow and ice cover from Wrangel Island during both 1973 and 1974; and (4) poor habitat conditions for Bylot Island greater snow geese during the summer of 1974.

Our schedule calls for stepped-up utilization of satellite photos for monitoring arctic breeding ground conditions this summer. Two additional photo locations have been established to provide better coverage of arctic North America. The first is in north-central Quebec (55° N. Lat., 70° W. Long.) and on Axel Helberg Island (80° N. Lat., 90° W. Long.), in the high arctic. To assure acceptable imagery during the crucial mid-June period, the three-day period has been lengthened to five days with the additions of June 14 and 18. Because imagery will be on a real-time basis, the exposures should be more precisely centered over the designated photo points. More importantly, the photos should be available within a week after the last day of each of the three series of dates. In addition, we contemplate ordering complete ERTS coverage of Canada for the full month of June.

In our initial efforts to evaluate satellite imagery, attention will necessarily be directed to identifying years and areas of probable catastrophic nesting failure. Populations utilizing the high arctic are subject to the greatest limitations imposed by snow and ice cover and length of period within which to nest and rear young. For these nesting populations we should be able to identify situations where production obviously is impossible because of snow and ice cover on critical dates.

Supplemental information, however, will be required for ascertaining the probable degree of nesting success for many arctic nesting geese. Among these informational needs are:

1. Identification of goose nesting areas, by species, and breeding population sizes. Considerable information is already available in the literature and unpublished theses and field notes. The Canadian Wildlife Service has already mapped known nesting colonies. Alaskan areas should be systematically mapped on standardized topographic maps, such as the standardized 1:250,000 series now available for all of Canada and Alaska. Larger scale maps, when available, should be used for defining breeding colonies.

2. Data on physical characteristics of major breeding locations should be gathered and quantified. Topographic features would seem particularly important for assessing runoff or tidal flooding risks.

3. Larger scale EROS images, when available for key areas during critical time periods, should be examined for details facilitating the interpretation of VHRR imagery.

4. Relationships among migration routes, harvest locations, and breeding areas should be documented from the literature and through the further analyses of banding data. The recent comprehensive study of lesser snow geese banding data by the Canadian Wildlife Service provides a wealth of pertinent material (Dzubin, Boyd and Stephen, 1973; Dzubin, 1974). Information of this sort makes possible the identification of migration and wintering areas benefited by good production, or adversely affected by poor production.

5. Age-ratios of geese in family groups (Jones, 1970; Lynch and Voelzer, 1974), and harvested geese, harvest levels, and population estimates from Canadian and U.S. surveys, should also provide means for evaluating predicted productivity.

6. Insofar as brant are concerned, a ready means for monitoring the effects of storm tides on important nesting areas is needed.

With the continued accumulation and study of satellite imagery over the years, and the gathering of supplemental information as outlined above, it seems reasonable that we could progressively improve our predictive ability for arctic nesting geese. Exactly who will do what is yet to be resolved. Obviously the Canadian Wildlife Service and the respective Provincial conservation agencies are better prepared to assemble and evaluate data for the Canadian arctic, whereas the U.S. Fish and Wildlife Service and the Game Division, Alaska Board of Fish and Game, can provide similar information for the Alaskan arctic. We are hopeful that in the near future respective areas of responsibility can be determined, and that the operational utilization of satellite imagery can be realized.

Summary

Spacecraft imagery, especially from NOAA's Improved TIROS Operational Satellites, offers exciting possibilities for real-time evaluation of habitat conditions encountered by arctic nesting geese. Retrospective imagery for five widely scattered locations in arctic North America were obtained for three 3-day intervals in June 1973 and 1974. These satellite pictures grossly confirmed the fragmentary data available from a limited number of ground observations. Relationships between environmental conditions confronted by returning breeders, and result reproductive effort and success are discussed. Our immediate aim is to recognize catastrophic

production failures, but supporting information from ground studies, ERTS imagery, analyses of banding data, studies of age ratios in populations and harvests, and other sources may eventually permit assessment of the degree of reproductive success. Real-time imagery has been scheduled for 1975 and the temporal and geographical coverage expanded. Hopefully, the output will be available for consideration in setting the 1975-76 hunting regulations.

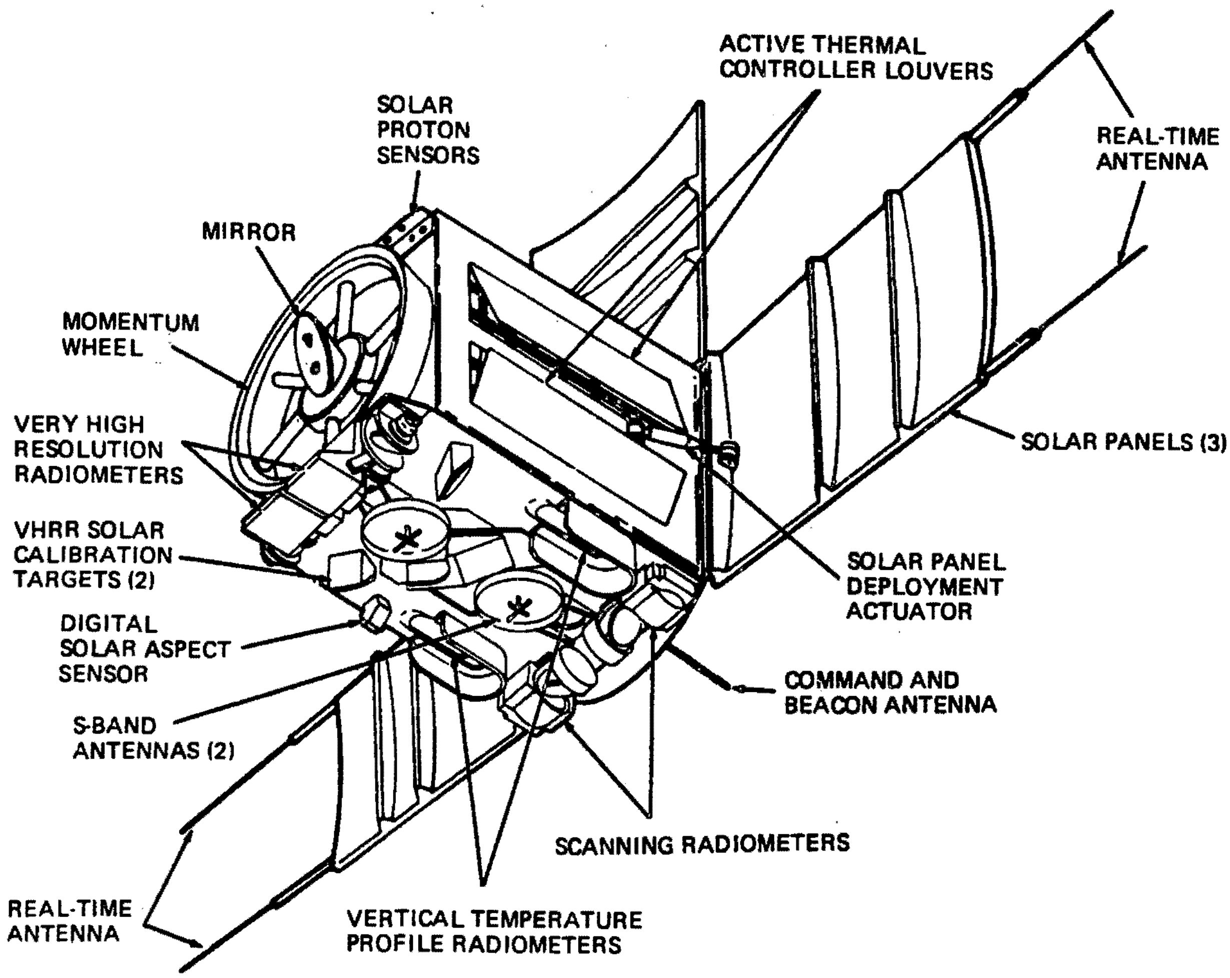



Figure 1. External features of modified ITOS spacecraft (from Schwalb, 1972).

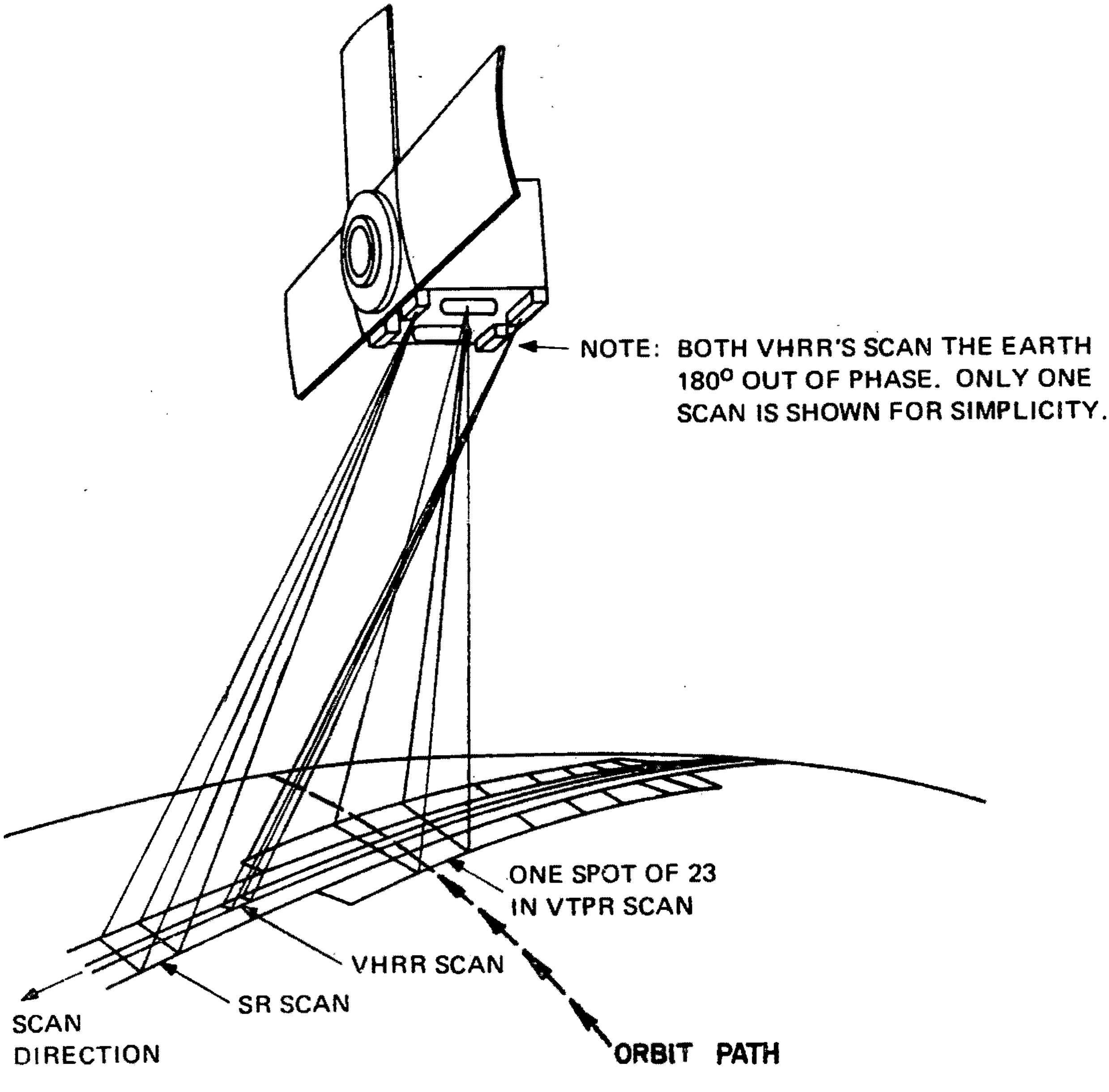
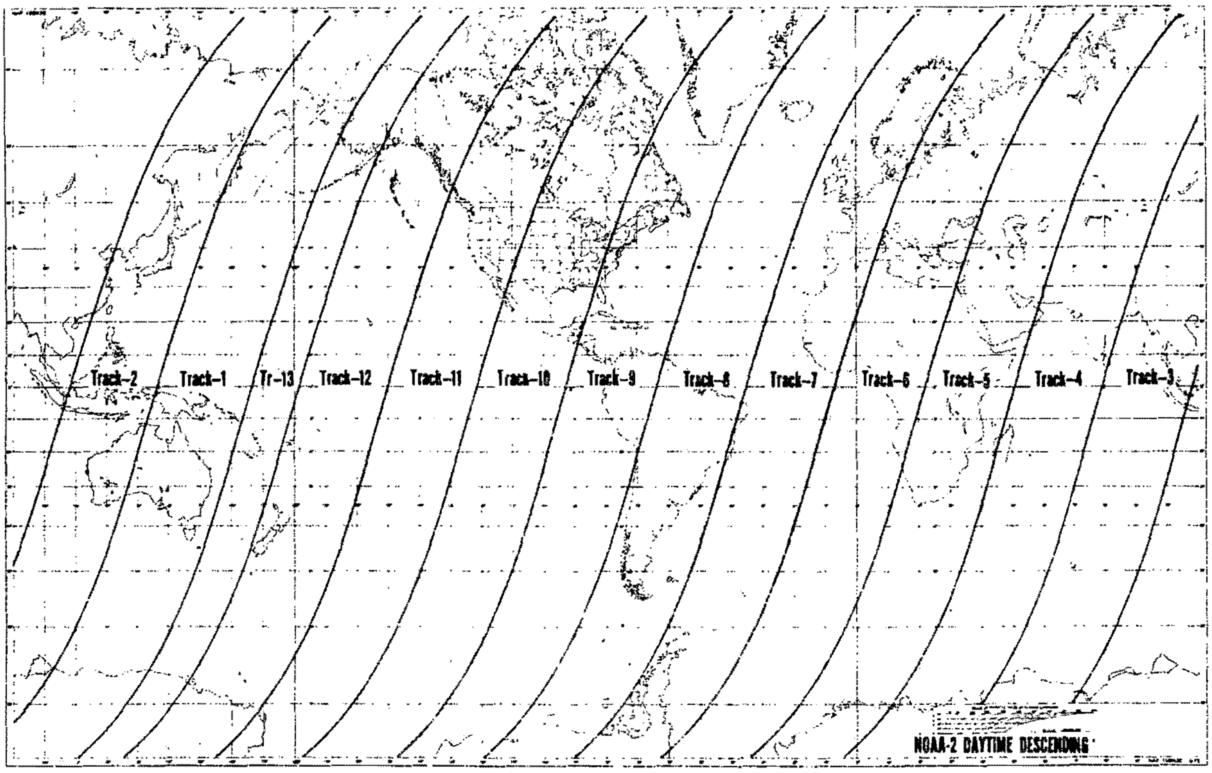



Figure 2. Modified ITOS spacecraft in operational mode showing sensor field of view (from Schwalb, 1972).



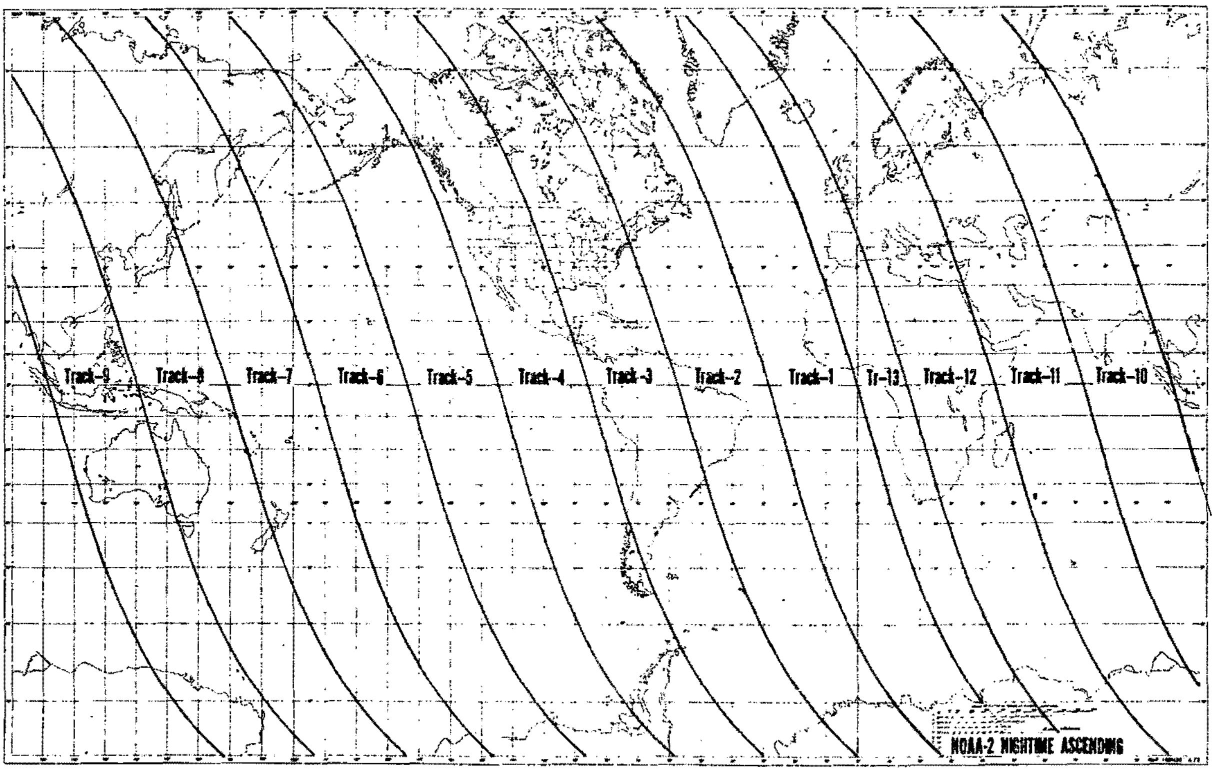




Figure 3. NOAA Subsatellite point tracks (from Hoppe and Ruiz, 1974).