

MONITORING THE OCEAN WITH NAVY RADAR ALTIMETER LIGHTSATS

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A system of three radar altimeter lightsats would provide optimum temporal and spatial sampling of the sea surface height signatures of ocean features at mid latitudes and above. Merging this data with satellite infrared images would provide a robust, affordable, all-weather, global ocean monitoring system in support of the Navy Tactical Oceanography mission.

The present Navy system for mapping ocean features uses sea surface temperature maps from NOAA satellite radiometers and sea surface height profiles from the Navy GEOSAT radar altimeter satellite. GEOSAT is a 1450-pound, completely redundant satellite with a 207-pound, 165-watt radar altimeter. GEOSAT was developed by JHU/APL and launched in March 1985 on an Atlas-E.

A lightsat-compatible radar altimeter instrument has now been developed at APL that achieves full GEOSAT measurement capability in one-half the weight and power (95 pounds and 69 watts), primarily by applying the latest advances in RF and digital components. A form, fit, and function engineering model of the altimeter is being fabricated for performance validation.

The conceptual design of GEOSCOUT, a Scout-launched version of the GEOSAT satellite, was completed to establish the technical feasibility of the radar altimeter lightsat concept. The spacecraft weight was reduced to 395 pounds and the configuration made Scout-compatible. These weight and volume reductions were made possible by downsizing the instrument, eliminating subsystem redundancy, and by updating subsystem designs.

The success of the GEOSCOUT conceptual design has encouraged APL to pursue the next logical step: a combined altimeter/radiometer lightsat. Work on that concept has now begun.

THE TACTICAL OCEANOGRAPHY MISSION

There is a growing awareness that successful detection and tracking of modern quiet nuclear-powered submarines requires precise and detailed knowledge of acoustic propagation conditions from the surface of the ocean to the bottom and over broad regions of the ocean. Consider the first order sonar propagation problem: a mixed layer of nearly constant temperature water near the surface can create a very efficient sonar propagation duct between the ASW sensor and the target. A target at the same range but a few hundred feet below the duct may be invisible. The propagation duct ends at the range where the mixed layer is disrupted. This can be caused by ocean fronts (like the Gulf Stream) and eddies that can create such "duct ends," shadow zones, and hidden targets in a very complex field of ocean features (Fig. 1). This paper argues that satellite ocean remote sensing instruments that are compatible with lightsats are able to provide the information required to map the underwater sonar environment.

The Required System for Tactical Oceanography

At the output the system must deliver a powerful product: accurate predictions of acoustic propagation between any two points in the operating area of interest.

This acoustic product can only be realized as the output of a range-dependent acoustic model that incorporates bathymetry, inputs on background shipping noise, surface conditions that impact background noise, and oceanographic inputs that provide temperature, pressure, and salinity fields from the surface to the bottom over the ASW operating area.

This oceanographic information can, in turn, only be developed by an ocean model. The model embodies the physics of fluid flow over the entire ocean basin. In smaller regions, it accurately reproduces the characteristics of smaller features, like eddies, that are perhaps 150 kilometers in diameter.

The ocean model is the critical element in the system. It allows the required subsurface fields to be computed given surface measurements that can be provided by remote sensing. Once initialized with measured data, the model can run forward in time to "forecast" the subsurface fields that will exist approximately one week in the future.

The boundary conditions provided by oceanographic measurements are required to insure the accuracy of the ocean model. These boundary conditions can be developed from a combination of satellite remote sensing and in-situ data. Since these data sources have different characteristics; for example, different spatial and temporal sampling, an observational system is required to merge the available data into orderly boundary conditions on the ocean.

Mapping Surface Signatures Using Satellite Remote Sensing Data

Satellite remote sensing has unique potential for solving the surface boundary condition problem by providing fast, accurate, and repeated coverage of fronts and eddies over the wide ocean area. The oceanographic parameters that can be measured from space can be demonstrated by examining subsurface temperature profiles across the Gulf Stream front and eddy system (Fig. 2). Entering a 150-kilometer diameter cold core ring south of the Gulf Stream at 300 meters depth can produce a 5 to 10°C water temperature decrease. The water temperature can drop 10°C in 100 kilometers in crossing the Gulf Stream from the south. These sharp subsurface isotherm gradients that impact sonar propagation at the north wall of the Gulf Stream and around a cold core ring create a surface temperature signature where the isotherms intersect the surface.

A sea surface height signature is created by the hydrodynamic effects of the flowing current and rotating ring. These cause a dynamic height change at the surface, the mean sea level changing in proportion to the current depth and velocity.

Satellite sensors that measure sea surface temperature (SST), and sea surface height (SSH) can, therefore, provide data about the location and characteristics of this front and eddy system. The measurement of these parameters from space has been established by flight experience.

The Advanced Very High Resolution Radiometer (AVHRR), a 50-pound, 50-watt scanning optical radiometer with a 6-inch primary mirror, measures clear weather sea surface temperature with a precision of 0.5 degree. The AVHRR is an operational instrument on the NOAA polar orbiting satellites.

Sea surface height is measured by the radar altimeter on the Navy GEOSAT satellite. GEOSAT was launched 12 March 1985 into an 800-kilometer altitude, 108-degree inclination orbit. The satellite is maintained in a 17-day, exact repeat ground track, providing surface height profiles along tracks 120 kilometers apart at mid-latitude (Fig. 1). Fortunately, ocean features move at a leisurely pace compared with features in the atmosphere. A Gulf Stream ring may take 30 days to move its own diameter (150 kilometers).

A unique surface mapping system to merge GEOSAT sea surface height profiles, AVHRR sea surface temperature images, and XBT point measurements of subsurface temperature was developed at the Naval Ocean Research and Development Activity (NORDA). The system operates by laying the altimeter data into the sea surface temperature image. The GEOSAT ground tracks are plotted as straight lines on the image and the measured change in mean sea level plotted at right angles to the ground track. The system operator extracts feature locations from this combined image, and a front and eddy map is produced.

This operational technique of combining altimeter data tracks with an image of the surface has proven very useful. The altimeter-measured height profile directly reflects subsurface current flow, a complementary measurement that aids interpretation of the SST images. The all-weather altimeter locates features in SST images that are either cloud covered or have lost their surface temperature signature (the rotating cold water in a cold core ring sinks after a period of weeks and is covered over by warmer water).

The ocean coverage provided by GEOSAT and the AVHRR complement each other. The Gulf Stream front can be located in the IR images approximately 70 percent of the time at mid-latitudes, but cloud cover severely degrades the images allowing recovery only 20 percent of the time in the North Atlantic. The GEOSAT ground tracks, on the other hand, have 120-kilometer spacing at mid-latitudes, too wide to completely sample the oceanography, but become closely spaced (approximately 50 kilometers) in the North Atlantic where clouds degrade the IR images. Despite this, sparse data density at the input to the mapping system is a limitation of the existing system. Confusion develops in the location of fronts and eddies that must be resolved with AXBT data.

Optimum Temporal and Spatial Sampling of the Ocean

A system of three radar altimeter satellites would provide optimum sampling of the sea surface height signatures of ocean features at mid-latitudes and above. A spatial scale of 60 kilometers would be provided (twice the coverage indicated in Fig. 1) with a temporal coverage of 11 days (for features that move one diameter in 30 days). Merging this data with sea surface temperature images as described would produce an all-weather, global ocean monitoring system. The following sections discuss the advantages and the feasibility of realizing this as a lightsat system.

Evolution of Lightsat Remote Ocean Sensing

It is significant that of the 51 satellites designed and built at APL, the heaviest two were altimeter satellites (GEOS-C, GEOSAT). That is because, until recently, precision spaceborne radar altimeters were heavy, high-powered instruments with large antenna apertures. In addition, the reliability requirements placed on GEOSAT, as an operational satellite, dictated full redundancy (except for the altimeter itself, where it was not practical). As a result, GEOSAT weighed 1450 pounds and required an Atlas-E to launch it. The NOAA spacecraft that carry the radiometers (among other payloads) are even heavier (nearly 4000 pounds at liftoff) and are also launched by Atlas. It was not, therefore, obvious that a remote ocean sensing mission would be compatible with lightsats.

Following GEOSAT, the Navy began planning a Remote Ocean Sensing Satellite (NROSS) with a suite of the most advanced sensors for altimetry, radiometry, and scatterometry, along with ultra-precise tracking systems, fully redundant subsystems, and even redundant instruments. NROSS ultimately became too expensive for the Navy and it was cancelled. Ironically, however, the NROSS requirement on APL to develop a fully redundant radar altimeter having the same performance as GEOSAT's, but with no increase in size or power, became the enabling factor for altimeter lightsats.

Around the time NROSS was cancelled, voices within DoD began questioning the wisdom of the military's dependence on an ever smaller number of increasingly large and complex satellites. The DARPA Lightsat program was born, and the Navy began planning its own version of lightsats. (The Navy, in fact, had 15 years earlier declared operational the first military lightsat system: the APL-designed TRANSIT navigation satellites.) The risk of putting all one's eggs in one basket was emphasized in the aftermath of the Challenger disaster in 1986. Two years later, the DoD Commission on Integrated Long Term Strategy issued its report emphasizing the importance of space for national defense, but critical of the U. S. dependence on large, sophisticated (and, therefore, heavy, expensive, and vulnerable) "peacetime" satellites. The commission urged greater use of proliferated constellations of military lightsats, along with planning for rapid replenishment in wartime.

By early 1986, APL had made significant progress toward downsizing the radar altimeter to meet the NROSS goal of two altimeters in the size, weight, and power of one. An engineering unit was partially fabricated. We soon realized that by flying one non-redundant half of the redundant NROSS altimeter, a *lightsat* altimeter mission might be possible. To explore this possibility, APL performed a conceptual design of a Scout-launched altimeter lightsat. This GEOSCOU design study showed that with advanced electronics, a modified redundancy approach, and a little mechanical ingenuity, it is feasible to perform the mission of the original 1450-pound GEOSAT satellite with a 400-pound lightsat.

Lightsat System Design Principles

Traditional satellite design makes every effort to amortize the high launch costs. Additional requirements and secondary instruments are added. System complexity grows, and it soon becomes necessary to increase the overall level of R&QA, redundancy, testing, and documentation so as to protect what has now become a major investment. The lightsat design philosophy is the mirror image of this: missions are narrowly focused and spurious requirements are curtailed. Oversophistication, overspecifying ("gold-plating"), and specifying "how" rather than "what" are scrupulously avoided. The resulting small, light satellites--launched by small, low cost launch vehicles--can afford to accept a reasonable increase in mission risk.

In particular, consider the subsystem redundancy issue. Redundancy is without question a powerful technique for increasing the probability of mission success. APL has employed redundancy extensively in its spacecraft and instruments, and even developed some of the techniques in common use today. GEOSAT was designed to a "no single point failure" criterion, and we are providing a fully redundant altimeter for NASA's TOPEX spacecraft. But redundancy is expensive; it usually takes twice the weight and volume, often requires more power, and always increases cost, interfacing complexity, and integration and test time.

For military lightsats, in particular, a number of arguments can be made for reducing subsystem redundancy. First of all, military lightsat missions are often of relatively short duration (e.g., reconstitution of assets during a crisis). Secondly, there has been a great improvement in the overall quality of electronic components. In addition, the use of large-scale integrated circuits has reduced part and interconnect counts. This combination of a smaller number of higher quality parts has improved the reliability of single string subsystems to the point that redundancy can be less important for short missions. The lightsat philosophy of simplifying and combining subsystems also cuts parts counts and again improves the overall single string reliability. Most importantly, those military lightsat missions designed for a wartime environment must consider anti-satellite measures to be a greater statistical risk than component failure. Subsystem redundancy provides little protection in this case. It is wiser, instead, to maintain redundancy at the level of the satellites themselves (i.e., by proliferation). In today's budget environment that is possible only with simple, low cost lightsats.

RADAR ALTIMETER DESIGN DESCRIPTION

The altimeter has the same block diagram, functional design, and performance as GEOSAT, but incorporates many new electrical and mechanical design features in order to achieve the desired weight and power savings.

The altimeter functions as a 13.6-gigahertz nadir-looking pulse compression radar. Figure 3 is a simplified block diagram. The Digital Chirp Generator produces a 102.4-microsecond pulse with a 40-megahertz chirp bandwidth. The pulse is upconverted to 13.6 gigahertz in the Up Converter Frequency Multiplier, amplified in the Power Amplifier, and routed to the antenna via the Microwave Transmission Unit. The resulting transmitted waveform is a 7-watt, 102.4-microsecond pulse with a 320-megahertz bandwidth.

The Receiver uses the linear FM signal as the local oscillator at the first mixer, transforming range sampling into frequency filtering. The Digital Filter Bank function of the Signal Processor provides the required range gates, implemented as digital filters in the time domain using a Fast Fourier Transform process. The Adaptive Tracker performs precise height estimation by tracking the sharp leading edge of the waveform.

The Synchronizer provides the complex timing required for the entire altimeter. The Interface Control Unit provides the interface functions between the altimeter and the spacecraft.

Several design advances were made to realize a lightsat version of the altimeter. These include a solid-state Ku-band power amplifier, a Digital Signal Processor (DSP) chip-based digital filter bank, a multiple bandwidth ECL gate array digital chirp generator, and redesign of the Signal Processor using gate array implementation of the "synchronizer" and "interface control unit" functions. Also, the Up Converter Frequency Multiplier was repackaged to obtain a lighter weight and lower power unit. The new altimeter is a non-redundant instrument, with a single interface to the spacecraft (GEOSAT had fully redundant interfaces).

The altimeter is packaged as a single unit (Fig. 4) with electronics configured on a circular deck of 34.9 inches diameter. This honeycomb deck provides the mechanical and thermal interface to the spacecraft. The antenna is mounted above the electronics by supports extending to the deck. The necessary EMI shield of the electronics is provided by electrically bonding the sides of the spacecraft to the antenna and the deck, illustrating the lightsat principle of obtaining multiple uses from one component.

The transmitter in GEOSAT-A was a 20-watt traveling wave tube amplifier which consumed 70 watts of power. The new altimeter uses a solid-state Ku-band power amplifier with pulsed GaAsFET (Gallium Arsenide Field Effect Transistor) output devices to obtain 7 peak watts output with a power consumption of only 12 watts. The use of this amplifier saves 58 watts in power consumption.

Weight was further reduced by repackaging the UCFM (Up Converter Frequency Multiplier). The new unit has performance identical to the GEOSAT-A UCFM in half the volume and weight.

The "Digital Filter Bank" signal processing function was implemented in GEOSAT-A using standard logic integrated circuits and consumed 16 watts. The new instrument implements this signal processing function with a single Digital Signal Processing integrated circuit. This is a microprocessor that has been optimized for performing Fast Fourier Transform operations. The device was programmed by the design engineer for performance to match that of the GEOSAT-A unit, with a power consumption of only 4 watts.

The Digital Chirp Generator was implemented in GEOSAT-A using ECL logic integrated circuits, had a single chirp bandwidth, and consumed 20 watts. The new instrument implements this function in an ECL gate array integrated circuit. A gate array is a group of basic logic circuits which are interconnected by the manufacturer to provide the desired function. The logic design is performed on a mainframe computer, which allows circuit simulation before the final interconnection list and test functions are generated. The gate array for the Digital Chirp Generator has the ability to provide chirps of eight binary-related bandwidths under instantaneous computer control. This unit now consumes only 4 watts.

The Signal Processor is implemented using gate arrays and an 80C86 microprocessor. The high level of integration achievable by the gate arrays has enabled the functions that were previously realized as separate circuits on separate boards to be combined on one board and in several gate arrays. The functions are now divided by the logic speed requirements, with the fast, timing-critical portions of the function in an 80-megahertz ECL gate array, and the slower portions of the function in a CMOS gate array.

GEOSCOU SPACECRAFT BUS

Having established an altimeter design with significantly reduced volume, weight, and power from the GEOSAT mission, the design of a spacecraft bus which does not incorporate redundancy and meets Scout vehicle constraints was a relatively straightforward task. This was accomplished by orienting the team's approach to the constraints required by the Scout vehicle compared to the ample volume and weight afforded by Atlas. The product of this effort is a spacecraft design which is fully compatible with Scout yet does not rely on technology risks.

Attitude Control System

The GEOSCOU attitude control system (ACS) must satisfy the pointing requirements of both the orbital transfer and the on-orbit operation phases of the mission. During the transfer orbit phase of the mission, the ACS must maintain a stable pointing direction for the on-board thruster to enable orbital altitude and inclination changes to be effected. During the operational phase of the mission, the attitude control system must keep the radar altimeter pointed to within 0.5 degree of nadir. The attitude control system uses two entirely different control schemes to meet the requirements of the two distinct phases of the mission.

The Scout launch vehicle will place the spacecraft into a nominal orbit of 200 x 600 kilometers. In the transition to the operational orbit, the spacecraft is spin stabilized about its Z (yaw) axis. The spin rate is adjusted through the use of X (roll) and Y (pitch) axis electromagnetic coils. Spin axis precession is accomplished via open-loop commanding of the Z-axis electromagnetic coil. Passive nutation dampers are used during this phase of the mission to damp residual nutational motion. A spinning sun sensor and vector magnetometer provide the data for ground-based attitude determination. For the operation phase of the GEOSCOU mission, the satellite is three-axis stabilized with an active, closed-loop control system. The ACS utilizes an actively controlled reaction wheel mounted with its spin axis along the satellite's pitch axis, an IR scanner (horizon scanner) for sensing pitch and roll errors, control electronics, the vector magnetometer, and three orthogonal electromagnetic coils used with the orbit adjustment system. The active control system for this satellite will supply the desired ± 0.5 -degree off-nadir pointing control for the majority of the mission.

Power System

The power subsystem is based on a 28-volt (nominal) battery bus. The system consists of a Solar Cell Array, a Boost Regulator, a 22-cell rechargeable Nickel-Cadmium battery, a Power Management Unit (PMU) and a Power Conditioning Unit (PCU).

Power Requirements List. Table 1 lists the electrical loads as they are presently estimated. The orbit average load of 136.4 watts can be supported all the time by the solar array. The duty cycles of the transmitters were chosen to be 30 minutes, 6 times per day for the S-band transmitter and 30 minutes, 18 times per day for the Doppler Beacon transmitter. It is assumed that the altimeter remains on all the time as on GEOSAT.

The solar array consists of four solar panels, each with two segments and cells on both sides, deployed into a "+" configuration with the panel center lines lying in the X-Y plane. The rotation angle is fixed at 90 degrees for the "Y" panels and is adjusted periodically from 0 to 90 degrees for the "X" panels. This orientation provides orbit average power levels of 150 watts at end-of-life and worst-case sun angle.

Battery cell size is chosen based on the maximum desired depth-of-discharge (DOD) and the number of cycles at the various DODs. Twenty-two nickel-cadmium, 8 Ampere-hour (Ah) cells will suffice for the expected operating scenarios.

Table 1
Weight and Power Estimates

Subsystem	Orbit Average Power (watts)	Weight (lbs)
Power Subsystem	26.9	72.9
C&DH	8.0	22.6
Tape Recorder	10.2	13.9
Attitude	10.0	28.3
RF	2.7	7.3
Doppler Beacon	5.8	8.4
Altimeter	62.3	66.8
Propulsion	0	67.8
Thermal	0	4.0
Structure*	0	56.2
Vehicle Interface	0	22.0
Harness	0	24.0
Total	125.9**	394.2

**Includes Altimeter Shelf and Reflector.*

***136.4 watts with contingency.*

Command and Data Handling

The Command and Data Handling (C&DH) System processes encrypted uplink command messages for real-time spacecraft control, stores and processes delayed command messages for subsequent activation, formats and outputs altimeter data and housekeeping data for transmission to the ground station, encrypts and stores formatted altimeter and housekeeping data on the flight tape recorder, and dumps the tape recorder memory at a high data rate upon command. The C&DH system also continuously evaluates spacecraft health by monitoring and processing selected housekeeping data, and provides on-board fault protection in response to detected spacecraft anomalies.

The telemetry processor formats altimeter and housekeeping data into standard data frames for real-time transmission and/or storage on the flight recorder. During normal operation, recorder dump data will be transmitted on the carrier frequency with real-time data on the subcarrier.

C&DH Capabilities. The command system provides relay, pulse, data and logic pulse command outputs which are equivalent to the GEOSAT command forms. The command count for the spacecraft is reduced from the GEOSAT command counts due to the non-redundant spacecraft design.

The command system can process any command on either a real time or delayed basis. Delayed commands are executed by loading a delayed command sequence to the command system memory and, following confirmation of the sequence load via the automatic memory readout, sending the appropriate epoch start command.

The telemetry system processes single-ended analog voltages, differential analog voltages, temperature data, digital telteles, and serial digital data inputs which are equivalent to the GEOSAT telemetry data forms. Telemetry channel requirements are reduced from the GEOSAT requirements due to the non-redundant spacecraft design.

Data Storage System

Science and engineering data are recorded in the data storage subsystem of the spacecraft. Then, during the relatively short passes over the station, that data must be transmitted to the ground at a rate much faster than it was accumulated. For GEOSAT, and hence GEOSCOU, the storage parameters, with no redundancy, are as follows:

Record Rate	10,205 bits/second
Record Time (maximum)	13.61 hrs
Playback Rate	833,442 bits/second
Playback Time (maximum)	10.0 minutes
Ratio	1:81.67
Total Storage	500 megabits

For a small spacecraft such as GEOSCOU, a high data storage density is of paramount importance. Given the 500-megabit data storage requirement, a GE STR-108 (AT) tape recorder stores more bits per pound, per cubic inch, and per watt than any of the alternatives available now or in the near future. This includes competing tape recorders as well as solid-state systems.

RF System

The function of the RF system is

1. To serve as a front-end used in the reception of S/C commands generated by the Satellite Tracking Facility (STF) at APL and transmission/modulation of the S/C health-status data to the STF at APL; and
2. To transmit/modulate prerecorded altimeter data on the wideband data dump link from the S/C to the STF at APL.

Table 2
RF System

Unit	DC Power	Weight
S-Band Transmitter	21W	4.3 Pounds
S-Band Antenna		1" Diameter
Dual Command Receiver	240 mW	1.8 Pounds
Dual Command/Receiver Antenna		<1 Pound

Propulsion System

Delta-V Requirements. The delta-V requirements for the GEOSCOU mission are based on the Scout launch vehicle's ability to place a 400-pound payload into a nominal 200 x 600-kilometer orbit with an inclination of 108 degrees. Launch dispersion errors are:

-10 km perigee
-125 km apogee
±0.57 deg inclination

These reflect a 1.65-sigma low deviation from nominal launch parameters based on previous Scout launch experience.

The propulsion system will be used to accomplish two major orbit maneuvers. The apogee of the launch injection orbit must be raised to 800 kilometers; this will require 89 meters per second. The second orbital maneuver will consist of orbit circularization and inclination correction if required. Since these two delta-V adjustments represent orthogonal vectors, they can be accomplished simultaneously with a delta-V expenditure of 183 meters per second. Based on GEOSAT experience, an additional 14 meters per second is budgeted for orbit maintenance.

Using a specific impulse of 215 seconds for monopropellant hydrazine leads to a 50.5-pound propellant requirement for a total delta-V of 286 meters per second.

A monopropellant hydrazine propulsion system will be used to attain the desired orbit and provide incremental velocity as required to maintain the GEOSAT ground track. This system will consist of two thrusters, a fuel tank, a pressure transducer, a fill/drain valve, and a fill/vent valve.

A 5-foot-pound thruster will be used to raise the apogee of the orbit, circularize the orbit, and adjust the inclination of the orbit, if required. A 0.1 foot-pound thruster will be used to maintain the desired GEOSAT ground track.

The fuel tank is identical to tanks used on previous APL Navy programs. An elastomeric diaphragm inside the spherical tank separates the hydrazine fuel and the gaseous nitrogen pressurant.

Mechanical Configuration

The GEOSCOUT configuration (Figs. 5 and 6), is unusual in that the altimeter reflector is the attachment to the launch vehicle adapter. The reflector is supported around the outside by a metal ring insert in the honeycomb parabola. It is from this ring insert that spacecraft separation takes place. The launch vehicle adapter (below the reflector) stays attached to the Scout 4th Stage. A vee-band clamp releases the spacecraft from the lower adapter. During launch, the spacecraft loads are carried from the body above the reflector, through the ring insert in the honeycomb, through the launch vehicle adapter below the Reflector, to the Scout 4th stage. This will minimize the loads that the reflector itself will carry.

The spacecraft body consists of a lightweight framework to which four honeycomb panels are attached. Most of the spacecraft electronics boxes are attached to these panels. When the honeycomb panels are attached to the framework, the assembly provides a stiff structure which also supports the propulsion subsystem. A honeycomb shelf is attached to the bottom of the spacecraft body. This shelf also passes loads to a conical structure below which in turn, attaches to the rim of the altimeter reflector. Maximum use will be made of lightweight materials such as magnesium, aluminum lithium and titanium fasteners.

The altimeter reflector feed extends beyond the usable payload envelope, as is visible in the launch configuration drawing; however, this penetration has been addressed and the minimum clearance for the 4th stage motor and its initiators has been incorporated.

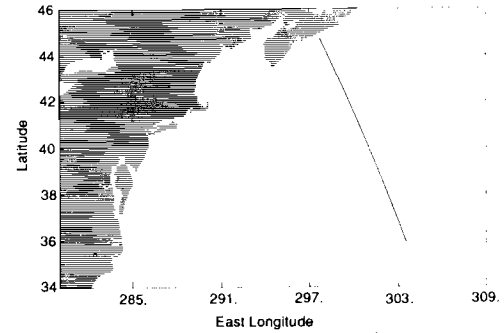
Acknowledgement

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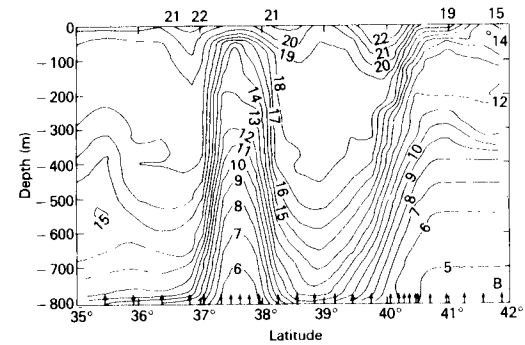


Figure 1. Gulf Stream Front and Eddy System

In-situ instrument locations (air-expendable bathythermographs-AXBTs) along a GEOSAT ground track (in-situ data provided by C. Horton of NAVOCEANO)



Measured AXBT isotherms indicate "sound walls" at a cold core ring and the Gulf Stream front. Satellite IR imagers measure the surface temperature signatures of these features.



Sea surface height signatures of the front and eddy computed from the AXBT data (dashed line) and as measured by the GEOSAT altimeter (solid line).

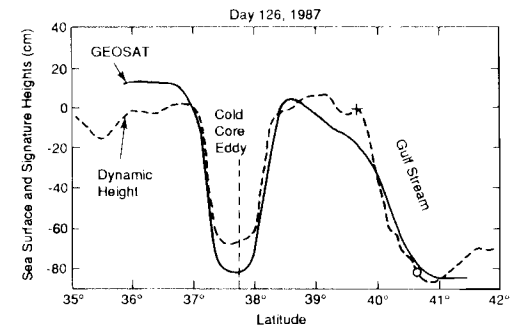


Figure 2. Satellite Measurement of Fronts and Eddies

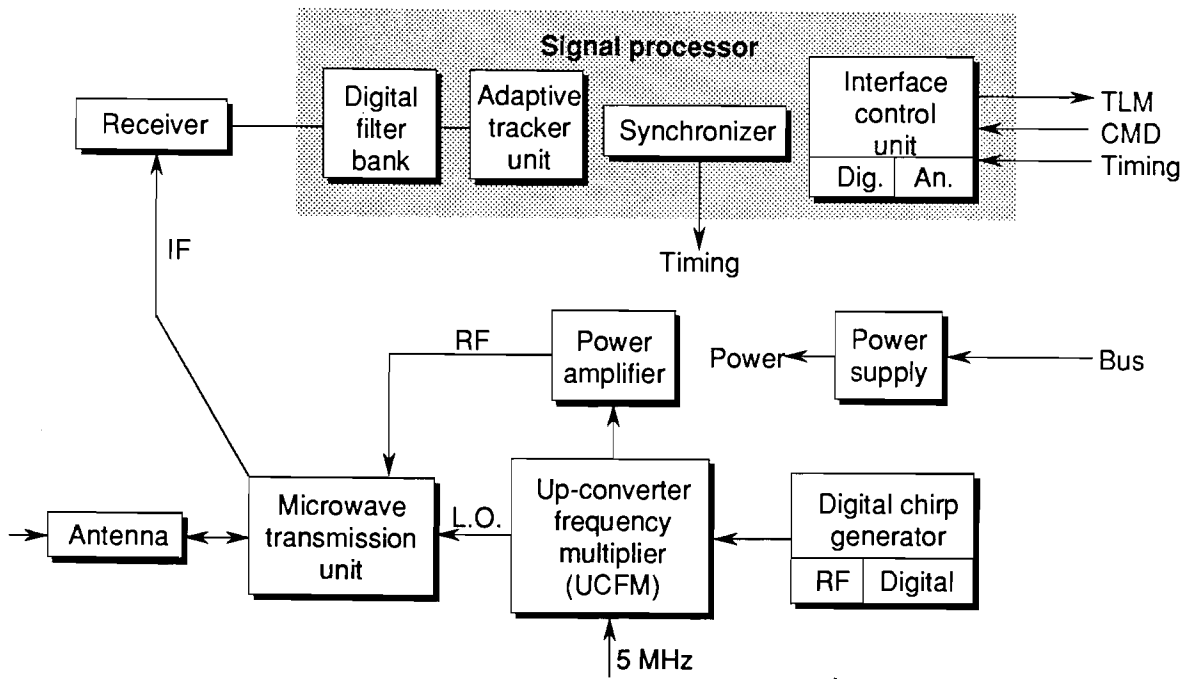


Figure 3. Radar Altimeter Block Diagram

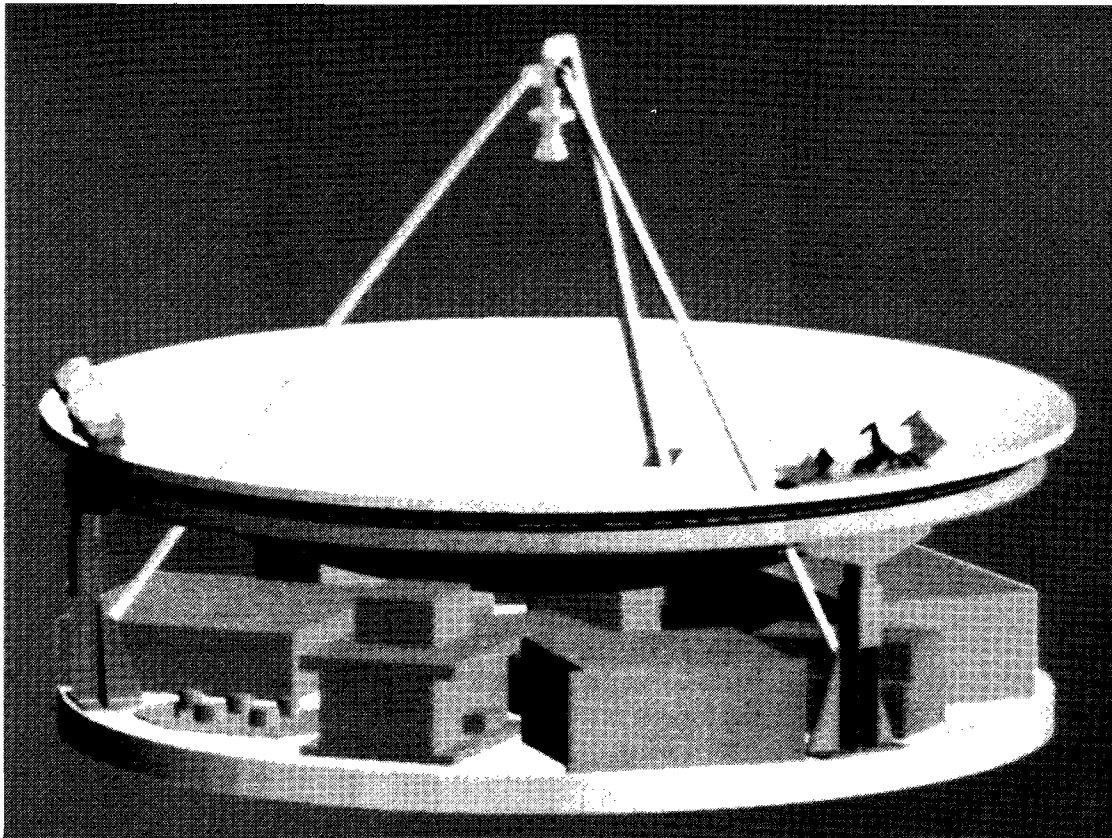


Figure 4. Altimeter Configuration

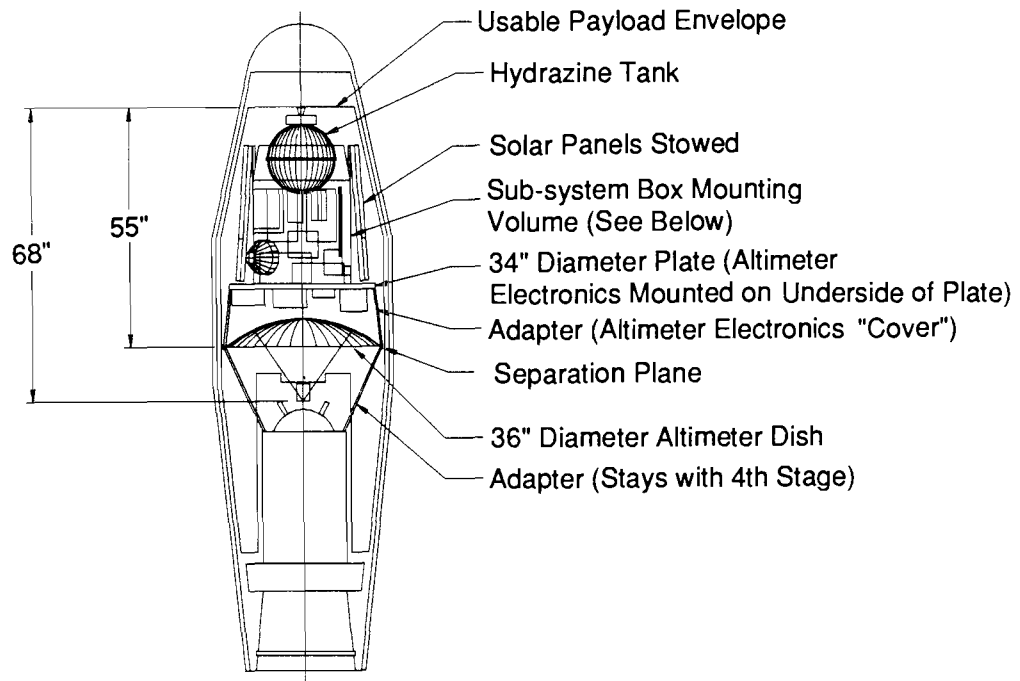


Figure 5. GEOSCOU Launch Configuration

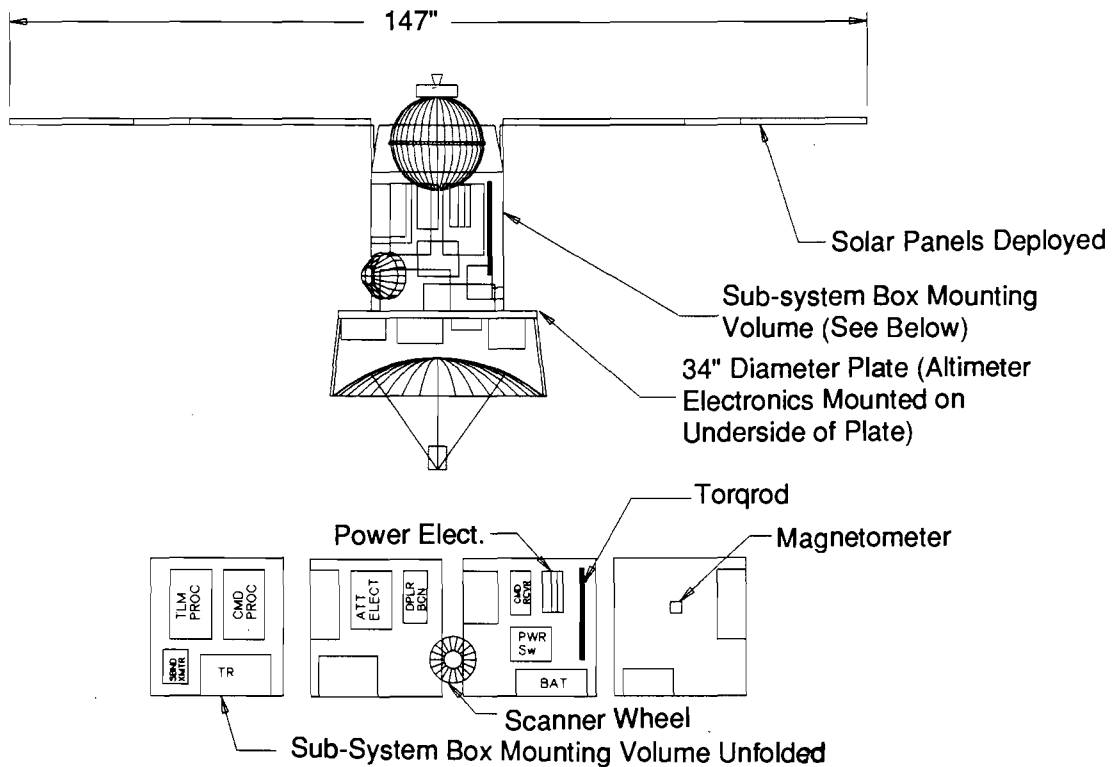


Figure 6. GEOSCOU Orbit Configuration