μ-GHOST

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
Boulder, Colorado • May 1980

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Contents

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FOREWORD

GHOST and the Global Data Network

Each day of the year thousands of observations of surface weather conditions are recorded throughout an international data network. Weather balloons released from many of the network stations report conditions above the surface, and this information is supplemented by data from aircraft, atmospheric sounding rockets, and meteorological satellites.

In spite of these many data sources, serious gaps exist in both surface and upper air weather information. Ocean areas and the most unpopulated land areas provide insufficient surface and upper air coverage. Most acute is the general lack of upper air observations, which fail to cover even the troposphere in adequate detail.

However, important steps have been taken to improve the weather network. In 1961, the United Nations requested that the World Meteorological Organization (WMO), a consortium of some 130 national weather services, and the International Council of Scientific Unions (ICSU), representing scientific societies and all national academies, draw up a plan to improve weather forecasts and strengthen atmospheric research. In its first report, the WMO recommended the creation of a World Weather Watch (WWW) that would combine weather satellite information with an expanded network of conventional observations to bring better weather services to all nations of the world.

Through a Joint Organizing Committee, the ICSU and WMO launched a program called the Global Atmospheric Research Program (GARP), which was to fill in the knowledge and work out the technology that will be needed to establish a scientifically sound basis for long-range forecasting. The GARP experiments were planned to examine the atmosphere's general circulation and culminated in a one-year intensive observing period during 1979 called the Global Weather Experiment.

The observations associated with the Global Weather Experiment applied new concepts of systems planning to improve meteorological observations, data collection, transmission, and analysis, both by expansion and improvement of existing techniques and by implementation of new techniques. The major technological emphasis was on the great potential of satellites to gather and transmit data and on high-speed computers to sort, store, and apply data to mathematical models used in long-range forecasting.

Key elements needed for numerical forecasting models are data on air motion at all altitudes and latitudes——a complete global map of the wind field, compiled accurately and economically. While able to deliver a great deal of information about the atmosphere, satellites are unable to supply quantitative measurements of many crucial parameters governing atmospheric behavior. Without numerical data, computer analysis and prediction falter. Additionally, the satellite's great potential as an overviewer in space cannot be fully realized until it is integrated with other devices in a global system.

A promising technique for providing the needed global wind data has been the Global HOrizontal Sounding Technique (GHOST). This technique is based on the use of strong plastic superpressure balloons to trace air circulation patterns by drifting with the wind at altitudes of constant density.

Since late 1966, an NCAR team has launched several hundred GHOST balloons from Christchurch, New Zealand, and several tropical stations to test their ability to remain aloft for long periods. These balloons have been capable of providing temperature, pressure, altitude, and, most important, wind data. The sensors on the balloon telemeter data to the orbiting satellites, and the position of the balloon is calculated from the known location of the satellite. The GHOST balloons have been shown to fly stably at a constant density level, with maximum deviations of less than 100 m. Balloons flying at 100 mb and higher are able to remain aloft for many months, and some have been flown for over a year. The longest duration is 744 days at the 100 mb level. Balloons at lower altitudes (200, 300, and 500 mb) suffer in varying degrees from ice or frost accumulation, which limits flight durations at these levels to months, weeks, or even a few days, respectively.

The three major superpressure balloon flight programs to date are the French EOLE program; the Tropical Wind, Energy Conversion, and Reference Level Experiment (TWERLE); and the Tropical Constant-Level Balloon (TCLB) Program—one of the special observing systems implemented for the Global Weather Experiment. The costs of these systems were too high to consider for use as a continuing operational system.

To meet the needs for an *operational* system as an integral part of the future world weather system, the μ-GHOST concept has been developed. The μ-GHOST platform is envisioned as a low-cost superpressure balloon and state-of-the-art microelectronics. These platforms will provide a reference level and data set of the global wind and temperature fields at the 200 mb level in the midlatitudes of the Southern Hemisphere. The balloon is a tetrahedral design with minimum seams that is prestressed into a quasi-spherical shape. The μ-GHOST platform does not require a stable transmitter for the satellite interferometer system to determine balloon locations. The elimination of the need for a stable transmitter results in a substantial cost reduction in electronics and permits day and night transmission with a frangible balloon package (one that is nonhazardous to aircraft).

MAJOR SUPERPRESSURE BALLOON PROGRAMS IN METEOROLOGICAL RESEARCH

Date	Title	Sponsor	Tracking System	No. Launched	Altitude (mb)
1966-1970	GHOST	NSF/ESSA/New Zealand Met. Service	Ground Stations (HF)	280	500,300,200 100,30
1967-1970	QBO Study	NASA/NSF	IRLS (Nimbus-4)	50	50,30
1971-1972	EOLE	CNES	EOLE	500	200
1971-1975	TWERLE	NASA/NSF	RAMS (Nimbus-6)	440	150
1971-1975	Carrier Balloon System	NASA/NSF	SMS/GOES/RAMS	30	30
1975	Monsoon Boundary Layer	CNES/CNRS	RAMS (Nimbus-6)	45	955,910,860
1976-1979	TCLBS	NOAA/NASA/NSF/CNES	ARGOS (TIROS-N)	313	148
1979	BALSAMINE	CNES/CNRS	ARGOS (TIROS-N)	88	900

Tropical Constant-Level Balloon System

The Global Weather Experiment, part of GARP, was an international cooperative effort to observe the atmosphere in greater detail than ever before. Observations collected during the field phase in late 1978 and 1979 are being processed, analyzed, and then disseminated to atmospheric scientists around the world for use in diagnosing and predicting atmospheric behavior.

The Tropical Constant-Level Balloon System (TCLBS), designed for the Global Weather Experiment, combined an orbiting satellite containing a receiver to produce a windfinding system predicated on Doppler frequency-shift principles. Three hundred thirteen balloons, transmitting through the ARGOS system aboard the TIROS-N and NOAA-6 satellites, provided wind data in the upper tropical troposphere, particularly in the deep tropics (10°N to 10°S).

The Balloon

The TCLBS superpressure GHOST balloon, made of bilaminated polyester, was 4 m in diameter and spherical when fully inflated. It weighed 4.5 kg and carried a payload weight of 2.9 kg. The average lifetime of the TCLBS balloon was two months, since balloons were cut down if they strayed too far from the equatorial regions.

Measurements

Since the balloon moves with the air, wind speed and direction can be determined by monitoring balloon position. Satellites receive radio transmissions from the payload and constantly measure the frequency of the carrier wave. The change in received frequency (Doppler shift) is used to locate the balloon's position.

Air temperature is measured by a bead thermistor that is 0.254 mm (0.01 in.) in diameter. The surface of this sensing element is coated with a vacuumdeposited aluminum film that reflects solar and infrared radiation. This reduces errors caused by external radiation. The thermistor has been made as small as possible because conductive coupling with the atmosphere increases as the size decreases.

The entire sensor assembly is suspended 4 m below the next lowest component in the flight train to prevent the thermal wake of that component from affecting temperature measurement.

It is impossible to obtain thermistors as small as 0.254 mm in diameter that have consistent resistance-temperature characteristics, so it is necessary to adjust the temperature-sensor circuit components to compensate for differences between thermistors. Thermistor characteristics are read into a computer, which reads out the component values of resistance to be installed for that thermistor. The computer also calculates the values of resistance of two reference temperatures. Resistors for these reference values are installed as inputs to data channels.

With two temperature references and a computer-designed compensation circuit, the telemetry output from the air temperature measurement system is so uniform that one calibration equation can be used for all balloon systems.

The temperature of a black-ball sensor is also taken. This sensor is an aluminum sphere that is painted black. It is thin-walled so it has low thermal mass. A thermistor network inside measures temperature. The sun and reflected radiation heat the sphere during the day and give an estimate of the earth's albedo in the vicinity of the balloon. Air motion (gravity waves and turbulence) causes variations in the temperature.

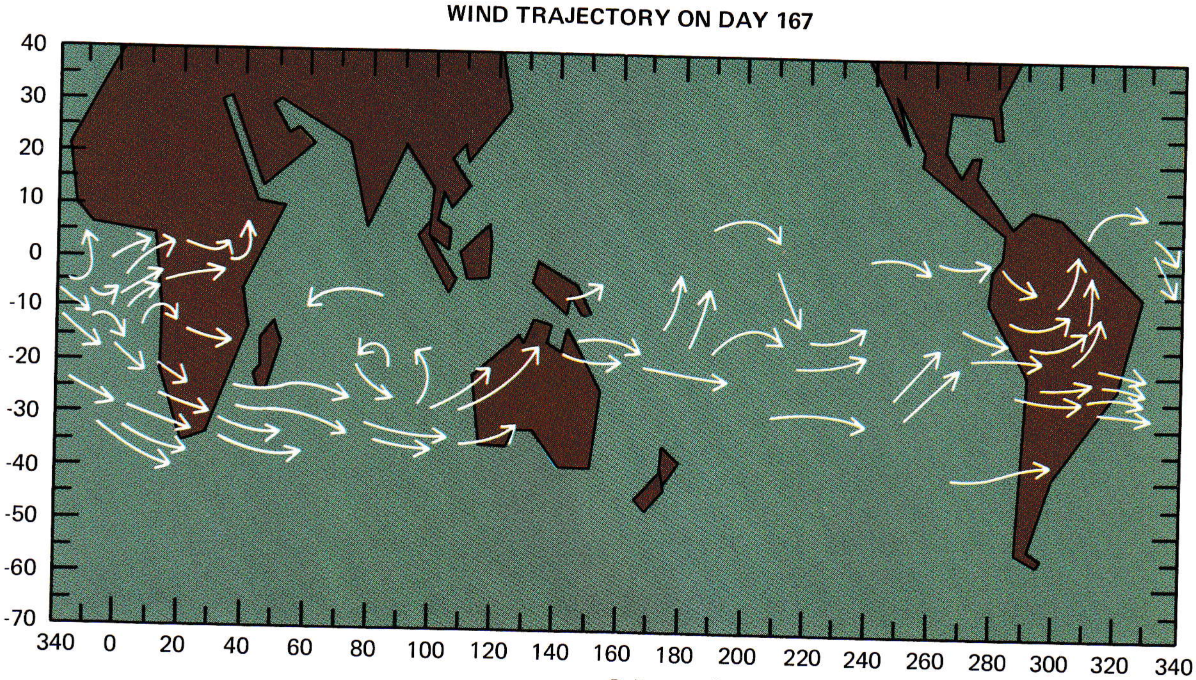
The mobile launch technique, adopted from the TWERLE program, easily allowed launching of 313 TCLBS platforms from Ascension Island (South Atlantic), Canton Island (central Pacific), and Guam (western Pacific). At the time of launch, the balloon is only partially inflated to allow for expansion of the helium as the balloon rises and the atmospheric pressure decreases. When the mass of air displaced equals the mass of the balloon plus its payload, the balloon stops rising and floats at this density level, moving with the air circulation.

Performance of the ARGOS System

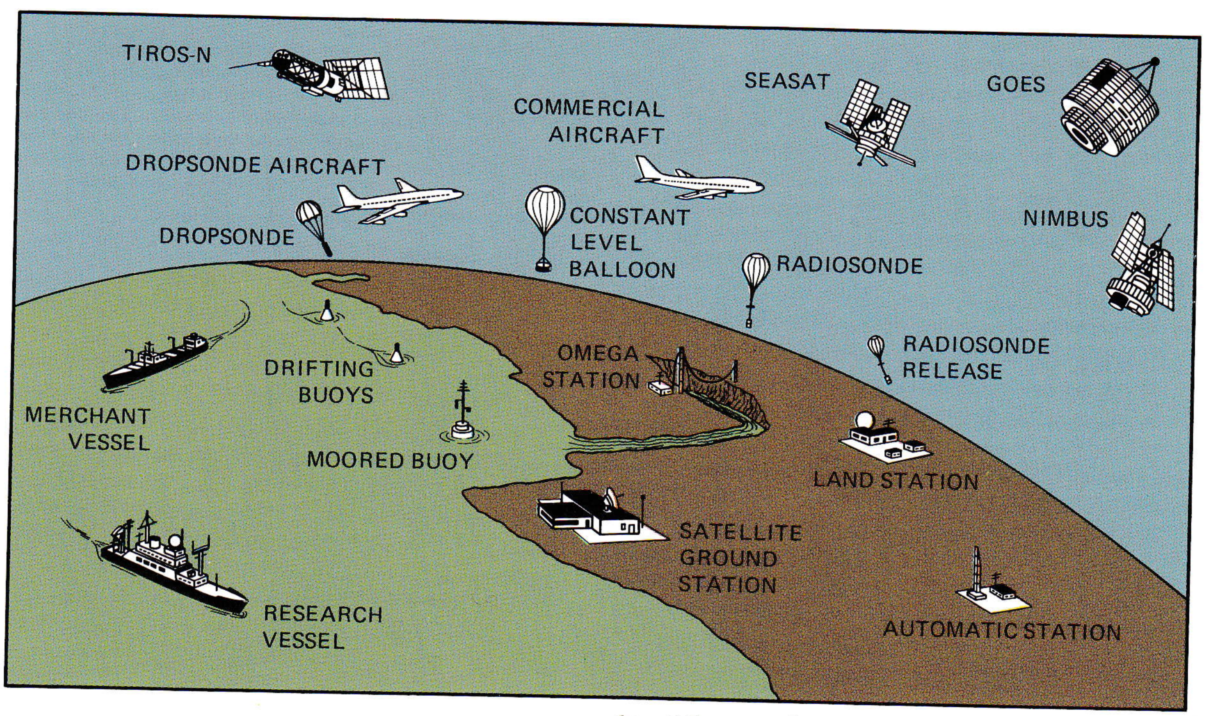
The ARGOS system performed extremely well during the Global Weather Experiment. On the average, data and locations were obtained for each balloon four times per day. This resulted in approximately 50,000 wind and temperature measurements for the complete program. The balloon platforms transmitted 1 W to the satellite; tests, however, have shown that 0.1 W would have given location and data for 70% of the overpasses. Balloons were located that had gone to the surface and were hanging in trees.

There were no independent means of locating the balloons, but the consistency of locations and wind velocities was so good that the investigators are convinced that the data exceeded the system design specifications.

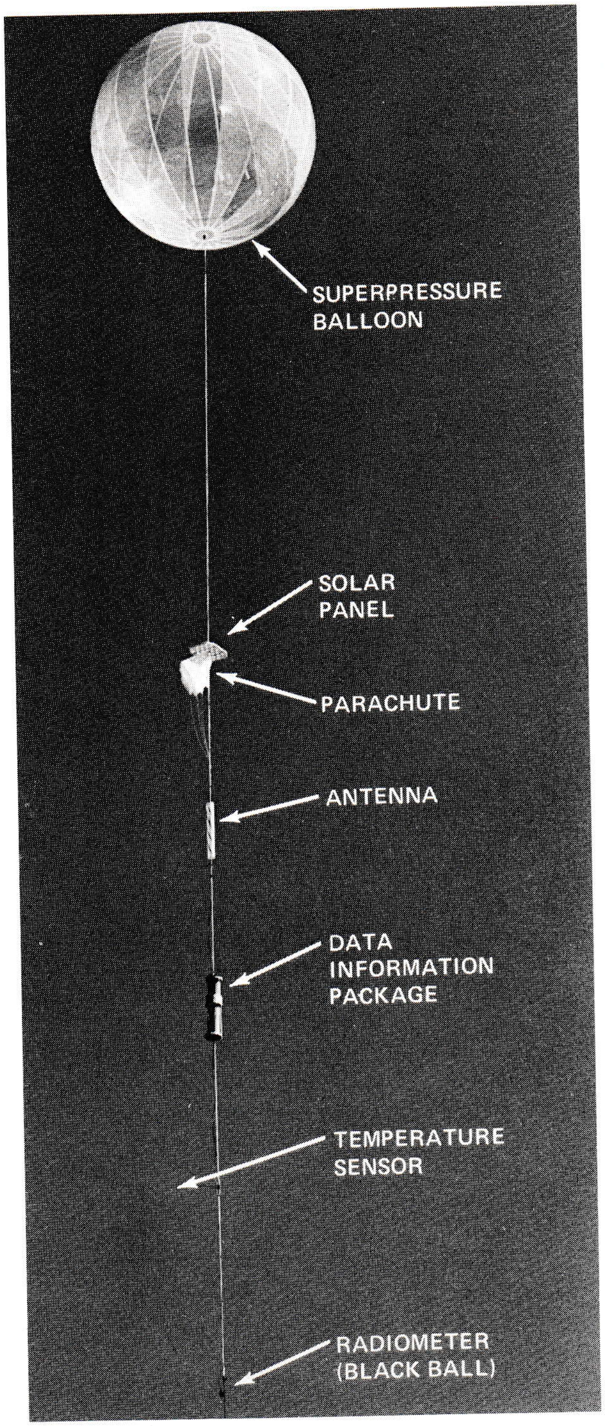
The TCLBS gave a useful data set for the study of the wind circulation in the tropics. In addition, the program demonstrated that a balloon system is a practical and economical means of collecting meteorological data. The 50,000 wind data points cost approximately $16 per measurement.



Balloon trajectories for all TCLBS balloons flying during an 18 h period on 16 June 1979 (day 167). These trajectories are similar to a streamline analysis. Even with limited data it is possible to construct a wind map of the tropical circulation that cannot be derived in any other manner. Interesting features of this map are a blocking circulation in the Indian Ocean that is defined by a few balloons caught in it and slowly rotating counter-clockwise. Balloons jam up against this circulation and eventually spill out across South Africa; they then zoom across the South Indian Ocean, turning northward along the west coast of Australia. There are three waves in the equatorial Pacific. The most pronounced is over northern South America.



An artist's conception of the observing systems deployed for the Global Weather Experiment.



The TCLBS flight train is suspended from the balloon by 9 m of nylon line, which is sufficient to prevent the balloon from shadowing the solar panel at all sun angles below 80°. The top component in the flight train is the solar panel, which is flat and faces upward. This configuration produces the greatest electrical energy when integrated over one day for systems flying in the tropics. The 28 silicon solar cells (each 0.64 mm in diameter) produce 800 mA of current at 12 V at maximum solar angle. Underneath and attached to the solar panel is a small Styrofoam package that supports the panel and contains a cutdown mechanism. This mechanism consists of nichrome wire wrapped around a nylon suspension line. When the mechanism is activated, an electrical current passes through the nichrome wire and melts the nylon, separating the flight train from the balloon. A parachute opens and slows the descent of the flight train. Three meters below the solar panel is a right-hand, circularly polarized antenna. It radiates in the upper hemisphere, with its gain maximized at 20° above the horizon. The total weight of this antenna is only 125 g.

The data information package contains a thermal control system, a transmitter with a frequency-stable oscillator, data and format encoding circuits, pressure and magnetic cutdown sensors, and battery and charging circuits.

NEW TECHNOLOGY

Satellite Interferometer System

We have seen in the last ten years a continuing improvement in the capabilities of polar-orbiting satellites to locate and retrieve data from moving platforms. Nimbus-4/IRLS, EOLE, Nimbus-6/RAMS, and ARGOS have moved from $25,000 platforms to $2,500 platforms. The ARGOS system is now operational and can provide a valuable service for buoys, research balloons, and limited programs involving large numbers of balloons. However, the requirement for oscillator stability precludes the economic use of the system for a continuing operational balloon flight program. A day and night capability is not feasible with ARGOS-type balloon electronics, which are hazardous to aircraft.

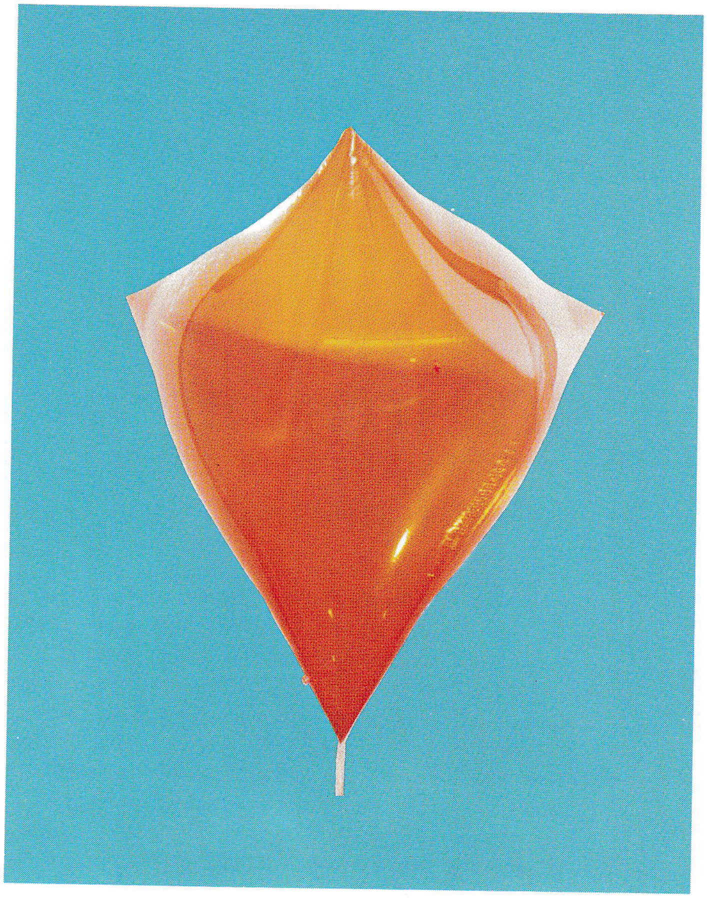
Goddard Space Flight Center is now developing a satellite interferometer system which will permit balloon location with no stability requirement on the platform other than transmission within the passband of the satellite receiver. This breakthrough permits the design of balloon electronic systems no more complex than good-quality radiosondes. Nighttime operation is possible without thermal mass or oven temperature control.

The reduced electronics mass permits the use of "tetrasphere" balloons with minimum seams and minimum costs. The projected costs for a balloon payload flying at the 200 mb level for three to five months is now reduced from $2,500 to less than $500. An operational μ-GHOST system which can maintain hemispheric coverage with more than 100 balloons at all times is now realizable—at an annual cost of less than $200,000.

μ-GHOST Superpressure Balloon - The Tetrasphere

The superpressure balloon under investigation for the μ-GHOST program is a stretched tetrahedron. A conventional tetrahedron is formed from a basic cylinder of length h and circumference equal to 2.31 h. One end is sealed to form a pillow end. On the opposite end, the points that correspond to the center of the sealed pillow end are used as the corners of the second pillow end, so that the end seams are skew lines running in perpendicular directions. The length h of the basic cylinder becomes the altitude of each triangular face of the fully inflated tetrahedron. The payload is attached to one corner and the opposite triangular face forms the top of the balloon in flight.

The NCAR design is made of bilaminated polyester film with bi-tapes (a sealing tape on both sides of the gore). This construction allows a higher overpressure and sufficient stretch or creep of the film to approach the shape of a sphere. The balloon is stressed for several hours at elevated temperatures and at overpressures 50% higher than will be experienced in flight. The balloon is permanently deformed into a spherical shape with four points. It now will perform equivalently to a sphere but with a minimum of seams and with a minimum of manufacturing cost. Pinholes will be detected and repaired in the field prior to launch to eliminate costly factory testing.



The NCAR tetrasphere is made of bilaminated polyester film sealed with bi-tapes. The superpressure balloon is permanently deformed into a spherical shape with four points. It performs equivalently to a sphere, with a minimum of seams and with a minimum of fabrication costs. The 6 m^3 tetrasphere will carry 500 g to 200 mb (12 km).

μ-GHOST Electronics

The satellite interferometer system greatly reduces the frequency stability requirements of a balloon transmitter. This opens the door to a whole group of new designs and experiments. The frequency stability required on ARGOS and RAMS dictated that thermal (and therefore mechanical) mass be designed into a system. A large thermal time constant was required to prevent a significant change in frequency with time. In past balloon flights, a crystal oven was included in the design. Buoys and remote terminal systems were successfully built using temperature-compensated crystal oscillators, but, in all cases, these systems included a large thermal time constant to prevent rapid frequency changes.

With the reduced frequency stability requirement, it is now possible to build truly nonhazardous balloon systems and very lightweight low-power systems that can be used in applications that were previously not practical.

This section describes a balloon flight system that will measure wind and air temperature and be non-hazardous to aircraft. The description assumes a data link between balloon and satellite that is similar to RAMS and ARGOS. Listed below are the assumed specifications for the system.

Frequency: 401 MHz
Bit Rate: 400 bps
RF Power: 1 W
Terminal Repetition Rate: Once every 40 s
Word Length: 8 bits
Words per Message: 40 to 32
Data Coding Format: Biphase
Modulation: Phase ±60°
Message Format: Bit Sync: 15 bits
Format Sync: 8 bits
Initialization: 1 bit
Number of Sensors: 4 bits
Identification: 20 bits
Data Words: 4 to 32

NOTE: The above specifications are chosen to be identical to ARGOS to facilitate a flight test using an existing satellite.

Transmitter

A design concept for the transmitter is to use distributed parameter resonant circuits to avoid the mass of lumped parameter components. Strip lines provide the easiest, most understood design approach, but they require a ground plane, which is usually provided by the opposite side of a printed circuit board. This approach may require a thicker printed circuit board than is acceptable. An alternative approach might be a foam sandwich to eliminate the glass epoxy mass or a transmission line design that does not require a ground plane.

The block diagram for the transmitter will be similar to the design used on the TCLBS.

A crystal-controlled oscillator operates at 57.31 MHz with a X7 multiplier. The crystal may be the most difficult component in the transmitter to reduce to a safe mass. Experiments were performed with crystals where the enclosing cans were removed. The crystals deteriorated with time due to oxidation of the plating on the quartz. Gold-plating would improve unencapsulated performance, but, in actual practice, encapsulated crystals will probably be required and the problem will reduce to obtaining or designing the most frangible enclosure possible.

Antenna

The antenna design proposed is a modification of the quadrafilar helix antenna used on the TCLBS. Modifications to this antenna would be to make it more frangible by redesigning the phasing network and mechanical support structure. Mechanical support could be provided by using an inflated structure or a very lightweight foam structure.

System Power Requirements

The power requirements are estimated by the table below:

1. Transmitter: 1 W peak, 30% efficiency .440/40 = .011 duty cycle =	40 mW
2. Data Encoding Circuit: 5 mA X 7 V =	35 mW
3. Sensor Circuits: 3 mA X 7 V =	21 mW
4. Voltage Regulator: 8 mA X 2 V =	16 mW
TOTAL =	112 mW
Battery capacity required for 12 h night: .112 X 12 =	1.34 W-h
Solar Panel Power Required:	
Daytime steady state =	112 mW
Battery charge, 112/.75 =	149 mW
TOTAL =	261 mW

Solar Panel

Silicon solar cell development over the last several years has lowered the price to about $20/W (cell cost), and prices are projected still lower. The power output of a solar panel is related to the panel orientation with respect to the sun. A horizontal panel looking directly upward has a power output proportional to the sine of the solar elevation angle. A pyramid-shaped panel, like the one used in the TWERLE project, is the best design for high and middle latitudes. This panel is constructed using equilateral triangles and gives essentially a constant power output at all solar elevation angles. The pyramidal sides slope at 60° with respect to horizontal and collect reflected light from the clouds, resulting in an increase of about 40% in the power output. For high-latitude flights using the pyramid-shaped solar panel, the total cell area required is dependent on the season. Increasing the cell area above 80 cm^2 does not greatly improve the global coverage season.

Large solar cells are more cost effective than small cells. However, the balloon design may require the use of small cells to develop the voltage required to power a transmitter. DC-to-DC conversion techniques using air core transformers and voltage multipliers will be investigated.

Silicon solar cells unmounted are not hazardous to aircraft. Cells can now be obtained which are 2/1,000 in. thick. Care must be taken in designing a structure to support and distribute the cells in a safe configuration.

Battery

Batteries are constructed from thin sheets of "anode and cathode" material, separated by an electrolyte. This construction is very compatible with a frangible configuration. However, the world wants a battery that is compact and has a high power-to-volume ratio. Commercial batteries are constructed with the thin sheets rolled or packed into a small dense package.

The only two batteries packaged in a low density configuration designed for balloon flights were the EOLE battery and a battery developed by Melpar; both batteries were nickel-cadmium. The Melpar battery was simply packaged in a plastic envelope. The problem with this battery was that gas generated inside forced the sides of the envelope apart, and the electrolyte went to the bottom of the package.

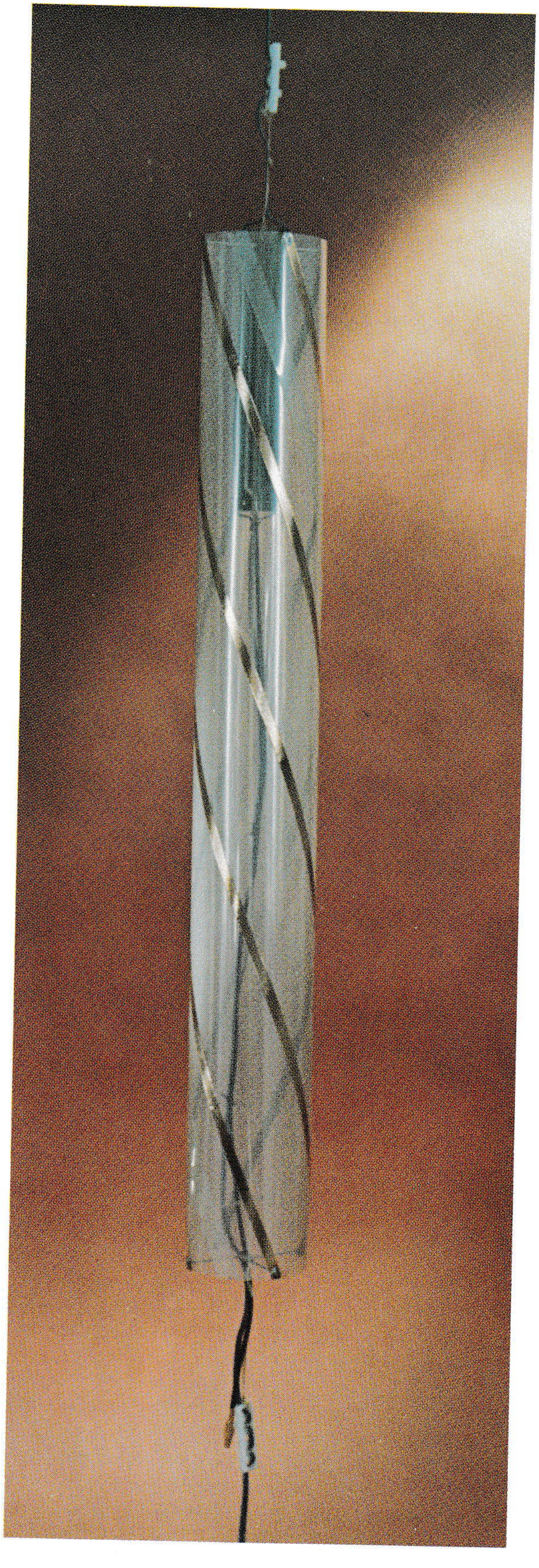
The French EOLE battery performed well. It consisted of two thin strips ("anode and cathode") separated by an electrolyte-saturated blotter. The sandwich is enclosed in a plastic envelope and wrapped around a fiberglass cylinder. This is a very workable configuration, but the design was heavier than necessary. A more frangible battery can be constructed by scaling down the size and thickness of the battery and fiberglass support. A new approach would be to use an inflated structure, instead of fiberglass, to support the battery. Other batteries than nickel-cadmium will be investigated. Sealed lead-acid technology has come a long way since the EOLE battery was constructed. Lead-acid does not recharge for as many cycles as nickel-cadmium, but it has adequate recharge capability and better low-temperature performance.

Data Encoding System

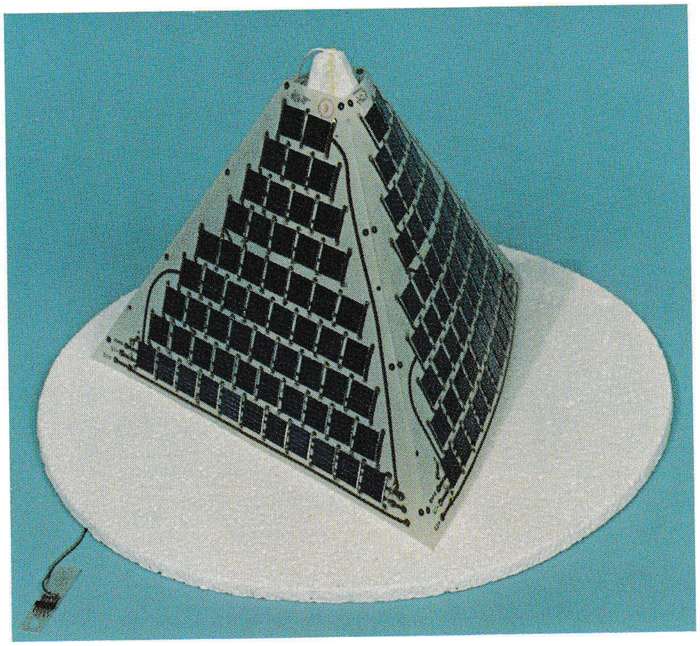
The development of the microprocessor has been so rapid over the last five years that the complexity of a data encoding system is trivial compared with a modern microprocessor. However, most microprocessors consume large amounts of power and, therefore, are not usable in a lightweight, low-power balloon system.

In the last few months, several new microprocessors have come on the market. These devices are actually microcomputers that contain a microprocessor random access memory and programmable read-only memory. They are now manufactured using COSMOS technology, which has low power requirements. The parts diagram of a data encoder would consist of two logic blocks, a sensor input circuit, and a microcomputer. A circuit assembly consists of a few resistors, capacitors, and five or six logic modules.

The microprocessor module presents a problem in building a flight system that is aircraft safe. These modules typically have 40 pins, and a large mechanical structure is needed to provide the pin space. However, the semiconductor chip that contains the circuit is small (less than 1 cm^2). Alternative chip carriers to the standard dual inline package are available and are small enough to meet aircraft safety requirements.



The μ-GHOST antenna will be a modified version of the quadrafilar helix used on TCLBS. The phasing network and supports will be made frangible.



Pyramidal solar panel used in TWERLE is the best design for middle and high latitudes. μ-GHOST will incorporate a lightweight support structure.

Close-up view of TCLBS flexible data-encoder circuit board.

A PROPOSED OPERATIONAL SYSTEM

Superpressure balloon and satellite technology is now available to establish an operational meteorological balloon system for the middle latitudes. This system would complement satellite observing systems by providing measured reference points for IF sounders.

The proposed balloon network should consist of at least 120 μ-GHOST balloons in the air at one time. On 15 June 1979, 100 TCLBS balloons were flying. This was a demonstration of what could be obtained from an operational system. A launch rate of seven balloons per week is required to maintain the operational system. A launch crew of four people located at one site could easily accommodate this rate. The table below gives a breakdown of projected costs for the expendables.

The launch techniques used in the TCLBS program are adaptable for this concept. If launch days are lost due to inclement weather, two or more balloons could could be launched on good days.

For a continuous launch program, liquid helium shipped to the launch site would be more economical than using steel cylinders. The rate of gaseous helium used would approximate the boil-off rate of the dewar.

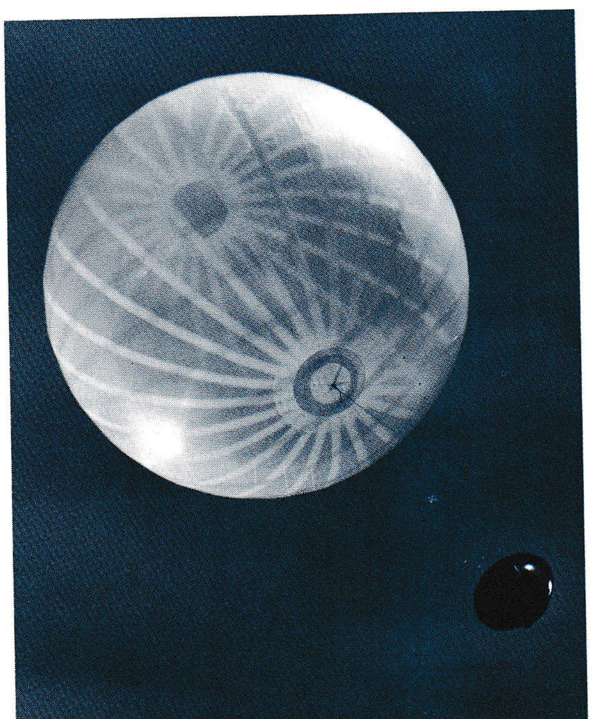
COST OF 365 FLIGHTS/YEAR (1980 Dollars)

Item	Unit Cost	Total Cost
Balloons	$220	$ 80,300
Electronics	250	91,250
Helium	10	3,650
	$480	$175,200

GHOST BALLOON PROGRAMS

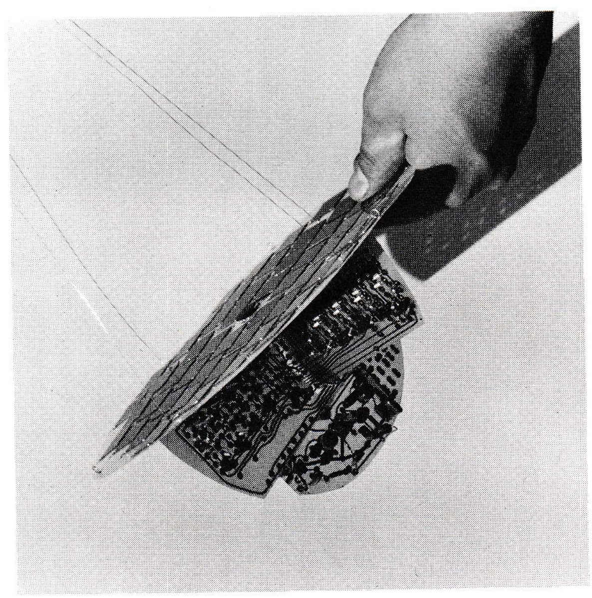
Southern Hemisphere GHOST Program

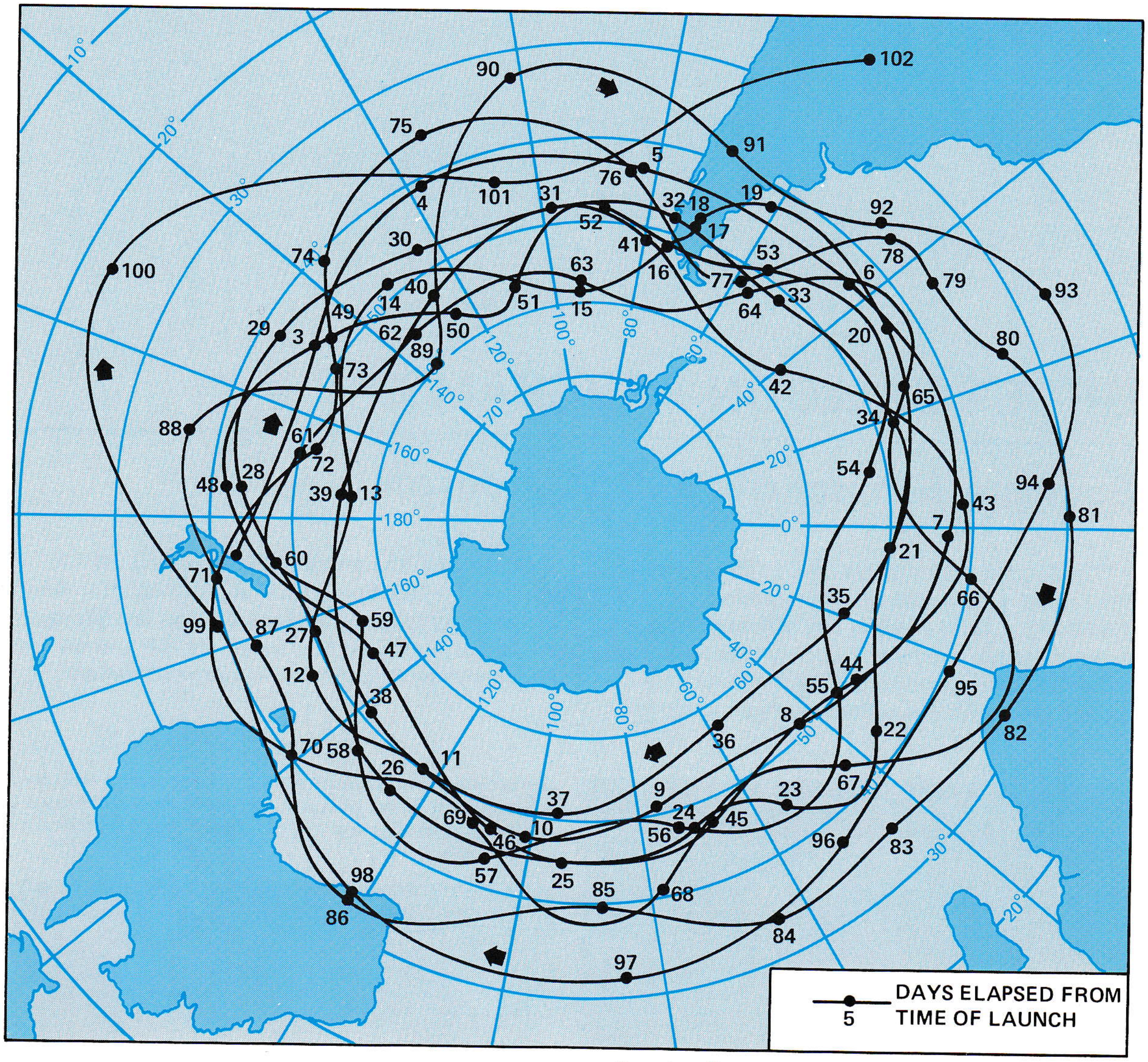
The Southern Hemisphere GHOST Program was the original superpressure balloon program (1966-1970), using 2 m and 3 m balloons carrying a sun-angle sensor and high-frequency telemetry. Locations were determined by ground tracking stations around the world. The balloons were all tested and launched from Christchurch, New Zealand. NCAR managed the flight program. This research effort was a joint undertaking of the New Zealand Meteorological Service and two U.S. groups—NCAR and the Environmental Sciences Services Administration.



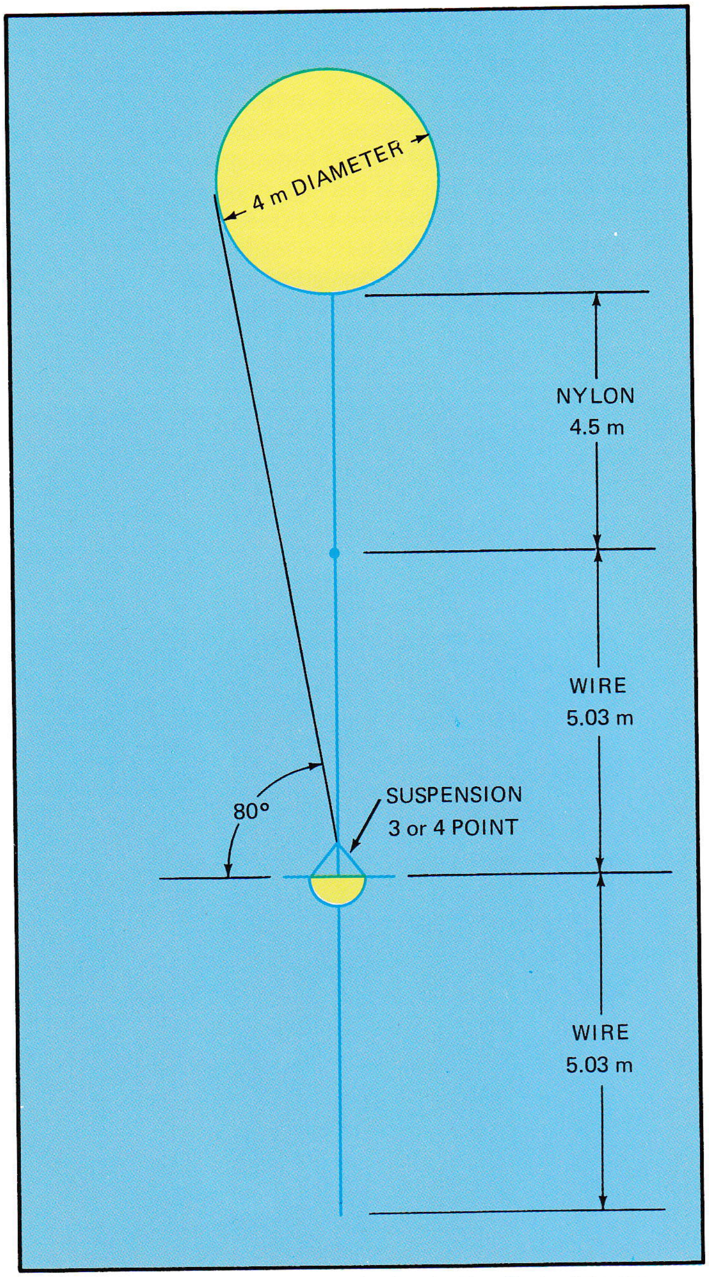
A superpressure GHOST balloon. Balloons designed for flight at 500 mb are about 1.5 m in diameter; for 200 mb, about 2.25 m; and for 30 mb, about 7 m, when carrying a 150 g package.

GHOST electronics package (150 g). Basic circuitry is on the semicircular printed-circuit board. Circuitry for four-channel telemetry is on the smaller rectangular board; the sun-angle sensor is mounted in the middle of the solar cell panel.





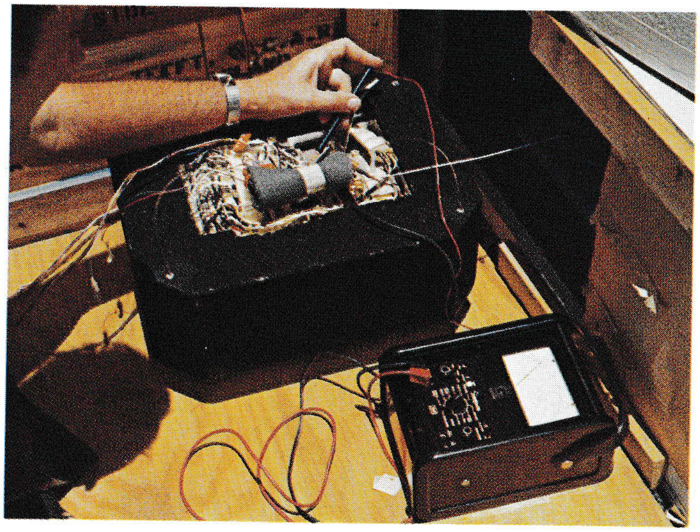
Complete flight trajectory for balloon no. 79R, launched from Christchurch, New Zealand. Flight level was 200 mb.



GHOST balloons launched from Christchurch, New Zealand, have a simple rigging consisting of a nylon line, thin wire antenna, and the GHOST package. Larger balloons require a longer line to prevent the balloon from shadowing the package at too low a sun angle. Procedures for launching GHOST balloons 4 m or less in diameter are similar to those used by any weather station to release standard radiosonde balloons, and require no special preparations or apparatus.

Nimbus-4/IRLS Program

The Nimbus-4/Interrogation, Recording, and Location System (IRLS) balloon program was the first to use satellite location and telemetry on a global scale. The experiment was conducted jointly by the U.S. National Aeronautics and Space Administration (NASA) and NCAR. The Nimbus-4/IRLS, developed by NASA's Goddard Space Flight Center, was designed to gather quantitative meteorological and geophysical data on a global scale. The demonstration project chosen was an investigation of the quasi-biennial stratospheric oscillation by balloons flown at 30 and 50 mb in the deep tropics. Although the cost of the electronic systems was too high to permit an adequate number of flights for a complete investigation, the system worked. Modest payloads were carried for several months at high altitudes, and a technique for launch in high winds was demonstrated.



The balloon payload for the Nimbus-4/IRLS Program consisted of instruments necessary to accurately record measurements of ambient air temperature and provide ranging information to the Nimbus-4 satellite so that a position could be determined. The IRLS was designed to interrogate each instrumented platform twice every 24 h.

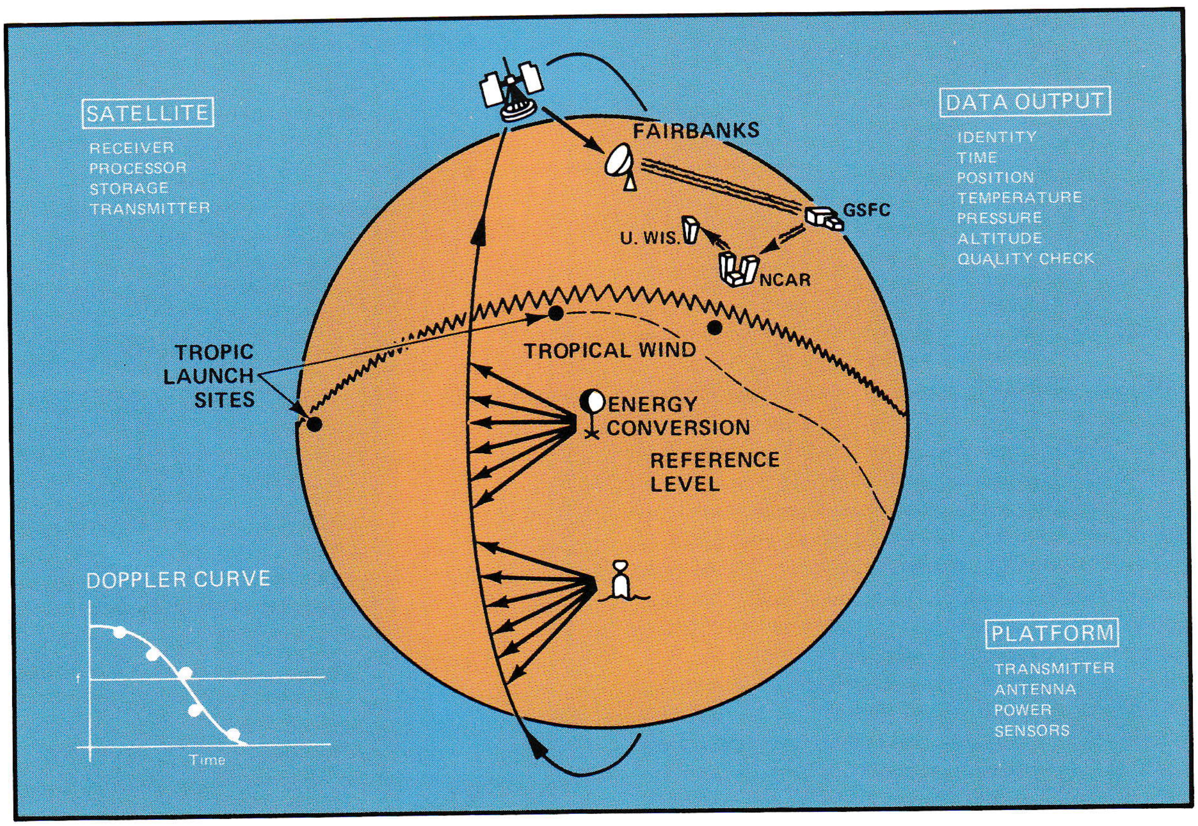
The large size (12 m diameter) of 30 mb balloons and the strong trade winds at Ascension Island necessitate special launching techniques. The partially inflated balloon is held under a nylon cover in a "GHOST wagon" while a towing vehicle drives downwind to neutralize the wind speed. The cover is then opened, allowing the balloon to rise undisturbed.

Nimbus-6/RAMS - TWERLE Program

With the launch of Nimbus-6 on 12 June 1975, the Tropical Wind, Energy Conversion, and Reference Level Experiment (TWERLE) was under way. The scientific team for TWERLE consisted of investigators from NASA's Goddard Space Flight Center, the University of Wisconsin, and NCAR.

The experimenters were interested in learning what the winds do in the tropics, in finding the rate of conversion of potential to kinetic energy in the upper atmosphere, and in the establishment of a reference level (a measure of pressure and temperature at a given altitude) for use in calibrating remote sensors on satellites. Solar input in the tropical atmosphere is an important driving force in the entire atmospheric circulation, but little is known about tropical atmospheric dynamics because it has not been feasible to take measurements necessary to gain an understanding.

The TWERLE system used lightweight, low-cost, constant-level superpressure balloons, each of which carried a long flight train array of specialized sensors. More than 400 TWERLE balloons were launched during the experiment, primarily from sites in the tropics. As the balloons were carried along by the wind, they transmitted information about pressure, temperature, and altitude for one second out of every minute at their float level (150 mb) to the Nimbus-6 satellite. The receiver aboard Nimbus-6 is called the Random Access Measurement System (RAMS). It distinquishes balloons by their separate identification codes; locations are determined from the Doppler shift as the satellite flies past the balloon. Balloon trajectories are diagnostic of tropical winds, and this information is derived from the Nimbus-6 data.



In TWERLE, 400 superpressure balloons were launched in the tropics and transmitted data to the polar-orbiting Nimbus-6 meteorological satellite, which processed signals and relayed them to ground stations. The Random Access Measurement System (RAMS) aboard Nimbus-6 also relayed data from drifting buoys and other GARP oceanographic experiments.

A TWERLE balloon and mobile launcher. Over 400 of these systems were launched during 1975 from tropical sites and from Christchurch, New Zealand.

French Superpressure Balloon Programs

A predecessor to TWERLE was the French EOLE system, but, like the Nimbus-4/IRLS, it required that the satellite interrogate the balloons in order to receive data. The French space agency, the Centre National d'Etudes Spatiales (CNES), developed and built the EOLE satellite, as well as 500 superpressure balloons and associated electronics. This program was conducted from three sites in the Republic of Argentina from September 1971 through August 1972.

The EOLE balloons were launched from the three sites of Mendoza (33°S), Neuquen (39°S), and Lago Fagnano (52°S); the actual average was less than five balloons per day. These balloons floated at the 200 mb level and generally described the climatological aspects of the Southern Hemisphere general circulation, i.e., mean zonal and mean meridional flow and standing longitudinal wave patterns.

EOLE was the first constant-level balloon program using sufficient platforms to describe completely the circulation on a hemispheric basis. The many scientific reports resulting from the program provided new insight on wave motion, energy transfer in large-scale eddies, and two-dimensional turbulence. The meridional flow toward the pole in late winter and equatorward during the summer was documented. The program gave promise of the utility of a superpressure balloon system for operational use. Balloon attrition was heavy in the tropics due to accumulation of ice in clouds and frost formation at night. The long-term distribution of balloons demonstrated that a single launch site would have sufficed for the program.

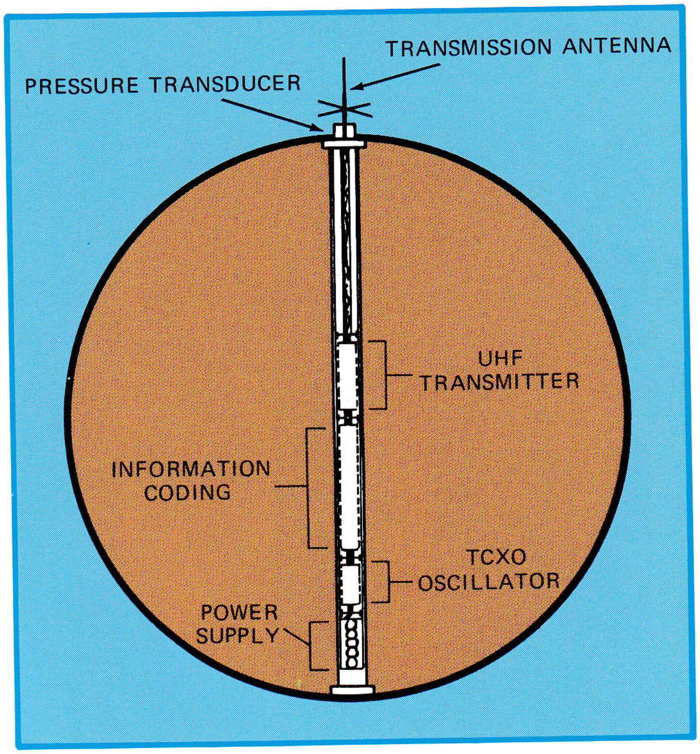
During the northern summer of 1975, the French Laboratoire de Météorologie Dynamique (LMD) conducted another superpressure balloon program to study the large-scale dynamics of the monsoonal flow.

Forty-five balloons were launched from the Seychelles Islands (4.7°S, 55.5°E) for flights at 955, 910, and 860 mb, within the tropical boundary layer. The balloons were located by the RAMS equipment on board the Nimbus-6 satellite. Atmospheric pressure measurements were also made by the balloon sensors and relayed to the satellite. The mean lifetime of the balloons was about four to five days, with some lasting more than eight days.

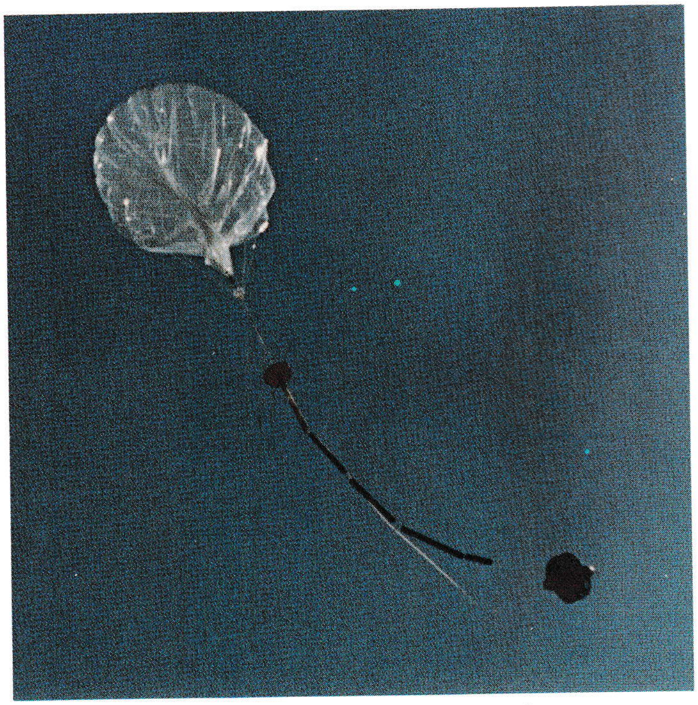
The balloon trajectories show drastic changes in the airflow direction over the Arabian Sea associated with high or low activity periods of the monsoon over the western coast of India.

The BALSAMINE Experiment (15 May to 10 June 1979) launched 88 of the monsoon boundary-layer balloons equipped with temperature, pressure, humidity, and overpressure sensors from the Seychelles (60) and Diego-Suarez (28). This experiment provided low-level trajectories during different phases of the monsoon.

The trajectories of these balloons show the possibilities offered by the constant-level balloon technique to map low-level air currents and study their large-scale dynamics over vast unsurveyed areas.



The BALSAMINE Experiment boundary-layer balloon.

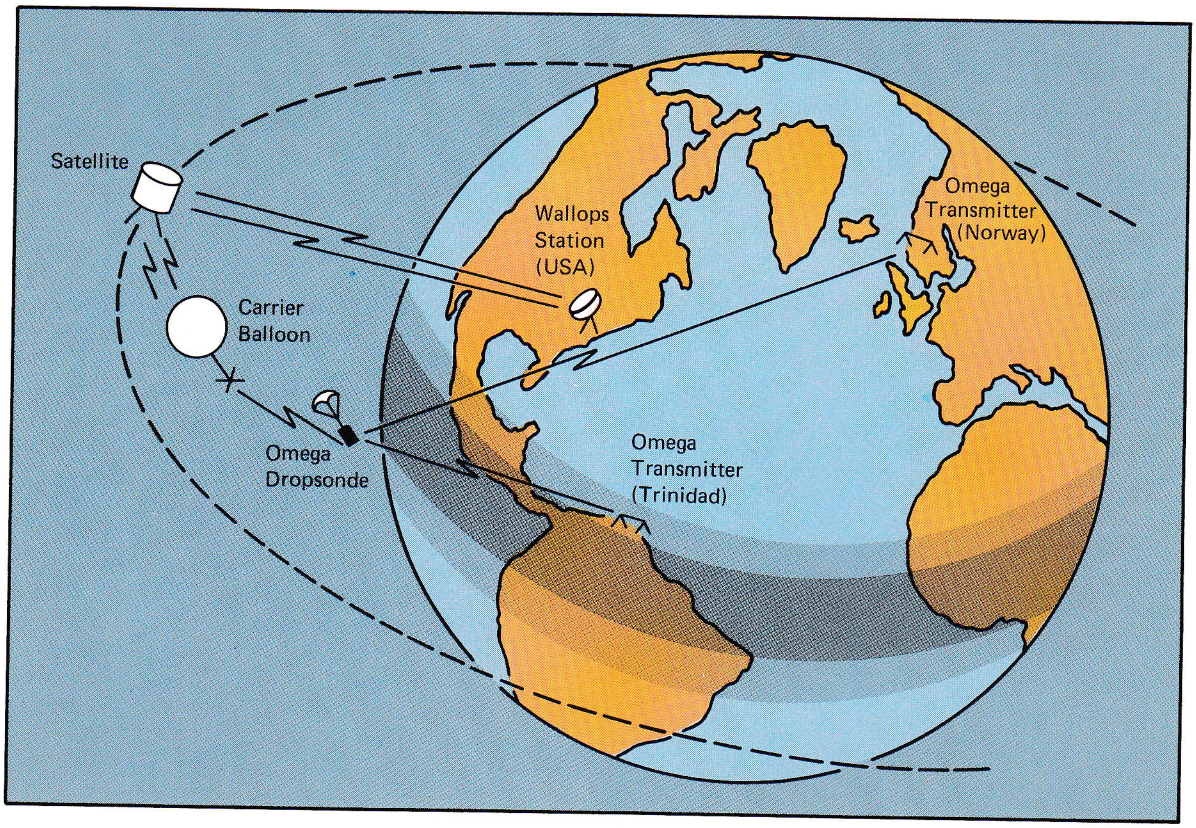


A French EOLE system at launch from one of three launch sites in Argentina. This program launched 500 superpressure balloons in the middle latitudes which floated at the 200 mb level. The launches took place during 1971 and 1972.

Carrier Balloon System

The Carrier Balloon System (CBS) was designed to provide essential tropical wind data from the surface to 24 km. These superpressure balloons were 21 m in diameter and were designed to float at 24 km. Each balloon carried 100 dropsondes, each weighing 300 g. They were commanded for release from one of four geostationary satellites. As the dropsondes descended, they relayed signals to their parent balloon from a worldwide network of Omega navigation stations spaced around the world. Signal strength and phase relationships among separate Omega signals were registered by electronics aboard the balloon. The Omega data were digitized and retransmitted via one of the geostationary satellites to a ground station, where signals were converted to the wind field.

CBS was tested in 1974 and 1975 from Kourou, French Guiana. Fourteen systems were flown to determine balloon life and the performance of the complex electronics system. The program demonstrated that 100 kg payloads could be flown successfully at 30 mb, that the wind profile from 24 km to the surface could be determined by retransmission of Omega signals from dropsonde to balloon to synchronous satellite to ground, and that balloons flown in the equatorial stratosphere remained in the equatorial belt as they circled the globe. For the Global Weather Experiment, CBS was replaced with an aircraft dropsonde system to ensure better coverage of the most active areas in the tropics.



Mother GHOST carrier balloons flying at 30 mb in the equatorial stratosphere were commanded via geostationary satellites to launch dropsondes. Winds at various levels were determined from analyses of Omega navigation signals relayed from the dropsondes via the carrier balloons and geostationary satellites back to a ground processing station.

The Carrier Balloon/Omegasonde System (CBS) was designed to provide upper air data in areas where they are not available by other means. The CBS involved large (21.4 m diameter) superpressure balloons carrying cargoes of miniature dropsondes. The sondes were released on radio command and their reports relayed by the carrier balloon to a satellite and then to earth. This system was developed by NCAR to provide a means of obtaining wind profiles in equatorial regions to meet the goals of the Global Weather Experiment. Field tests of the complete system were completed at Kourou, French Guiana.