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John E. Masterson

National Center for Atmospheric Research

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AN *IN SITU* MEASUREMENT SYSTEM FOR GARP USING BALLOONS, BUOYS, AND A SATELLITE

John E. Masterson
National Center for Atmospheric Research[1]
Boulder, Colorado

ABSTRACT

The goals of the Global Atmospheric Research Program are to increase our understanding of the general circulation of the atmosphere and to develop bases for extended weather prediction. Data to fulfill these goals may come in part from a low-cost random access doppler system using orbiting satellites to recover meteorological and oceanographic data from freely drifting balloons and buoys. Such a system will be used in a scientific study in the tropics and southern hemisphere in 1974 and will involve the Nimbus satellite and some 300 constant-level balloons. This program, to be conducted by the National Center for Atmospheric Research, the University of Wisconsin, and Goddard Space Flight Center, will have a threefold scientific objective:

- Investigation of tropical winds in the upper troposphere
- Production of a pressure reference level at 150 mb in the middle latitudes of the southern hemisphere
- A study of energy conversion in the atmosphere

INTRODUCTION

The Global Atmospheric Research Program (GARP) is an international cooperative program whose ultimate goals are to increase our understanding of the general circulation of the atmosphere and to develop physical and mathematical bases for extended weather prediction.(1,2,3) GARP was established in response to United Nations resolutions asking for studies directed toward greater understanding of global weather and improved weather forecasts.

GARP encompasses two separate but closely related communities: the World Meteorological Organization (WMO), made up of national meteorological agencies and services and including most of the observing, telecommunications, and automatic data-processing facilities now obtaining weather data; and the International Council of Scientific Unions (ICSU), a research community composed of national academies, university groups, and research organizations and institutes operated by agencies other than national meteorological services. This latter group devotes a large portion of its effort to fundamental research problems of the atmosphere and oceans, while the WMO is concerned in a related way with a worldwide system for meteorological observations and services known as the World Weather Watch, or WWW.(4,5)

Ten years ago GARP would not have been possible, on either a national or an international basis. But in this last decade there has been explosive growth in technology and understanding. The tools for accomplishing a global program of weather prediction are now available: we have high-speed electronic computers, meteorological satellites that observe and collect data, and mathematical models which represent in precise terms the behavior of the atmosphere and enable us to predict the movements of the atmosphere and thus the weather.

The investigation of tropical disturbances and the evaluation of the net effect of organized tropical convective processes on the energetics of the general circulation are among the most important studies to be made under GARP.(6,7) The GARP tropical programs, primarily concerned with the problems related to energy exchange processes between the various scales of tropical atmospheric motion, are second only to the GARP global experiment in importance.

SENSOR PLATFORMS AND SATELLITES

In this discussion one aspect of using satellites will be considered: to retrieve meteorological and oceanographic data from *in situ* platforms in the atmosphere and on the sea. The feasibility of obtaining such data in this way has been demonstrated. Two systems tested by the United States are the Interrogation, Recording, Location System (IRLS)(8) and the Omega Position and Location Equipment (OPLE).(9) IRLS used an earth-orbiting satellite, OPLE a goestationary one. Later this year the French meteorological satellite Eole(10) will be launched from Wallops Station, Virginia, in an inclined orbit and will interrogate, locate, and obtain data from some 500 balloons launched in the southern hemisphere.

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Table 1 illustrates the evolution of satellite-balloon systems for measuring winds. IRLS was proposed for Nimbus in 1964; the position and location experiment, OPLE, using the ATS-I geostationary satellite, was proposed later. Key elements that relate to all the systems are the number of balloons, payload weight, peak power, and cost per package.

Table 1

	1964	1967	1968	1969	1970	'71-'72	1974	1976
SYSTEM			OPLE ATS	IRLS NIMBUS 3	IRLS NIMBUS 4	EOLE	RADEM NIMBUS-F	TIROS N
	CONCEPT, PROPOSALS, TECHNOLOGY, DEVELOPMENT, FEASIBILITY DEMONSTRATION				30-50mb SO. HEM TROPICS	200 mb SO. HEM. MID LAT.	150 mb SO. HEM. TROPICS MID LAT.	OPERATIONAL
NUMBER OF BALLOONS			2	2	27	500	~300	
PAYLOAD WT. KG.			50	45	~6	~3	1	
POWER WATTS			~25	~25	6	5	1	
≈COST PER PACKAGE K$			~35	~50	20	10	2	

The OPLE experiment uses the Omega ground-based navigation system for platform location. Data from which positions will be computed are relayed through a geostationary satellite to a ground station for reduction. The OPLE is significant because it has demonstrated the feasibility of locating balloons and buoys on command and could therefore produce observations more frequently than once or twice a day. Simplification of the system would make it useful for location of mobile platforms in the tropics and middle latitudes. A system using Omega transmissions to locate dropsondes from a stratospheric carrier balloon has been proposed by V. E. Lally to measure winds in the tropics at a number of levels.

The IRLS flew successfully on Nimbus 3 in 1969; two balloons were interrogated and significant technological data were obtained. The first scientific experiment with IRLS was with Nimbus 4, which was launched on 8 April 1970: 26 balloons launched in the second half of 1970 from Ascension Island in the south equatorial Atlantic floated at 30 and 50 mb and provided data on the 26-month stratospheric wind cycle. Scientific results of this experiment were presented by James K. Angell at the American Geophysical Union session on Meteorological Measurements from Constant Level Balloons, 13 April 1971. The complete data set of balloon positions as determined by the IRLS will be distributed by Goddard Space Flight Center (summer 1971) as the Nimbus 4 Data Catalog, Vol. IV.

Technology for location of IRLS, OPLE, and Eole platforms, and data collection from them, require that the electronic packages on each platform be commanded and interrogated by the satellite. The balloon-borne packages are costly and complex. For a global program such as GARP, in which we will need a great amount of data from many sensor platforms over extended periods of time, they are too costly and too complex.

How can we reduce the unit cost of the electronic packages in order to sample, at low cost, a significant portion of the global environment? The costs of the complex system cannot be reduced by mass production of the existing packages because we do not need that large a number of packages. But costs per package can be reduced by simplifying the electronics of the package. The trade-off--more platforms with simpler and less expensive platform electronics--may result in either a more complex spacecraft payload or additional ground equipment.

RADEM AND THE TWERL EXPERIMENT

In Table 1, the column headed RADEM Nimbus F shows the system of primary interest to us now: a Random Access Doppler for Environmental Measurements.(11) It is an approved experiment for the payload on Nimbus F to be launched in 1974. The significant and important feature in this system is the comparatively low cost per platform package, i.e., vehicle, electronics, and sensors. It is a one-way, passive system wherein the balloon randomly transmits to an orbiting satellite, which picks up the transmission, processes and stores the information, and relays it to a ground station. The balloon platforms *are not interrogated*; therefore they do not need receivers and transponding electronics, nor does the spacecraft need command capability.(12) The payload carried by the balloon weighs 1,000 g or less.

A significant factor in the development of this system is that the scientific objectives of the program were set forth early and the system was designed around the scientific requirements. Many systems involving spacecraft undergo technological development and feasibility demonstration prior to becoming useful to scienfitic investigators. For the RADEM system, scientists were brought in from the beginning, and the tool that has evolved is more than usually appropriate for scientific investigation.

The random access doppler system as a payload experiment aboard Nimbus F will be part of a cooperative research program involving scientists from the National Center for Atmospheric Research (NCAR), the University of Wisconsin (UWis), and Goddard Space Flight Center (GSFC). The program has come to be known as the Tropical Wind, Energy Conversion, and Reference Level (TWERL) Experiment. The scientific objectives are:

- Investigation of tropical winds in the upper troposphere
- Production of a pressure reference level at 150 mb in the middle latitudes of the southern hemisphere
- A study of energy conversion in the atmosphere

The direction of the balloon-satellite experiment is in the hands of a management team, rather than of a single principal investigator. This team is representative of the interests and capabilities of the various groups participating in the experiment:

William Kellogg, NCAR, Team leader

Verner Suomi, Director of the Space Science and Engineering Center, University of Wisconsin

Paul Julian, NCAR

Charles Laughlin, GSFC

Vincent Lally, NCAR

William Bandeen, GSFC (ex officio)

This management team will share in the direction of the entire experiment, and in the responsibility for it. Individual responsibilities for several aspects of the experiment have also been assigned: Suomi for the energy conversion experiment and the radio altimeter,(13) Laughlin for the engineering and systems aspects of the satellite's random access doppler technique, Julian for the tropical winds and reference level experiments, and Lally for the constant-level GHOST (Global HOrizontal Sounding Technique) balloons and their electronic payloads.

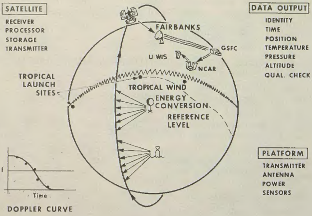
In 1968, GSFC and NCAR proposed the random access doppler system for the balloon-satellite experiment to study the evolution and structure of the organized tropical circulation in the upper troposphere and the interactions of tropical and mid-latitude circulations. At the time of the proposal, we felt that science and technology were advancing so rapidly that our program should remain flexible for 18-24 months. With this flexibility, we have been able to increase the scientific value of the whole experiment: an amended proposal was submitted in October 1970 for adding the reference level and energy conversion experiments. A pressure reference level(14) is a geometric altitude at which pressure and temperature are measured directly, *in situ*. The measurements provide a means whereby one can determine the distribution of the mass field as a function of height. In the global observing system which has been proposed for the First GARP Global Experiment (FGGE), the temperature field will be determined primarily by remote sensing from spacecraft. The temperature profiles are obtained as a function of pressure. In vast areas of the southern hemisphere which are without observations of any kind, the reference level for FGGE might be obtained from either constant-level balloons or drifting buoys--thus providing fiducial points in the relation of the mass and temperature fields.

In the TWERL Experiment, the reference level data will come from 300 balloons floating at 150 mb in the southern hemisphere. The balloons will be launched from a number of sites in the tropics, and will first provide data on the dynamics of the tropical wind field. They are then expected to drift gradually out of the tropics. Those that drift into the southern hemisphere middle latitudes will continue to provide wind velocity, temperature, pressure, and the geometric altitude of the 150-mb level; those that may drift into the northern hemisphere will be cut down by magnetically activated devices.

As for the energy conversion part of the experiment, the prospect of having these balloon data available opened up the intriguing possibility of studying how the potential energy inherent in the mass distribution of atmosphere is converted into the kinetic energy of atmospheric motions--one of the most fundamental questions in meteorology. A University of Wisconsin team headed by V. E. Suomi will use the information provided by the balloons to delve into this problem.

Figure 1 shows the geometry of a balloon-buoy-satellite system for location and data retrieval. The Nimbus polar-orbiting satellite, in a sun-synchronous orbit with a period of 108 min, completes about 13.5 orbits every 24 hr. Its location is computed from satellite ephemeris data.

Figure 1



Signals randomly transmitted by the moving platforms are received by the orbiting satellite when the platforms are within the antenna pattern of the satellite. For example, each 64-bit transmission consists of synchronization, identification, and four data channels (8 bits each) of measured variables.

Transmitted signals are recorded by the satellite, and a time reference signal from the satellite master clock is added. The satellite also performs on-board processing of the signals, thus reducing the amount of data to be relayed. The processed and recorded data are stored in the satellite until the Nimbus ground station in Fairbanks, Alaska, requests their transmission. The ground station receives the data and relays them to GSFC, where they are processed and reduced by computer. The data products are:

- Identity of each platform
- Time of transmission
- Position, computed from doppler frequency shift and known satellite position. Since the balloon electronics are powered by solar cells,

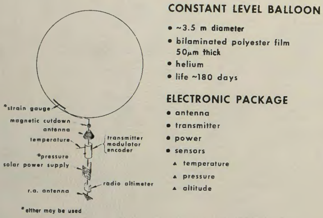
only daytime positions are possible. Wind velocity is computed from two successive satellite passes.

- Temperature
- Pressure
- Altitude (geometric height measured by radio altimeter)

An estimate of the quality of the data received from the satellite is added at the data reduction center. The data are then transmitted to NCAR (after every orbit or at least once every 12 hr) where they will be processed for analysis and distribution to other users.

The superpressure GHOST balloons that will be used for the balloon-satellite experiment are shown in Figure 2. These balloons, developed by Lally,(15) are about 3.5 m in diameter, and are made from laminated Mylar polyester film 50 μm thick. They have been tested with more than 180 flights at 100, 150, or 200 mb in the southern hemisphere; their lifetimes average 180 days in the middle latitudes, and some have flown more than a year.

Figure 2



The balloons will carry low-density instrument packages consisting of a transmitter, crystal oscillator, solar cells for power, a data modulator, and three sensors: a temperature bead, a pressure sensor, and a radio altimeter.

BUOYS

The Global Atmospheric Research Program is, as its name implies, primarily concerned with the atmosphere. However, the surface of the earth--particularly the 70% of it that is water--cannot be ignored in its influence on the air above it. Although the dynamics of the ocean are many times slower than those of the atmosphere, the tremendous reservoir of heat affects the atmosphere through energy exchange mechanisms. Measurements at the interface of the ocean and the atmosphere can be accomplished by remote soundings from satellites, by ships of opportunity and weather and oceanographic research ships, and by aircraft. The use of moored and drifting buoys for the collection of oceanographic data(16,17) is also becoming feasible, especially since an effective location and data retrieval system is now available.

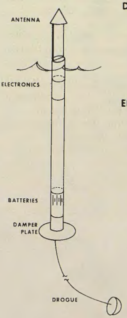
A buoy program is not now part of the NCAR-UWis-GSFC proposal, but fits into this discussion in that data collected by drifting buoys could be relayed via satellite in the same manner as data collected by balloons. Expendable drifting buoys offer an opportunity to obtain a low-cost ocean-surface data base. In the thesis of the GHOST constant-level balloon-satellite system, the drifting buoy data would be limited to the primary variables of atmospheric pressure, air-sea temperature difference, near-surface wind velocity, and possibly two or three water temperature measurements in and below the mixed layer. Ocean current measurements would be derived from buoy positions. These data would be obtained daily and nightly from battery-powered buoys at times determined by the satellite passages.

Requirements for ocean data have been laid out in GARP documents, although not as explicitly as those for meteorological data. Models of ocean circulations are not yet as advanced as are those of the atmosphere, but the drifting buoy and satellite combination would provide a powerful tool for obtaining surface and near-surface measurements from remote areas. Since the buoys are responsive to currents rather than wind, they are Lagrangian tracers and provide suitable measurements of transport. The addition of water temperature measurements to the surface current data may contribute significantly to the solution of problems in the transport and diffusion of the mixed layer. Measurements of wind, air temperature, and barometric pressure would be on a synoptic scale, however, rather than in sufficient detail for air-sea interaction studies. The surface and temperature measurements would provide a sea-level reference level for satellite temperature profile derivations in areas not covered by balloons; furthermore, these *in situ* data would be useful in calibrating satellite remote soundings.

Some investigations for surface observations suggested by the Williamstown Study of 1969(18) involve placing clumps of 12 buoys in locations such as the central equatorial Atlantic, the north-central Pacific near the boundary between the subtropical and subpolar gyres, and the equatorial Pacific.

A drifting spar buoy proposed by William Richardson of Nova University in Ft. Lauderdale, Florida, for studying the South Equatorial Current is shown in Figure 3. This spar buoy, deployed from ships or possibly (in a modified version) from aircraft, is the sort of simple, effective, expendable buoy we need. The drifting buoy must survive in a harsher environment than a balloon, and yet must not be so sturdily built as to endanger ships. This buoy is a plastic (polyvinylchloride or PVC) water pipe with a damper plate at the lower end and an antenna at the upper end. It is 5-7 m long and 20-40 cm in diameter depending on the volume required for electronics, batteries, and stability.

Figure 3



DRIFTING SPAR BUOY

- 5-7 M LENGTH
  0.3-0.5 M DIAMETER
- PVC TUBING
- DAMPER PLATE & DROGUE

ELECTRONIC PACKAGE

- ANTENNA
- TRANSMITTER
- POWER
- SENSORS
  - ▲ AIR TEMPERATURE
  - ▲ WATER TEMPERATURE
  - ▲ WIND VELOCITY

The RADEM system lends itself to measurement from a drifting buoy of the following variables:

- Position: ±5 km every 12 hr
- Air-sea temperature difference: ±0.5°C over ~ 2 hr
- Atmospheric pressure: ±0.5 mb averaged over ~ 2 hr
- Wind speed: ±1 m/sec
- Wind direction: ±10°

Additional water temperature sensors and atmospheric sensors may be added as the system develops. Prime considerations are power requirements, the effectiveness of sensors exposed to the ocean environment for six to twelve months, and the efficiency of the transmissions to the satellites. Expendable buoys such as these should be designed for specific investigations and ocean areas. For example, an important meteorological variable to be measured in the tropics is wind velocity; pressure measurements may be of higher priority in middle latitudes.

CONCLUSIONS

We believe the RADEM system has evolved into a usable observational tool for GARP. This simple system, based on the doppler location technique, has evolved from the complex and costly platforms of the IRLS and Eole. With it, the scientific community can afford to conduct scientific investigations on a global basis.

The GARP criterion for wind measurements of 1-3 m/sec is within the capability of the RADEM system. Each balloon can be located within a radius of 5 km; winds are determined from positions of the balloon on two successive satellite passes.

Expendable drifting buoys could provide for GARP an *in situ* data collection system over the ocean similar to GHOST constant-level balloons in the atmosphere; that is, they can measure motion and provide sensor and communication platforms for the variables measured. Among specific areas of investigation applicable to the use of drifting buoys during GARP are air and sea temperature measurements, near-surface wind velocities, and sea-level pressure measurements. The last could be used as a pressure reference level. In addition, buoy data can be used to calibrate remote soundings from satellites.

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