6.7 RESULTS OF THE DEMONSTRATION FLIGHT OF THE GAINS PROTOTYPE III BALLOON

C.M.I.R. Girz*, A.E. MacDonald,
NOAA Forecast Systems Laboratory, Boulder, Colorado

R.L. Anderson
Basic Automation, Boulder, Colorado

T. Lachenmeier
GSSL, Inc., Hillsboro, Oregon

B.D. Jamison, R.S. Collander
CIRA, Ft. Collins, Colorado

D. Latsch
CIRES, Boulder, Colorado

R.A. Moody
GSSL, Inc., Hillsboro, Oregon

J. Cooper
NMSU/PSL, Las Cruces, New Mexico

G. Ganoe, S. Katzberg
NASA/Langley, Hampton, Virginia

T. Johnson, B. Russ
Aerospace Innovations, Yorktown, Virginia

V. Zavorotny
NOAA Environmental Technology Laboratory, Boulder, Colorado

1. INTRODUCTION

Our limited understanding of Earth's geophysical systems and the feedbacks between physical and living systems means that we cannot yet cleanly sort out natural variability in the environment from the effect of human activities. In many ways our understanding is limited by current sampling, be it the frequency of samples, instrument accuracy, the period of record, or the sparsity of sampling locations.

Initial results from an analysis of a 50-year radiosonde records point to the value of in-situ observations in quantifying climate trends (E.C. Weatherhead, personal communication). Observations in the free troposphere have lower noise levels, allowing trends to be detected in a significantly shorter period of time than is needed at lower altitudes. GAINS is conceived as an operational program of instrumented platforms to collect data in the free troposphere, as well as other parts of the environment. A network of ~400 platforms evenly distributed over the global lower stratosphere. (Fig. 1) will provide coverage at every 10° latitude by 10° longitude location delivering a complement of sondes over a period of time. To maintain a distribution of observing platforms at specified locations and for specified times presents a technical challenge. A mix of balloons and autonomous aircraft (Fig. 2) is envisioned for providing such coverage. Superpressure balloons would populate the southern hemisphere through the northern hemisphere midlatitudes, running on solar power. Solar-powered autonomous aircraft in the midlatitudes of the northern hemisphere would be able to maintain their position against strong displacements from winds in the jet stream and baroclinic systems. In polar regions of the northern

**Corresponding author address:* Cecilia M.I.R. Girz, NOAA/Forecast Systems Laboratory R/FS1, 325 Broadway, Boulder, CO 80305; email: cecilia.girz@noaa.gov

hemisphere, the GAINS platform would be fueled autonomous aircraft staying on station for shorter periods than the solar powered vehicles.

The GAINS payload on both balloons and autonomous aircraft will consist of a mix of small, expendable sondes that will be dropped on command to measure a number of environmental parameters, including weather, climate, atmospheric chemistry and ocean variables. Atmospheric sondes currently measure pressure, temperature, moisture, and incorporate GPS sensors for location and wind computations. Development of inexpensive, accurate, light weight, in-situ sensors for atmospheric profiling of ozone and CO_2, and for ocean soundings of pressure, temperature, salinity, and currents is anticipated.

This paper emphasizes development of the GAINS balloon platform. The superpressurized GAINS balloon vehicles maintain a regular network through “shear direction”. These balloons can be made to change altitude and thus be moved horizontally by taking advantage of vertical shear in the horizontal wind. The helium cell of the balloon (Fig. 3) contains sufficient lift to keep the payload aloft. The pump controls the amount of air in the air cell, pumping air in to increase the balloon’s density and driving it to a lower altitude, or venting air to decrease density for a higher float altitude. Balloons that are air ballasted for varying float altitudes follow widely varying trajectories. To illustrate, “launched” from Tillamook, Oregon on the northwest coast of the U.S. with float altitudes ranging from 16.7 to 22.8 km, four simulated trajectories (Fig. 4) have a 1000-km spread after 48 hours. It is this shear that makes a distributed network of GAINS balloons a viable concept for the southern hemisphere.

A demonstration flight of the GAINS superpressure balloon is planned for the week of 22 October 2001. The objectives of this test are fourfold: to demonstrate the operation of the 18.3-m-diameter PIII balloon at a nominal float altitude of 16 km for 48 hours; to fly the FSL payload and supplemental systems from PSL and GSSL; to fly experimental payloads from NASA/Langley and Edge of Space Science (EOSS) collaborators; and to recover the balloon and payload. This paper describes the instrument systems that will be flown, and the infrastructure that will support the flight. Results from the flight will be presented at the conference.

2. BALLOON AND PAYLOAD

2.1 Balloon vehicle

The full-scale GAINS vehicle is 33.5 m in diameter and carries a payload of 350 kg to an altitude of 18 km. The triple-layered vehicle (Fig. 3) has an outer envelope of Spectra™ fabric, and two concentric polyurethane cells for air and helium. Air is used as a renewable ballast, and is moved into and out of the balloon with a pump and valve. The balloon conforms to Federal Aviation Regulation 101 (FAA, 1992), having two independent termination systems. For more details on the GAINS balloon vehicle see Lachenmeier et al. (1999).

A smaller version of the balloon, Prototype III (PIII) shown in Fig. 5, will be launched from Tillamook, Oregon, for the demonstration flight. PIII has an 18.3-m diameter and can carry a 150-kg payload to 15.8 km. Critical to a successful flight for a long-duration balloon is its ability to maintain altitude between day and night. During the day, shortwave radiation is the major forcing on the balloon, heating the internal gases and causing the balloon to rise. In the absence of sunlight, the balloon radiates long wave energy, making the internal gases denser, and resulting in a drop in balloon altitude. Among the several objectives of this demonstration flight, a key objective is to monitor performance of the PIII balloon over two day-night cycles.

2.3 Instrumentation

Each full-scale GAINS vehicle carries a set of instruments for location, communication, command and vertical control. These include GPS location, line-of-sight (LOS) and over-the-horizon (OTH) communication and command systems, and a pump for altitude control. The full-scale balloon will be powered by solar cells and rechargeable batteries. Included among the instruments are a number of safety systems. To ensure aviation safety and to be under positive control, an aircraft transponder is active while the balloon traverses domestic air space. Redundancies are planned into the hardware to minimize the event of a catastrophic failure (defined as a loss of communication and control) of any balloon in the network. Further details on GAINS instruments can be found in Anderson et al. (1999).

The payload for the 48-h PIII flight consists of the communication, command, control and power systems noted above with two exceptions. First, no pump will be flown. Consequently, vertical control will be demonstrated only through venting the air or helium that the balloon carries at launch. Secondly, a rudimentary solar collection system will be flown for the purpose of gathering data at altitude, but the onboard power will be provided by batteries.

In addition to the GAINS instruments, the toroidal capsule will carry a GPS-glistening or surface reflection experiment. Two GPS receivers, viewing upward (surface reflected) and downward (direct) transmissions are used to look at ocean winds derived from sea state (Komjathy et al., 1999) and test a soil moisture capability over land.

The GPS instrument is a PC-104 bus stack consisting of a Pentium processor, a specially modified GPS dual front end receiver in a rugged enclosure, and two GPS antennas. One antenna oriented upward receives direct signals from GPS satellites, and the downward-oriented antenna with reversed polarity receives signals reflected from the surface of the earth. The initial use of this instrument technology was to investigate the measurement of sea surface roughness by performing a cross-correlation between the diffusely reflected signal and the pseudo random noise code which underlies all GPS transmissions (Garrison and Katzberg, 1998).

The current version of the GPS instrument to be flown on the balloon has been redesigned to be more compact, use less power, and withstand a greater variation in environmental conditions than previous versions. This instrument has also incorporated a new data collection mode and other software modifications needed to begin the exploration of another potential use of the reflected GPS signal which is the remote detection of ground surface soil moisture conditions. The new data collection mode was developed to track five direct satellites (providing a continuous navigation solution) and multiplex the remaining seven channels to track the reflected signal of the satellite tracked in channel 0. The new software mode has been shown to increase the signal-to-noise ratio of the collected data and enhance the science return of the instrument.

While there is no coordinated effort on this mission to compare measurements with ground truth, the testing in a relevant environment of the instrument along with the potential qualitative data expected will provide valuable information with which to proceed toward the further development of a soil moisture measurement capability. Results of this experiment are provided in a companion paper (Ganoe et al., 2002).

3. INFRASTRUCTURE

Planning and execution of the flight are as important as the hardware described in section 2. This section describes the support systems required for preflight planning, launch, and recovery of the balloon.

3.1 Trajectory calculations

Prediction of balloon trajectories is critical for successful launch and recovery operations during test flights, as well as for routine operations of a network of balloons. Because we desire to recover the balloon and payload, landing locations with high accessibility, relatively flat terrain, and minimal or grassy vegetation are sought.

Climatological winds from radiosonde data are used for an initial assessment of whether the mean winds will produce a useable trajectory for flights. A trajectory forecast for the PIII 48-h flight for the date of interest in late October (Fig. 6) shows a potentially favorable landing location. Although close to the mountains, there are wide valleys in this region of Montana that are suitable for a landing, and access from major highways is a boon for quickly moving recovery crews to retrieve the equipment.

The trajectory in Fig. 6 is based on average winds. For day-to-day planning, however, real-time flight trajectories are automatically generated twice daily from the synoptic radiosonde observations and from weather model forecasts of winds. Each trajectory is started using a sounding generated from the RUC2 model at the grid location of the METARS station outside of Tillamook. Inputs of launch location, ascent and descent rates, float altitude, and time at float are fixed on the automatic code. An interactive version of the code is also available for specifying each of these parameters. On the day of launch, the latest real-time and interactive trajectories are used to determine GO or NOGO operations for test flights. For flights during this initial development phase, only those trajectories that remain within the U.S. will be flown.

3.2 Launch and recovery

Detailed launch criteria have been developed in the system qualification tests discussed in section 4. Many of these launch criteria are weather related. Weather is a safety factor for the integrity of the balloon. In contrast to launches of zero-pressure balloons which are filled outdoors, the GAINS balloons are filled inside a hangar. The large surface area of these balloons necessitates weak surface winds at launch, and a balloon remains indoors until conditions are right. The aviation guidelines of FAR 101, as well, spells out specific weather requirements for sky conditions. Balloons are not launched through overcast skies because they are a potential hazard to aircraft. And launch through cloud could add unwanted mass as water collects on the balloon's surface.

Once launched chase and recovery crews follow the balloon, collecting data from the line-of-sight telemetry, monitoring the balloon's instruments, and terminating the balloon at the end of the flight or under catastrophic conditions. During the first four hours of flight, the balloon will be monitored from a base station at a fixed location in Oregon and with a chase vehicle on the ground. Each of these vehicles has a ground station that receives and displays in real time flight parameters including latitude, longitude, altitude, balloon and environmental pressure and temperature, battery voltage. After the first four hours of flight, coordination control is transferred to the base station in Boulder, Colorado. A chase aircraft follows the balloon for the entire flight. Personnel on this aircraft coordinate with Air Traffic Control during the flight, send the radio termination signal at the end of the flight, and direct ground vehicles to the landing location.

4. QUALIFICATION TESTS

In preparation for the PIII flight, a series of balloon and instrument prototypes have been built to test capabilities in a step-wise manner. Spectra™ balloons of ~5-m diameter (Prototype II, or PII) were used from 1998 to the present on 1- to 5- h flights (Table 1) to test LOS telemetry, OTH communications, Air Traffic Control coordination, radio termination, and balloon descent properties. These balloon tests have also refined launch, chase, and recovery procedures.

The first flight of the FSL instrument package was performed in Sept. 1998. This test qualified the telemetry radios, ensuring that data on balloon state and the external environment would be received and recorded at the ground.

The balloon flight is actively ended by a radio command that releases a mass to tear a hole in the helium cell. Radios for balloon termination were qualified on the second flight in Dec. 1999.

The GAINS balloon does not carry a separate parachute but uses the BERS (Balloon Envelope Recovery System) feature for deceleration. Several tests were performed between Dec. 1999 and April 2000 to transform the superpressure envelope from the lifting vehicle into a parachute for descent. As the helium and air in the gas cells are vented at termination, dynamic pressure of the falling system, forces the fabric at the bottom of the sphere upward, creating the parachute, This minimizes the several Gs of force that can occur on traditional balloons when the parachute opens and takes the weight of the falling payload. In the April 2000 test, envelope transformation was confirmed and safe descent speeds of 3-4 m s^{-1} were documented.

The final test in preparation for the 48 hour flight was performed in Tillamook in May 2000. Payloads from FSL, GSSL, PSL, NASA/Langley and EOSS were physically and electronically integrated into the torus (Fig. 7). Near and distance radio checks were performed to ensure that radio interference would not occur from the multiple experiments on board. This test was successful.

5. SUMMARY

GAINS is a multi-year test and development program of the vehicles, instruments, and sensors, and the launch, control, and recovery infrastructure to operate a global observing network. Individual tests of the telemetry, command, power and safety components of a prototype GAINS system have been completed. A demonstration flight is scheduled for Oct. 2001. Results will be reported at the conference.

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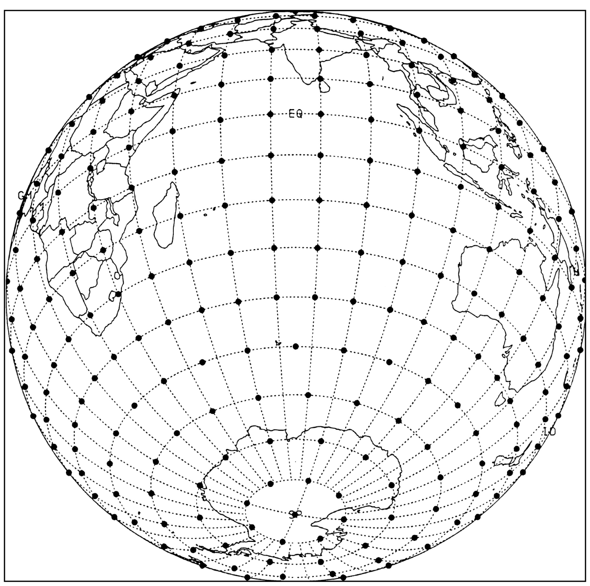

Fig. 1. Sample distribution of 408 platforms spaced in a 10˚ x 10˚ grid.

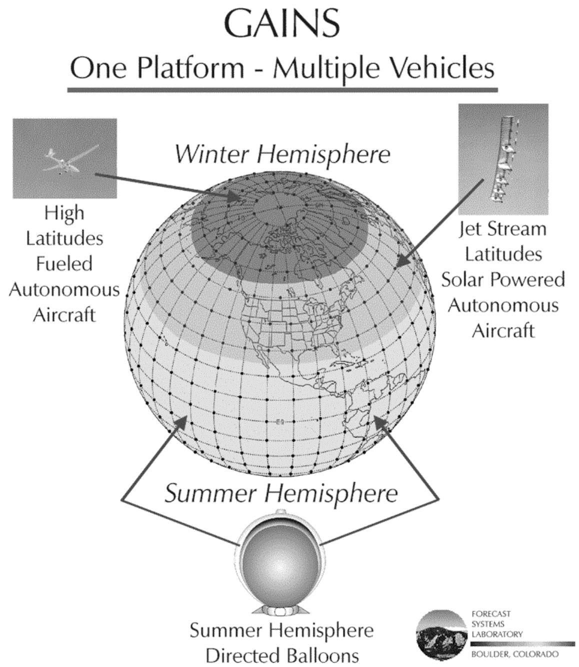

Fig. 2. GAINS uses a mix of balloon and autonomous aircraft to observe the globe.

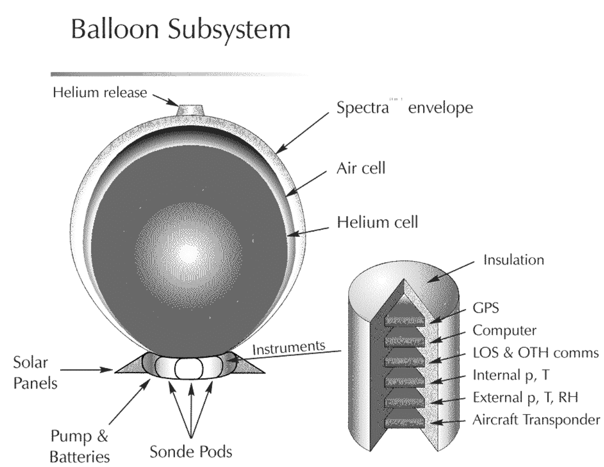

Fig. 3. Schematic of the GAINS balloon vehicle (left) and payload (right).

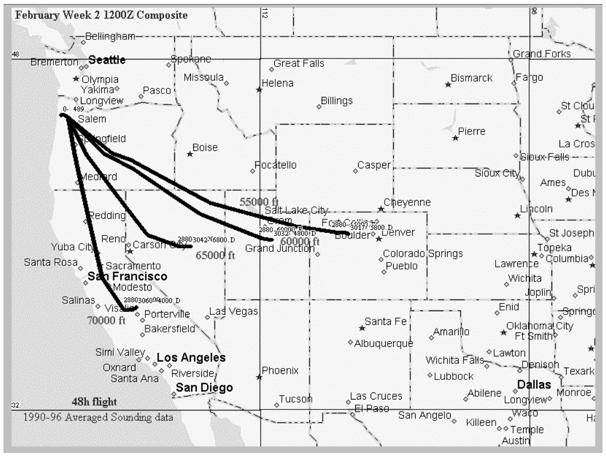

Fig. 4. Dispersion in 48 hours of simulated trajectories of balloons floating at four altitudes between 17 and 23 km.

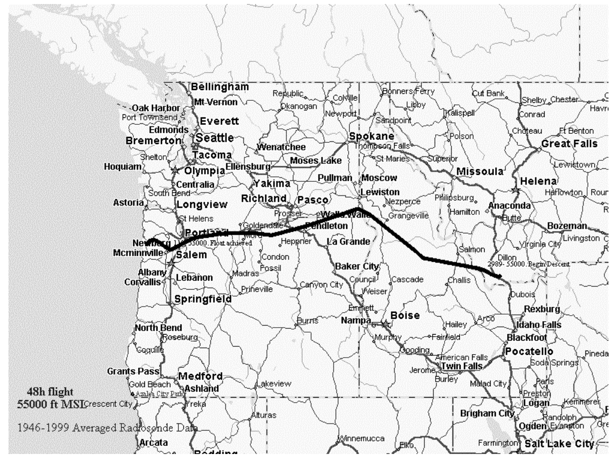

Fig. 6. Balloon trajectory forecast for 24 Oct. based on climatological winds.

Fig. 5. The 18-m diameter, PIII prototype GAINS balloon. The toroidal payload capsule (on which the balloon appears to be sitting) is closely coupled to the base of the balloon. A plastic sheet protects the balloon from dirt and debris in the hangar

Fig. 7. Loading payload instruments for the 48-h flight into the torus. The top cover has been removed from the instrument bay at right, and the porthole is open in the bay at left.

Table 1 Qualification tests for the GAINS prototype balloons and instruments

Date	Balloon (Diameter)	Payload	Altitude	Distance (km)	Objective
Sep. 98	**PII (4.8 m)**	**11 kg**	**9.1 km**	**402 km**	**PII instrument check**
Dec. 99	**PII-LF (4.5 m)**	**7 kg**	**8.5 km**	**4 km**	**Termination**
Apr. 00	**PII-LF (4.5 m)**	**7 kg**	**8.8 km**	**193 km**	**Descent rate**
May 00	**PII (4.8 m)**	**9 kg**	**6.7 km**	**59 km**	**Radio check**
Oct. 01	**PIII (18.3 m)**	**100 kg**	**18.0 km**	**625 km**	**Concept demonstration**