1.1 EVALUATION OF EXPERIMENTAL DATA FROM THE GAINS BALLOON GPS SURFACE REFLECTION INSTRUMENT

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Abstract—The GPS Surface Reflection Instrument was integrated as an experiment on the GAINS (Global Air-ocean IN-situ System) 48-hour balloon mission flown in September 2001. The data collected by similar instruments in the past has been used to measure sea state from which ocean surface winds can be accurately estimated. The GPS signal has also been shown to be reflected from wetland areas and even from subsurface moisture.

The current version of the instrument 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 to track 5 direct satellites (providing a continuous navigation solution) and multiplex the remaining 7 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.

During the 48-hour flight over the Northwest US, the instrument will measure surface reflections that can be detected over the balloon's ground track. Since ground surface elevations in this area vary widely from the WGS-84 ellipsoid altitude, the instrument software has been modified to incorporate a surface altitude correction based on USGS 30-minute Digital Elevation Models. Information presented will include facts about instrument design goals, data collection methodologies and algorithms, and results of the science data analyses for the 48-hour mission.

1 INTRODUCTION

The Global Positioning System (GPS) signal has been shown to be reflected from bodies of water, marshland areas, wet soil, and even from subsurface moisture. An instrument has been developed by the NASA Langley Research Center with the ability to record the power of the reflected signal over a range of pre-selected time delays. Various implementations of this instrument technology have been used to collect reflected GPS data, primarily over the oceans and seas[1]. The data collected has been shown to be useful for measurement of sea surface roughness[2] and surface wind speed[3]. Continuing studies are underway to determine other potential uses for those data sets. Our current experiment seeks to determine if there may be value to making measurements over terrestrial areas for measurement of soil moisture or other remote sensing applications. A new implementation of the GPS surface reflection instrument has been designed and built with the goal of being compatible with high altitude balloon environments. The software for the new instrument has incorporated the capability to make measurements using both of the most useful modes from previous implementations as well as some new functionality considered necessary for terrestrial applications. This paper describes the target mission for the new instrument, the instrument background and capabilities, the data collection, and the data analysis approaches to be used.

2 MISSION BACKGROUND

It has long been known that various materials including metallic objects and bodies of water reflect the signals transmitted from the GPS satellite constellation[4]. While these reflections can be sources of error for the intended use of the GPS signal to provide accurate position information, the information that may be gleaned from measuring the reflected signal has been shown to be useful.

2.1 *Past Missions*

The GPS surface reflection instrument has flown on aircraft and balloon missions in the past. These missions have been primarily flown over water with the purpose of validating concepts for determining the sea state and hence wind speed and direction from the scattered reflected signal received by the instrument. Good correlation with comparative data has been shown by researchers[5].

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Numerous aircraft flights have been conducted using the early instrument version, and recently some have been conducted using a reconfigured version of the compact GPS surface reflection receiver built for the GAINS balloon mission.

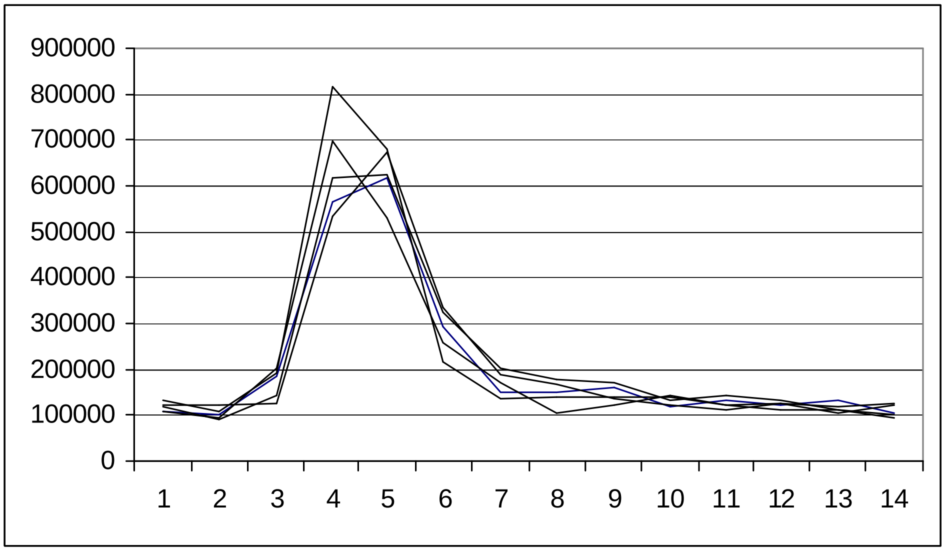

Figure 1. Representative power vs. delay measurements for terrain sampling

2.2 *Evidence for soil moisture*

Some data sets included data taken while the specular reflection point of the GPS signal being monitored was located over inland areas. In many of these instances, some reflected signal power was received where no apparent reflection sources were available. The strength of the reflected signal appeared to be correlated to the level of moisture in the soil at the reflection point. In order to corroborate that finding, an additional data set has been collected during a flight over East Texas[6] which shows evidence that the reflected signal power varies monotonically with the level of soil moisture in the ground. An example of the power versus delay measured for some representative samples is shown in Figure 1. The horizontal scale represents the time delay in code chips, and the vertical scale is a relative power measured in digital units.

3 INSTRUMENT BACKGROUND

The GPS Surface Reflection Instrument (GSRI) consists of a PC compatible computer running the DOS operating system and a GPS receiver peripheral compatible with the GPS Builder II from the company formerly known as GEC Plessey Semiconductors. A photo montage depicting the instrument and its integration into the GAINS Balloon gondola is shown in Figure 2. This

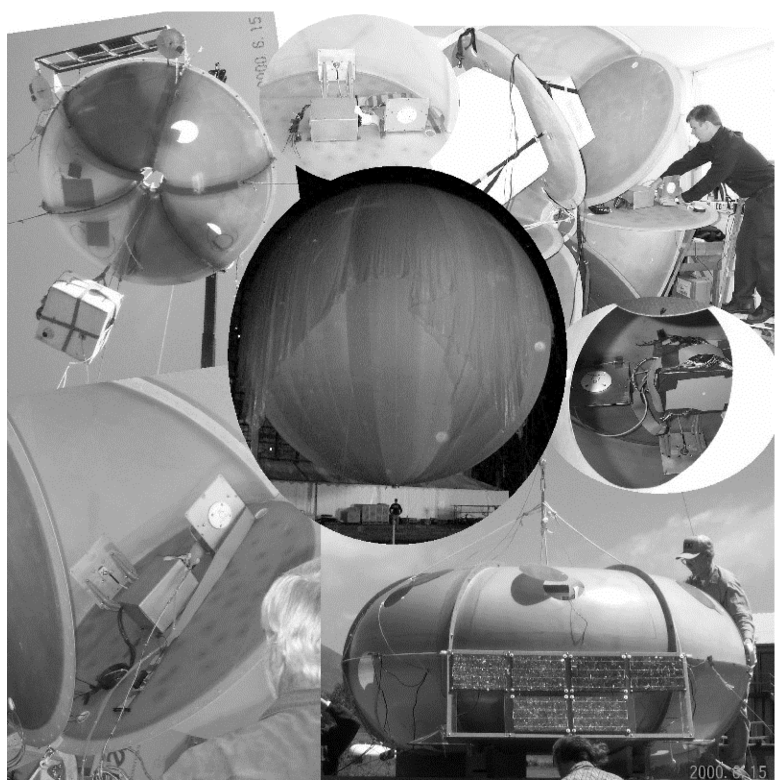

Figure 2. GPS Surface Reflection Instrument integration on GAINS Balloon

hardware runs a modified version of the GPS Builder II development software. The modified software currently being used is capable of being operated in one of four operational modes. The default mode provides a standard GPS receiver capability which uses all 12 correlator channels to receive signals from one (selected by a startup option) of the two antenna inputs. The default mode is used extensively for performing system functionality checks on the ground, and for comparing the sensitivity of the two RF input channels. The other three modes split the 12 correlator channels between the antennas and some channels receive direct signals while the rest receive the reflected signal data of interest. The data from these channels is then saved for later post flight processing to extract the desired information. The three data collection modes are described in a subsequent section. Since the elevation of the ground reflection point for the desired signals can not be calculated accurately over areas where the actual elevation varies from the WGS-84 ellipsoid, an optional elevation correction technique has been incorporated into the software to insure that the time delay range of reflected signals being scanned is reasonable. The elevation correction technique can be selected as a start up option for either of the two modes that have the ability to compute real time position solutions. That elevation correction technique is described in the next section.

3.1 *Elevation Correction*

The flight of the GSRI on the GAINS 48-hour balloon mission will carry the instrument over a ground track that varies widely from the WGS-84 ellipsoid. Since the GSRI software assumes reflections are centered about the WGS-84 ellipsoid, modifications were required in order to collect relevant data onboard the GAINS balloon. The GSRI software was modified to account for deviations from the WG-84 ellipsoid by utilizing the GSRI position and an elevation data set that was derived from the USGS 30 minute digital elevation map.

Since on-board storage space available for this function was limited to 8 MBytes, a file containing the digital elevation map for the area of interest was constructed from the USGS data set. The elevation data file header contains the information required by the GSRI software to easily index to the requested elevation data based on the GPS position solution (that is already produced by the GSRI). The software uses the current GPS latitude and longitude and calculates the file position in the elevation map file based on the header information provided. The elevation data is then read from the file as a binary floating point value. The algorithm provided a simple and fast solution for obtaining the necessary elevation data without requiring a lot of memory or processing power. The data file header is detailed in Table 1. After the header, the file is packed with floating point values representing discrete elevations. The order of the elevations is detailed as follows:

[min lat, min lon]	[min lat, min lon + delta]	…	[min lat, max lon]
[min lat + delta, min lon]	[min lat + delta, min lon + delta]	…	[min lat + delta, max lon]
…,			
[max lat - delta, min lon]	[max lat - delta, min lon + delta]	…	[max lat - delta, max lon]
[max lat, min lon]	[max lat, min lon + delta]	…	[max lat, max lon]

Table 1: Elevation File Header

Data type	variable Name	Description
Float	minLat	minimum latitude of data in file
Float	minLon	minimum longitude of data in file
Float	maxLat	maximum latitude of data in file
Float	maxLon	maximum longitude of data in file
Float	nlat	number of discrete points of latitude along a single degree of longitude (=[maxLat-minLat]/delta)
Float	nlon	number of discrete points of longitude along a single degree of latitude (=[maxLon-minLon]/delta)
Float	delta	delta latitude (in degrees) of data set

3.2 *Data Collection Modes*

The current GSRI hardware provides a single 12 channel GPS correlator to correlate data between the RF interface receiving the direct GPS signals (RF0) and the RF interface receiving those same signals reflected from the Earth's surface (RF1). Each of the 12 channels must be assigned to a particular satellite on one of the RF interfaces. The initial software tracked 6 direct satellites on the RF0 interface, and used the remaining 6 channels to monitor the reflected signals from each of those satellites on the RF1 interface. Since only one reflected channel exists for a particular satellite and multiple delay bins are needed, each measurement cycle (1 millisecond) the delay offset of the reflected channels is incremented by a half codechip step. Thus the desired delay bins are sequentially updated once each tick (0.1 seconds). This software provides a single correlation for each satellite (over several measurement cycles), while providing a GPS position solution. In the current software this mode is called the STEP mode. To increase the data return of a single satellite, a second version of software was created to track 2 direct satellites on the RF0 interface and split the remaining 10 channels to track 5 reflected channels for each satellite. The code delay for each of the 5 reflected channels is offset by 1 codechip step from the previous channel with the delay for the starting channel set by the expected path length delay determined by calculation using the WGS-84 elevation at the specular reflection point. Therefore multiple measurements at different offsets are collected in parallel on the particular satellite during each measurement cycle. While it is advantageous to gather more data on a given satellite, this version of software could not provide a position solution requiring the operator to know which satellites were in view (preventing autonomous operations). This mode is known as 2SV.

A new data collection mode is a compromise between collecting multiple measurements in parallel at different delay offsets each measurement cycle and providing a position solution for autonomous operations. The new mode tracks 5 direct satellites on the RF0 interface in order to provide a position solution. The other 7 channels are used to track the reflected signal of the satellite tracked in the first channel, with the delay offsets separated by 1 code chip steps. With two correlations per channel, this yields 14 half code chip delay steps. This mode is called 1SV. One disadvantage to this software mode is that data is collected on a single satellite. The ideal solution would be to collect data at multiple codechip offsets on multiple satellites. One enhancement for this software is to multiplex the data collection (switch the satellite tracked by the 7 reflected channels). The 7 reflected channels would switch between collecting data on each of the 5 satellites tracked for the position solution. This would provide a position solution, and provide multiple measurements on up to 5 satellites.

4 CURRENT MISSION

Since the number of data sets for evaluating the capability of the GPS surface reflection instrument to measure soil moisture and other terrestrial applications is currently very small, the GAINS balloon opportunity is particularly valuable. This mission provides the ability to collect approximately 48 hours of reflected signal data over varying terrain types in the Northeast United States. The information presented here will consist of the approaches that will be used for data collection and for data analysis. The conference presentation will detail the status of the data analysis that can be completed by then.

4.1 *Data Collection Approach*

The data collection approach has been selected to provide a balanced data set from the most useful of the data collection modes currently available. Since the actual path of the balloon and the timeline for the path are not known in advance, the data collection will automatically rotate through the selected modes. Each mode will be exercised for 30 minutes, then the next mode will be exercised. The resulting collection of data sets should provide data from each mode over a variety of terrain types. The modes selected are the STEP mode and the 1SV mode. Each of these modes will be operated half the time with elevation aiding turned on, and the other half with elevation aiding turned off.

4.2 *Data Analysis Approach*

While the primary purpose of this flight is to provide flight test experience for the instrument in the balloon environment, the potential for collecting valuable research data can not be ignored. The recorded data set will first be reviewed to determine what segments have returned useful reflected signal data. The specular reflection point for these segments will then be plotted in a Geographic Information System (GIS) and detailed maps of those areas will be obtained in order to find tracks that are useful for finding correlation between the actual ground conditions and the measured reflected signal. When a suitable track is found, the received data will be correlated with the estimated ground conditions. If actual ground conditions can be determined by some corroborating ground truth, then those conditions will be used and given extra weight in the process of trying to deduce an algorithm for extracting the ground conditions from the received data. The data sets will be made available to interested researchers for their own analyses via a web site that has been set up for this purpose.

5 CONCLUSIONS

In this paper, we have reported the current readiness status of the GPS Surface Reflection Instrument for the GAINS balloon mission. We have discussed the mission background, highlighting the evidence for the usefulness of the reflected GPS signal for remote sensing. That section also cited the potential of utilizing the reflected signal over terrestrial areas for measurement of the ground soil moisture. We then discussed the capabilities of the GSRI as it has been configured for the GAINS balloon mission. The instrument capabilities of elevation correction and its multiple modes of data collection provide a versatile basis for an initial exploration of the potential for utilization of the terrestrial reflected GPS signal. We then provided an overview of the data collection methodology for creating the data set, and the approach that is to be used for the initial analysis of that data set. As a result of the initial analysis, additional approaches to analyzing the data may be suggested. These approaches will be developed and evaluated as the research proceeds.

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