DEMONSTRATION OF INTERFERENCE SUPPRESSING Radiometry

AT C-BAND

Project duration: One year with an additional one year option
Funding requested from NPOESS IPO: 125K each year

Submitted to:
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DEMONSTRATION OF INTERFERENCE SUPPRESSING RADIOMETRY
AT C-BAND

Abstract—Development and flight of an interference suppressing receiver are proposed to
demonstrate advanced radio frequency interference (RFI) mitigation methods for C-band microwave
radiometers. Channel inputs for the receiver will be provided by an IF output of the PSR/C
radiometer to be implemented as part of a related project. This collaboration will allow the
proposed project to proceed without development of new RF, antenna, and calibration systems for
the digital receiver. The receiver is capable of suppressing RFI that is temporally or spectrally
localized, so that radiometric observations may remain possible even in RFI corrupted portions of
the spectrum. A tunable system will be developed, making measurements over frequencies ranging
from at least 5.8 to 7.2 GHz possible. Results from the experiments will provide substantial risk-
reduction in choosing C-band receiver technologies and channel assignments for future spaceborne
microwave radiometers.

I. INTRODUCTION

The C-band channel on the CMIS radiometer of NPOESS (currently proposed as 6.625 +/- 0.175
GHz) is designed to contribute important information for several environmental data records, with
a particular emphasis on sea surface temperature, soil moisture, and a possible contribution to
wind speed and direction [1]. However, the utility of the C-band channel may be degraded by
the presence of radio frequency interference in the passband of this channel. This is because no
primary allocation to passive Earth observations is available at C-band [2]; allocations to “fixed
and mobile service” and to “fixed satellite service” systems currently exist near 6.6 GHz [3]. Recent
data from the C-band channel on AMSR-E (6.925 +/- 0.175 GHz) [4] shows evidence of significant
RFI influence over land and coastal areas [5]. Airborne observations in four C-band channels with
the PSR/C sensor [6] have also observed significant corruption of brightnesses. Data from the
WindSAT C-band channel (6.8 +/- 0.625 GHz) [7] are currently under analysis to determine the
degree of RFI corruption. The possibility of RFI in the C-band channel of CMIS is clearly a major
issue to be addressed before the final CMIS specification is fixed [1],[3]. Incorporation of RFI mitigation strategies into radiometer design will likely be required if operation is to continue in corrupted bands. Although several such strategies have been proposed, at present no quantitative means is available for predicting the performance of these strategies.

To address this issue and to demonstrate an advanced technology for RFI mitigation in spaceborne radiometers, flights of a digital receiver designed to suppress interference is proposed. The receiver is based on technologies developed as part of a NASA “Instrument Incubator Program” (IIP) [8] at Ohio State; the proposed system is capable of sampling 100 MHz of bandwidth at near 100 percent duty cycle. This 100 MHz channel will be tunable through a minimum bandwidth of 5.8 to 7.2 GHz so that observations throughout a range of potential C-band channels will be possible; observations at lower C-band frequencies may be possible as well. To reduce development time and to ensure accurate calibration, channel inputs to the digital receiver will be obtained from the PSR/C radiometer of NOAA/ETL. An IF output will be provided by PSR/C from the scanhead to interface to the Ohio State system in a cabin rack in the aircraft; both systems will therefore share the same front end, calibration, and steering mechanisms enabling a direct data comparison of measurements. Results from the project will enable substantial risk-reduction for the CMIS C-band channel, as well as other future spaceborne microwave radiometers.

A detailed description of the project follows, while Section III provides a summary statement of work and schedule. References and the CV of the principal investigator are provided in Sections IV and V, respectively, and the equipment, facilities, and project budget discussions follow in Sections VI through VIII. A detailed description of project deliverables follows in Section IX.

II. PROJECT DESCRIPTION

1. Background: NASA IIP project

A NASA IIP project was awarded to Ohio State in 2001 for construction of an L-band microwave radiometer capable of operating even in the presence of significant radio frequency interference [8]. A detailed description of the project, along with the associated design documents, is available at the
The digital section is based on dual 10 bit (i.e. high dynamic range), 200 mega samples per second (MSPS) analog-to-digital converters (ADCs) followed by a digital processor implemented in FPGA hardware. The processor includes a digital filtering section to combine inputs from the two ADCs and filter to 100 MHz bandwidth, an “asynchronous pulse blanker” (APB) section for removing pulsed interferers (temporally localized RFI), a 1024 point FFT operation, and a “spectral domain processor” (SDP) section for removing remaining narrowband interferers (spectrally localized RFI). The SDP section also performs power computation and integration, with the output data rate after integration greatly reduced. Results of the integration are then transferred to a personal computer (PC) through a high speed interface. With a suitable choice of integration lengths, the resulting data can represent near 100% duty cycle (i.e. continual sampling of the antenna temperature). Note the use of FPGA components allows all interference suppression operations to occur in real-time.

The use of a rapid sampling rate (200 MSPS) in the receiver makes possible the suppression of micro-second level pulsed interferers, as are produced by many electromagnetic systems; this is in contrast to traditional radiometers which operate with much lower sampling rates (typically tens to hundreds of milliseconds). Traditional radiometric measurements can be corrupted by a single microsecond-scale pulsed interferer observed during the integration time, even though the vast majority of the integration time was interference free. Large amplitude pulsed interferers, easily identified by a system with rapid sampling, may appear as “low level”, difficult to remove, interference to traditional systems, due to the small fraction of the total integration time involved. In addition, the 1024 point FFT operation divides the 100 MHz bandwidth into 1024 approximately 100 KHz sub-channels, so that narrowband interferers are easily identified and removed. Again, traditional radiometers operating with single channel bandwidths on the order of 10-100 MHz can be corrupted by a single 1 MHz interferer within the band, even though the vast majority of the original channel was interference free.

Figure 1 is a photograph of the current digital back-end; note the use of single circuit boards for individual processor components to simplify testing and flexibility. The vertical cascade of three
circuit boards near the left hand side contains the dual ADC sections (upper and lower boards) and the digital channel combination and filtering section (center board). The APB section for removing temporal pulses is also implemented on the center board. Following the vertical cascade to the right is the FFT processor, then the SDP section for narrow band RFI removal, power computation, and integration operations. Finally a “capture card” provides the interface to the PC. Microcontrollers are also included on each card (the smaller attached circuit boards with ethernet cables) to enable PC setting of internal FPGA parameters through an ethernet interface.

The current baseline algorithm for detecting temporally localized interference is based on expected signal properties of thermal noise. In the APB section, a running estimate of the time-domain mean signal power and its standard deviation is computed continuously. When a sample is observed that is more than a specified number of standard deviations from the mean (and hence very unlikely for Gaussian noise), a “blanking” decision is produced. The output of the APB section is set to zero for a specifiable number of samples preceding and following the sample that triggers the detector. The effects of this process on power level estimation are compensated later in the processor through a record of the number of samples blanked. The blanking threshold and the number of samples to blank can be varied during system operation through the microcontroller interface to the APB. This temporal-interferer algorithm can also be implemented after the FFT on each FFT bin to detect pulsed sources at a higher signal-to-noise ratio. Detection of temporally constant, spectrally-localized interferers is performed through a similar process implemented across multiple FFT bins instead of in time. Note the use of continuously computed estimates of the power mean and standard deviation make the system adapt to the brightness environment that is currently under observation; the process is “asynchronous” because no periodic properties of any particular source are assumed.

The system has been tested to date through observations of local RFI sources received from a low-gain antenna on the roof of the ElectroScience laboratory. With a simple low-noise front end combined with a single stage downconversion section, numerous measurements were performed over the bandwidth 1306-1425 MHz. Figure 2 is an example of a sampled time series from 1331 +/-
25 MHz, with the upper curve illustrating a 2-3 μsec pulse around time 10 μsec and its associated multi-paths around time 20 μsec. Further tests showed a repetition of these pulses approximately every 3 msec; these properties are consistent with the transmissions of a local air traffic control radar. The lower curve in the figure is the “blanking” decision made by the APB processor section to suppress this interference; tests showed this procedure to provide effective removal of radar effects, demonstrating that interference suppression may be possible for future satellite based radiometers. However, the IIP project goals are limited to demonstration of the system only in laboratory experiments; operations from an aircraft are not planned under this program.

Because the RFI suppression algorithms discussed are applicable only to interferers that are temporally and/or spectrally localized, the IIP project is also investigating RFI suppression algorithms for other interference types. Two additional modes of operation of the digital receiver are available in this situation. In the first mode, time domain “snapshots” of data can be passed directly to the PC, so that detailed information on signal properties can be observed. In the second mode, the integration operation of the SDP section can be modified to a “max-hold” process that is useful for identifying and classifying interferer average temporal properties. Duty cycles for the “temporal snapshot” data are on the order of 10%, due to the higher data rate required for transfer to the PC, while the “max-hold” operation remains at near 100% duty cycle. Both of these options enable a wealth of information on RFI properties to be obtained, so that improved algorithms can be designed for use in continued tests. The use of FPGA components makes alteration of RFI suppression algorithms possible simply through re-programming system hardware.

2. Interfacing with PSR/C system

Use of the Ohio State digital receiver back-end does not require any major modifications in the RF front-end of a traditional radiometric system. Issues involved in selecting and steering an appropriate antenna, developing an accurate calibration methodology, and integration of these components into an airframe result in several technical challenges in producing a high quality radiometric front end. To avoid these problems, interfacing the Ohio State digital receiver to the
Figure 1: Photograph of IIP project digital back-end
Figure 2: IIP project measurement of an air-traffic control radar pulse

PSR/C radiometer of NOAA/ETL is planned. The PSR/C radiometer is a high-quality instrument with a proven track record in numerous aircraft experiments, and includes a C-band front end typically operated from 5.8-7.2 GHz. However, the current PSR/C system is designed so that the entire radiometer (including front end, detection, integration, and (low sample rate) digitization) is located in the scan head, with only a data communications link to the aircraft cabin. This communications link lacks the bandwidth necessary to transmit the desired 100 MHz channel to the Ohio State receiver. In a related project currently proposed by NOAA/ETL, the PSR/C scanhead will be modified to include an interface capable of passing a 100 MHz bandwidth IF output to the aircraft cabin. In addition, a tunable downconversion section will be added to the PSR/C scanhead so that the IF signal can be selected from the currently used 5.8-7.2 GHz band.

Inclusion of these components in the PSR/C system will not disturb its standard radiometric measurements, which occur in 4 400 MHz sub-bands centered at 6, 6.4, 6.8, and 7.2 GHz, respectively. This analog channelization procedure also provides some measure of interference mitigation, since data in corrupted channels can be discarded while retaining the remaining channels. This approach requires only a replication of standard analog receivers, and therefore has minimal technology risk. This PSR/C approach has been shown successful in mitigating RFI corruption in several experiments [10], although the possibility that all sub-channels could be corrupted remains.
In addition, data in RFI corrupted bands is unusable and must be discarded, so that the effective bandwidth of the instrument is reduced. Interfacing the Ohio State digital receiver to the PSR/C system will provide the additional benefit of a direct comparison between measurements from the two systems. The results will therefore directly illustrate the relative advantages and disadvantages of two distinct technologies for RFI mitigation.

3. Project plan

A one year project is proposed, estimated at present to coincide with calendar year 2004, followed by a one year option, estimated at present to coincide with calendar year 2005. Of course, administrative (i.e. contract negotiation) issues will determine the exact project start date. Overall this plan is consistent with the PSR/C modification schedule planned by NOAA/ETL. Note that the NPOESS IPO has committed to initial development efforts for this project late calendar year 2003 through a 4-month, 30K grant through the Naval Research Laboratory (20K received at OSU as of Sept 2003). The discussion below describes the entire combined project, but separation of tasks among these efforts will be described when appropriate.

RFI review and system planning: A review of available information on expected C-band RFI properties will initiate the project. Such information includes the licensed users survey reported in [3], AMSR-E and WindSAT data to the extent available, and results from previous PSR/C flights. The information gathered will be used to determine appropriate baseline receiver parameters, including APB and SDP algorithmic choices. Evidence of interferers for which the original APB or SDP algorithms may not be effective will be examined to suggest alternate algorithms. However, it is unlikely that sufficient information will be available at this project stage for complete conclusions in this regard. A complete design of the digital receiver will be developed based on results of the review, including appropriate tuning and scanning methods. A typical observation pattern could be to divide the 5.8-7.2 GHz band into 15 100 MHz channels, so that the system would tune to each of these channels and dwell for a set time period at each channel. If observations at lower C-band frequencies are not precluded by PSR/CX front end performance, additional channels at
these lower frequencies will be included in the measurements. It is expected that the majority of this research should be completed in the initial effort prior to calendar year 2004.

**Implementation:** The completed design will be implemented and incorporated into a housing suitable for use in aircraft experiments. A single coaxial cable will provide the IF signal from the PSR/C scanhead to the equipment rack. Included in the rack will be the digital receiver component, an analog subsystem for interfacing to the PSR, a control and data recording computer, and a power subsystem. Data from the measurements will be written to the computer hard drive; sufficient space should be available to enable data recording throughout a flight duration of several hours. Software for the system will be developed to allow operations in the absence of an operator. The proposed project schedule plans for inclusion in airborne campaigns beginning early-to-mid 2004. This is feasible because design and implementation of the digital back-end will require only modest effort due to its basis in the IIP design. Project development efforts will be devoted primarily to the detailed PSR/C interfacing plan, implementing and ruggedizing the digital receiver, developing the control/recording software, integration into the aircraft, and initial tests. It is expected that this task will be initiated in the initial effort prior to 2004 but will continue into 2004 before the first system flights. Continued refinement of the system throughout the project period is expected as well.

**Aircraft operations:** Co-flights with PSR/C eliminate requirements for flight plans dedicated solely to the proposed project; “piggyback” observations with PSR/C will still provide a variety of environments due to the wide range of deployments in which the PSR/C is used (including existing flights planned for RFI studies.) Although PSR/C flight plans for 2004 continue to evolve, at present it appears that several opportunities should be available in this time frame. Potential aircraft include the NASA P-3 as well as a WB-57F for high-altitude observations. The latter aircraft houses equipment in an un-pressurized compartment, making system ruggedization and heating more critical. Transport of the OSU system, integration into the aircraft, and operations will be supported under the current project. Collaboration with NOAA/ETL will be performed
to minimize the cost of these efforts to the maximum extent possible after initial system tests. Multiple flights in project year one are expected, with a re-assessment of flight plans for year two occurring at the end of year one.

**Data analysis:** Data from each flight will be analyzed by the project team to create a record of performance in varying environments. Through cooperation with NOAA/ETL team members, data from the digital receiver system will be compared with that from the PSR/C sub-channels to assess the performance of both approaches for RFI mitigation. Information obtained on the RFI environment, and on the effectiveness of varying suppression algorithms for the RFI observed will also be reported. A catalogue of observed interferers will be developed throughout the project, based on frequency sweep, RFI mitigation results, “max-hold” information, and “temporal snapshot” data. Optimal parameters for the baseline RFI algorithms will be determined to the extent possible, and new algorithms will be developed and tested if deemed necessary from observations.

**Risk reduction:** An analysis of project implications for CMIS and other future spaceborne radiometers will be performed in the project initial report and annually. Results from the measurements will provide the first quantitative information on the effectiveness of varying RFI suppression strategies. The analog sub-band measurements of PSR (to be reported under the NOAA/ETL related project) will provide direct evidence of an analog sub-band approach, while the digital receiver information will provide new information on the RFI mitigation capabilities of digital radiometer systems. However, the digital receiver system provides the additional advantage of a more clear picture of the C-band RFI environment. Information from the digital receiver will thus allow other mitigation strategies, such as a slightly increased analog receiver sampling rate for example, to be assessed without additional tests. A report describing project risk-reduction results will be provided to the sponsor for each project stage for possible use in future radiometer designs. The final project report will provide detailed suggestions for a modified CMIS design.

Reports will be developed to facilitate technical interchange with the CMIS contractors through the NPOESS IPO; no limitations on distribution of these reports to the CMIS contractors will be
imposed. Annual meetings with the CMIS contractors to inform them of project information, techniques, and technologies are also part of the project plan.

4. Team experience

The experience of the project team with the IIP project and with other receiver system developments will enable a rapid design and implementation phase. Digital receiver design and implementation will be led by Research Scientist Dr. Grant A. Hampson, while PI Dr. Joel T. Johnson will assist in data analysis and interpretation. Dr. Steven W. Ellingson of Virginia Tech will also participate in system design and in data analysis. Dr. Ellingson (formerly of Ohio State) is co-PI with Dr. Johnson of the NASA IIP project and is involved in all aspects of the IIP system. All team members will assist in supporting system flight operations. Team expertise in analyzing RFI for similar radio astronomy systems will also be invaluable. NOAA/ETL contact Al Gasiewski leads the related project to modify the PSR/C scan head and assist in data sharing between the two groups.
III. STATEMENT OF WORK

Project Year One:

- Complete digital receiver system implementation
- Delivery to flight location(s)
- System integration into aircraft
- Flight support for system flight(s)
- Analysis of data from system flight(s)
- Perform inter-comparison with PSR/C data
- Develop catalogue of effectiveness of mitigation strategies and RFI properties observed
- Analysis of current project results to estimate effectiveness of proposed CMIS modifications

Project Year One Deliverables:

- Quarterly technical/financial progress reports
- Project initial report detailing project plans and current progress
- Year one final report detailing year one progress, results, RFI/algorithm properties observed, risk reduction implications, and updated plans for remainder of project
- Year one final briefing detailing year one report contents

Project Year Two

- Continue system flights in varying RFI environments (delivery, integration, and operation tasks)
- Analysis of data from continued system flight(s)
- Continue inter-comparison with PSR/C data
- Continue development of catalogue of algorithm/RFI properties observed
- Update of analysis of estimated effectiveness of proposed CMIS revisions
- Develop final project recommendations for future spaceborne radiometers

Project Year Two Deliverables:

- Quarterly technical/financial progress reports
- Year two report detailing year two progress, results, RFI/algorithm properties observed, detailed implications for risk-reduction
- Year two briefing detailing year two report contents

See the appendix for specific information on project deliverables, including report due dates.
IV. REFERENCES


V. PRINCIPAL INVESTIGATOR JOEL T. JOHNSON

Education: B.S.E.E. (1991), Georgia Institute of Technology. 

Positions: Associate Professor, Department of Electrical Engineering 
The Ohio State University; 2000-Present. 
Assistant Professor, Department of Electrical Engineering 
The Ohio State University; 1996-1999.

Relevant Publications: (47 journal papers published or in press, 90 conference papers)


Awards and Activities:

1997 Office of Naval Research Young Investigator Award

1997 National Science Foundation CAREER award

1997 Presidential Early Career Award for Scientists and Engineers (PECASE) 
(“the highest honor bestowed by the United States Government on scientists and engineers beginning their independent careers”)

2002 Booker Fellowship, U.S. National Committee of International Union of Radio Science 
(“the pre-eminent triennial award to a young US radio scientist.”)

Associate Editor, IEEE Trans. Geoscience and Remote Sensing, 2000-Present


VI. EQUIPMENT

The proposed project’s hardware implementation efforts require allocation of test and measurement equipment and other tools. All these resources are currently available at the ElectroScience Laboratory at only minimal charge to the project. No additional stand-alone equipment costs are proposed in the project budget. The PSR/C system is the property of NOAA/ETL and will be available through the related project described previously.

VII. FACILITIES

Sufficient laboratory space exists in the ElectroScience Laboratory for implementation to take place, and access to the Laboratory roof is available for initial system testing. All of the OSU project team members maintain offices and laboratory space at this facility.
VIII. PROPOSED BUDGET

A detailed budget accounting for sponsor funds is attached in the following page of this proposal. OSU Project funds will be used to support a percentage of JTJ’s time, with the remainder of the effort by Research Scientist Grant Hampson and a Graduate Student Research Assistant. A subcontract to Virginia Tech to support Dr. Ellingson’s participation is also included. A small allocation for administrative support is present, as well as an allocation for travel to support installation and system flights. Note the collaboration is contingent on NOAA/ETL’s receipt of requested baseline support from NPOESS for NPOESS PSR calibration and validation efforts. Dates in the budget begin with the project start date, estimated to be approximately January 1st, 2004 at present. Tentative travel plans are as follows:

- Year 1: Two trips from Columbus, OH to Wallops Island, VA for 2 people, duration 3 days; two trips from Columbus, OH to Washington, DC for 2 people, duration 2 days; one trip from Columbus, OH to Los Angeles, CA (CMIS Contractor) for 3 people, duration 3 days

- Year 2: Two trips from Columbus, OH to Wallops Island, VA for 2 people, duration 3 days; two trips from Columbus, OH to Washington, DC for 2 people, duration 2 days; one trip from Columbus, OH to Los Angeles, CA (CMIS Contractor) for 3 people, duration 3 days

A sample listing of materials and supplies for the project is as follows:

- IF cables, connectors, adapters, and components
- Analog electronic components (including capacitors, inductors, resistors, etc.)
- Digital electronic components (including A/Ds, programmable logic ICs, discrete logic ICs, etc.)
- Printed circuit boards
- Data cables (including ribbon cables, RS-232 cables, IEEE-1294 cables, etc.)
- Enclosures and mounting hardware
- Power supplies and DC/DC converters
- Consumable construction supplies (including wire, solder, etc.)
- Data storage media (including zip disks, CD/Rs, tapes, etc.)
## NPOESS Project
### The Ohio State University
#### January 1, 2004 - December 31, 2005

**SPONSOR:** NPOESS

**PI:** Joel Johnson

**Sponsor OUS** | **OSU** | **Sponsor OUS** | **OSU** | **SUMMARY**
---|---|---|---|---

### Personnel

#### Faculty

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### Staff

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### Fringe Benefits

- **27.3%** (locally release time)
- **15.3%** (locally summer/duty days & specials)
- **29.7%** (A & P Staff)
- **30.0%** (Classified Staff)
- **29.7%** (Post-Doctoral Researcher)
- **3.5%** (GRA(s))
- **3.5%** (Undergraduate Student(s))

### Tuition & Fees (includes Computer Fee $480)

- **$10,092** student/year

### Indirect Costs

- **$23,659** of Modified Total Direct Costs
- **$12,375** of first $25,000 Subcontract

### Total Costs

- **$125,000** Sponsor
- **$125,000** OSU Cost Sharing
- **$250,000** Total

### Approved for Institution:

David B. Doty, Associate Director
IX. DETAILS OF DELIVERABLES

The following deliverables are the Contractor’s and the Government’s best estimate of the tasks to be accomplished during the Base period. The Parties to the contract reserve the right to mutually modify and add definition to the list of deliverables, as the research during the course of this contract progresses and further defines the areas of study required.

The Contractor shall deliver its best efforts to complete the following deliverables during the term of this contract:

1. The Contractor shall deliver the General Science and Technology, and Engineering Research and Development services in pursuit of the research objectives in the Statement of Work. The Contractor shall furnish all personnel, including but necessarily limited to: all salaries, fringe benefits, travel, equipment and other expenses, including those costs for the Principal Investigator, Program Manager, System Manager, and Engineers, and the supporting laboratories and facilities of the university. The research shall include the specific tasks discussed previously. These services are due beginning with the effective date of this contract, and continuing for a Base Period of 12 Months, and an additional period of 12 months should the second year option be exercised.

2. The Contractor shall minimally deliver quarterly statuses highlighting the progress made on the tasks for the previous period, and projecting the next quarter’s planned support to the NPOESS/IPO. These reports shall detail problems, issues and concerns in regard to the R&D Studies being undertaken by the Contractor team. The Contractor is obligated to bring to the attention of the Government any significant concerns that arise, at any time, especially if they could threaten support for development under NPOESS, cause an impact on risk reduction, or affect the quality of instrument data. The first report shall be delivered to the COTR and the Contracting Officer by electronic mail on the 15th day following the close of the first 90-day reporting period and every 90 days thereafter.

3. The Contractor shall deliver an Initial Report, including all research and scientific findings. These findings shall include a brief Executive Summary, concerns and risk areas, and a set of recommendations for further study in the succeeding performance periods, as well as a corresponding set of planned tasks. The Initial Report shall be due 120 days after the effective date of this contract. The Initial Report will be developed to facilitate technical interchange with the NPOESS IPO and CMIS Contractor. The Government has 30 days to review it and
request changes or clarifications from the Contractor. The Initial Report shall be submitted to the COTR and the Contracting Officer, in both hard copy and electronic copy form. Three (3) hard copies shall be submitted.

4. The Contractor shall deliver an oral presentation and briefing materials, including electronic copies of the briefing materials, to the NPOESS/IPO at a designated location to be determined by the COTR. The Contractor shall assume that the briefing will be conducted at the NPOESS, Integrated Program Office, in Silver Spring, MD. This briefing shall be delivered on or about 315 days after the effective date of this contract.

5. The Contractor shall deliver a Final Report, with all Government comments from the briefing and the Initial Report, in electronic and hard copy format, to the COTR and the Contracting Officer. Eight (8) hard copies shall be submitted. This Final Report shall be due 360 days after the effective date of this contract. It shall include findings gathered during the progress of this task.

6. Should the year two option be exercised, the same deliverables above will apply, with the exception of the Initial Report.