Global Precipitation Measurement Mission – Architecture and Mission Concept

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Abstract—The Global Precipitation Measurement (GPM) Mission is a collaboration between the National Aeronautics and Space Administration (NASA) and the Japanese Aerospace Exploration Agency (JAXA), and other partners, with the goal of monitoring the diurnal and seasonal variations in precipitation over the surface of the earth. These measurements will be used to improve current climate models and weather forecasting, and enable improved storm and flood warnings. This paper gives an overview of the mission architecture and addresses some of the key trades that have been completed, including the selection of the Core Observatory's orbit, orbit maintenance trades, and design issues related to meeting orbital debris requirements.

TABLE OF CONTENTS

1. INTRODUCTION

The GPM Mission plays a key role in the National Aeronautics and Space Administration's (NASA) Earth System Science (ESS) Research Strategy by providing measurements crucial to answering key questions related to the Earth's water and energy cycle (http://gwec.gsfc.nasa.gov). The GPM mission will provide this data by extending and improving the measurements made by the successful Tropical Rainfall Measurement Mission (TRMM).

The key elements of the GPM mission are its constellation of spacecraft containing microwave imagers, a Core Observatory with a Dual Precipitation Radar (DPR), a ground validation system, and a global data management information system for collecting, archiving, processing, and disseminating precipitation data to the user community. The NASA-provided Core Observatory carries the reference standard instrument set for a constellation of satellites carrying passive microwave radiometers. Instrumentation for the Core Observatory includes a Dual Precipitation Radar (DPR), provided by Japanese Aerospace Exploration Agency (JAXA), and a GPM Microwave Imager (GMI), being built by Ball Aerospace and Technologies Corporation. NASA's Goddard Space Flight Center (GSFC) provides GPM Mission project management and systems engineering. The project is currently in the formulation phase with an expected launch date for the Core observatory of December 2010, followed by a Constellation observatory with a launch date in summer of 2012.

2. MISSION OVERVIEW

2.1. Mission Architecture/Operations Concept

The GPM Mission Architecture (see Figure 1) consists of a constellation of satellites provides continuous monitoring of

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precipitation over the globe. The GPM project provides two of these spacecraft, which are designated the Core Spacecraft and the Constellation Spacecraft. The remainder of the satellites in the constellation consists of other existing and planned US government resources (e.g., NPOESS), as well as contributed resources from international partners (e.g., Megha-Tropiques). Each of these missions contributes key passive microwave radiometer data to enable the GPM mission to achieve its global coverage requirement.

Instrumentation flying on the Core spacecraft consists of the DPR and GMI instruments. The electronically scanned DPR provides a 3-dimensional mapping of precipitation over both sea and land, and is used to calibrate the passive microwave radiometers that contribute precipitation data to the mission. The conically-scanned GMI provides precipitation rate information over a much wider swath and estimates of global precipitation rates.

Science data from the GMI is continuously relayed over TDRSS to the Mission Operations Center (MOC) at GSFC, while science data from the DPR is stored and downlinked through scheduled TDRSS S-band Single Access (SSA) forward link contacts once per orbit. The GPM Data Information System (GDIS) collects science data from the GPM constellation of satellites, processes it and provides products to the user community. A separate Ground Validation System (GVS) is being developed to provide information for the improved accuracy of modeling based on precipitation measurements made at various sites around the world.

2.2. *Ground System Architecture*

The GPM Ground System consists of three major items: the Mission Operations Center (MOC), the Precipitation Processing System (PPS), and the Ground Validation System (GVS).

The MOC, developed and based at GSFC provides for control and monitoring of the spacecraft. It is responsible for maintaining the health and safety of the satellite, as well as managing the flow of science data from the satellite to the PPS. Once an orbit, a command load is relayed through White Sands Complex to the spacecraft via a TDRSS SSA link. Continuous monitoring of spacecraft health and safety is provided via the TDRSS Demand Access System (DAS). Science data from the GMI is provided via DAS every 5 minutes to satisfy data product latency requirements. The

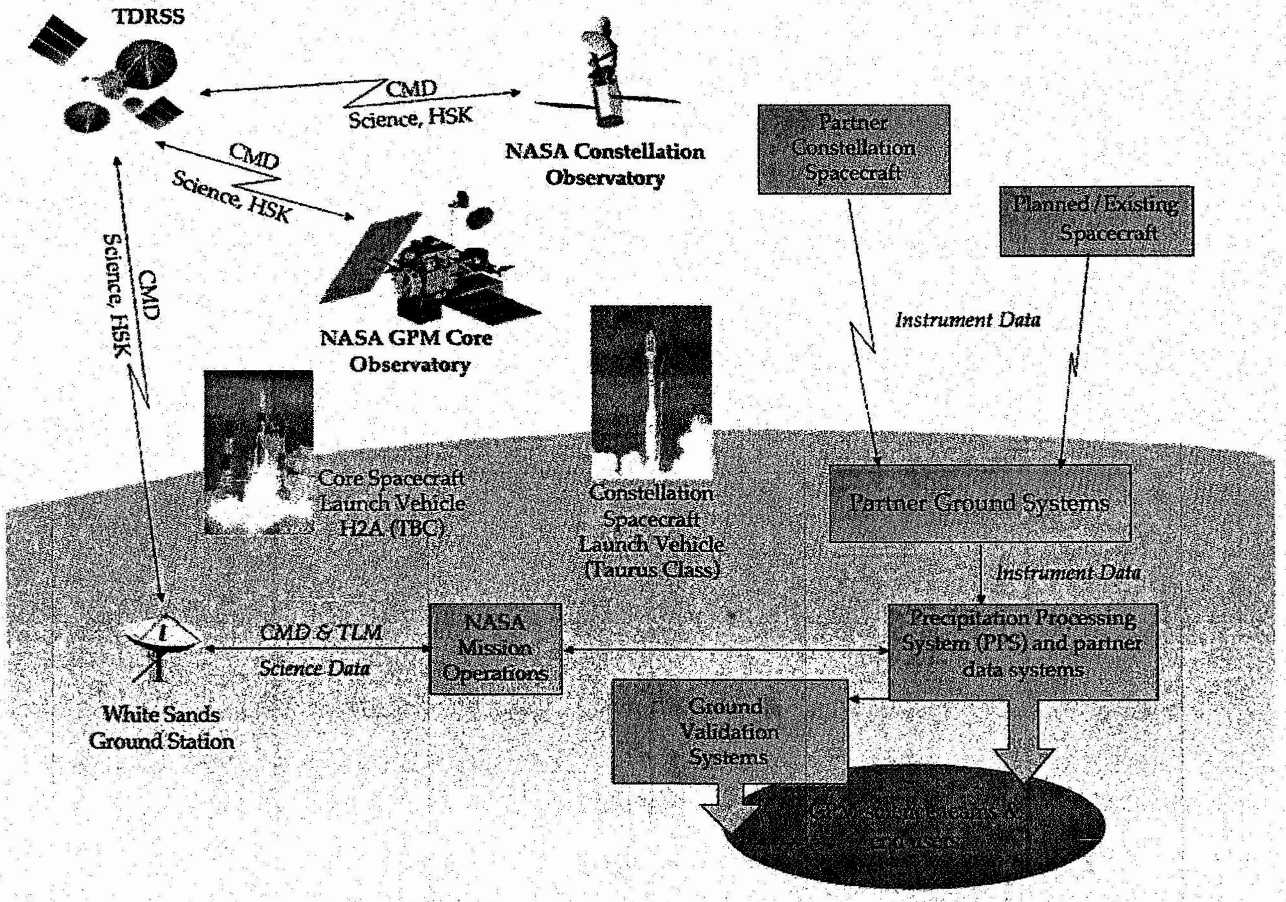

Figure 1. GPM Mission Architecture

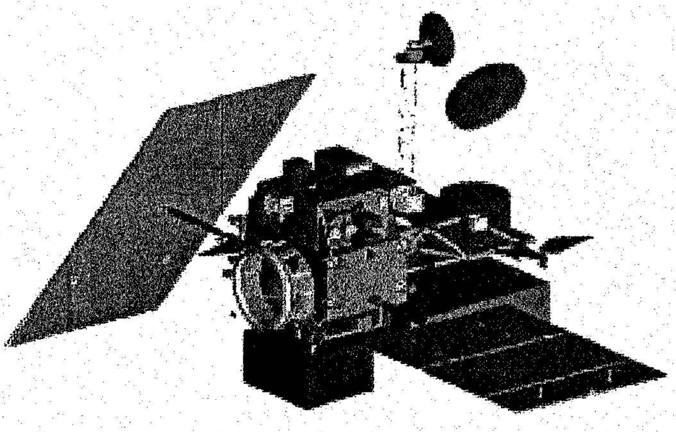

Figure 2. GPM Core Spacecraft Layout

large data files produced by DPR are downloaded via an SSA link to the MOC once per orbit.

The PPS, developed by GSFC, is based on the existing TRMM Science Data and Information System (TSDIS), and provides for processing of science data into application and outreach products. These products include surface rain rates, calibrated brightness temperatures, and rain images.

The GVS, by comparing ground-based precipitation measurements with those obtained from space, will enable improvements in the algorithms used to process future precipitation data products.

2.3. *Core Spacecraft*

The Core spacecraft, managed and developed by GSFC, will provide the platform for the instrument payload, including accommodating the thermal, mechanical, electrical, and data requirements of the instruments. Figure 2 shows the current layout of the spacecraft. Communications with the instruments is provided over a MIL-STD-1553 data bus. The spacecraft will be maintained in a nadir-pointing configuration, with infrequent yaw maneuvers to adjust for beta angle changes. Instrument operations require calibration maneuvers roughly once a month that involve leaving the nadir-pointing mode for periods of a few orbits. Spacecraft power, sized for a load of 1900 Watts, is provided by dual single-axis-articulated solar arrays, a Lithium-Ion Battery, and a direct energy transfer power system. The cant of the solar arrays ensures a minimum power production given any beta angle. Communications is provided via a steerable high gain antenna and two hemi-spherical omni antennas. GPS receivers on-board provide accurate orbit and time information to support the instrument geo-location requirements. A hydrazine propulsion system provides for orbit maintenance to meet the tight orbit control requirements of the DPR.

2.4. *GPM Microwave Imager (GMI)*

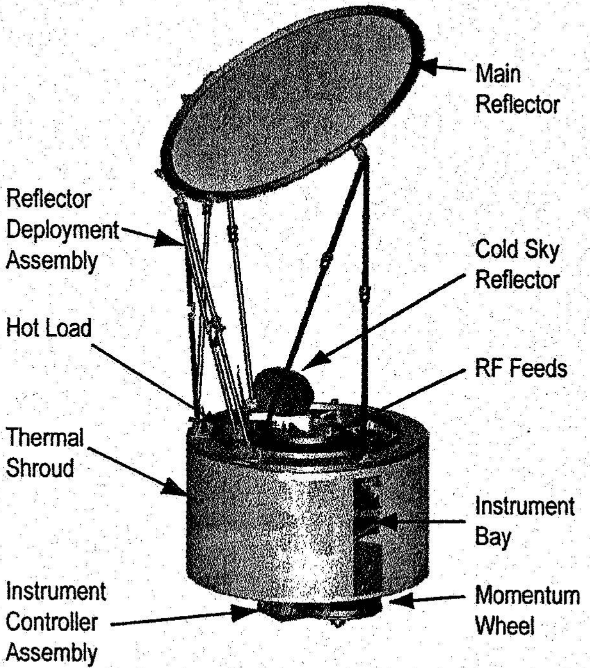

Figure 3. GPM Microwave Imager (GMI)

The GMI [1], a conically scanned microwave radiometer, is under development by Ball Aerospace, under contract to GSFC. See Figure 3. It has a 1.2 m aperture, and provides 13 channels over the range 10.65 GHz to 188.31 GHz, to measure precipitation, including light rain and snow. The scanning mechanism rotates at 32 rpm, providing cross track scanning of the earth over a 1700 km swath with IFOVs for the various channels ranging from 32 km for the 10.65 GHz channel, down to 3.6 km for the 188 GHz channel. GMI

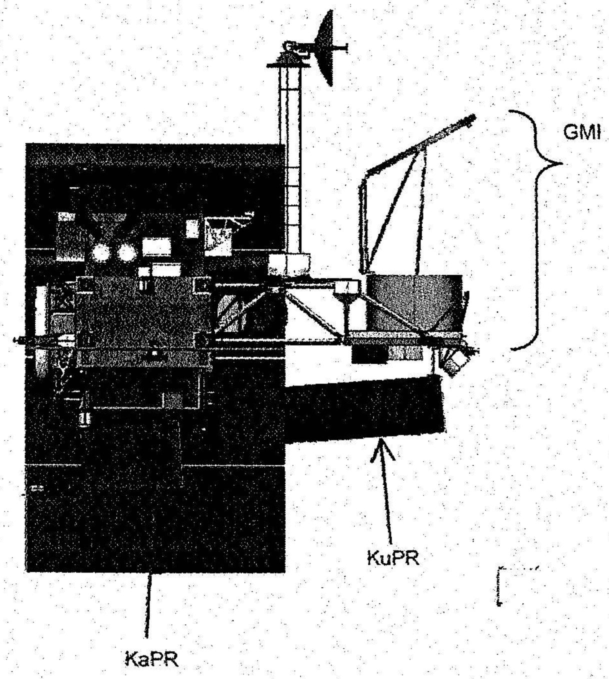

Figure 4. GPM Core Observatory Instrument Locations

	KuPR	KaPr	GMI
Type	148 Element Active Phased Array	148 Element Active Phased Array	Passive Microwave Radiometer
Frequency	13.6 GHz	35.5 GHz	10.65 to 183.3 GHz (13 channels)
Horiz. Resolution	5 km	5 km	approx. 32 to 4.4 km
Mass	450 kg	330 kg	125 kg
Volume	2.4mx2.4mx0.6m	1.44mx1.07mx0.7m	1.22m Antenna dia.
Power	384 W	326 W	155 W
Data Rate	108.5 kbps	81.5 kbps	35 kbps

Table 1. GPM Instrument Parameters

instrument parameters are listed in Table 1.

2.5. *Dual-frequency Precipitation Radar*

JAXA and the National Institute of Information and Communications Technology (NICT) in Japan are developing the Dual-frequency Precipitation Radar (DPR) [2]. Based on the TRMM [3] Precipitation Radar, the dual radars, one operating at Ku-band at 13.6 GHz, and the other operating at Ka-band at 35.5 GHz, are designed to provide three-dimensional profiles of precipitation with greater sensitivity (down to 1 dB). They will also aid in the calibration of the passive microwave radiometers that make up the rest of the GPM constellation of satellites. A key driver on the design of the spacecraft is the requirement to keep the footprints of the two radars co-aligned so that they view the same column of atmosphere. By a technique that compares the signals returned from both radars, Drop Size Distribution (DSD) of precipitation in the overlapped beams can be deduced, a key scientific objective of the mission. The dual radars are quite large with the KaPR 1.4 m x 1.1 m x 0.7m, and the KuPR nearly twice the size. Other DPR instrument parameters are listed in Table 1.

3. SYSTEMS TRADES

Over the course of GPM development, numerous system trade studies have been conducted, including the following abbreviated list (The outcome of the trade is listed in parentheses):

- Solar Array Configuration (Single axis articulated, canted arrays)
- Thruster Configuration (single-sided)
- ACS Safehold Strategy (Sun point)
- Instrument Thermal/Mechanical Isolation
- Grounding Scheme (Single point)
- Instrument Uncompensated Momentum Mitigation Approach (Instrument to compensate)
- Communications approach (TDRSS)

A summary of three system trades will be discussed below: selection of the core observatory baseline orbit to maximize earth coverage, trade of autonomous vs. ground-driven orbit maintenance, and a design trade study to meet the requirements of NASA Safety Standard NSS 1740.14, Guidelines and Assessment Procedures for Limiting Orbital Debris. Future trades include optimizing the orbit of the NASA-provided constellation spacecraft.

3.1. *Orbit Selection*

One of the driving requirements of the mission is to optimize the coverage of precipitation rate information over the globe. Since the majority of other spacecraft in the proposed GPM constellation are polar orbiting spacecraft, it was decided to optimize the orbit of the Core Observatory to coverage of the tropics as well as the temperate zones, yielding coverage over a plus-and-minus 65-degree latitude range. This coverage requirement leads to trades in selecting orbits for the Core Observatory as well as the Constellation Observatory. A trade study [4] performed during mission development led to the selection of an orbit for the Core Observatory with a semimajor axis (sma) of 407 km and an inclination of 65 degrees. To compare the ground coverage results between different orbits, figures-of-merit to be used for each instrument were devised. They included looking at the time for complete earth coverage (GMI), and the percent coverage for a given time period (DPR). In optimizing the GMI coverage, due to the large swath width, increasing the orbit height above about 405 km results in marginal improvements to the time for complete earth coverage. Varying the inclination once above about 405 km to optimize performance shows a slightly improved coverage at the higher inclinations. For the radars, which have much smaller footprints, the orbit was again optimized over a range of altitudes. Here, the orbit selection shows sensitivity to orbits with repeating ground tracks. For the GPM mission, non-repeating ground tracks are desired so that gaps in coverage can be minimized.

Figure 5 shows a comparison of the global coverage achieved with the current "TRMM Era" constellation of satellites versus the "GPM Era" constellation of satellites [5]. On the left side of the figure, the TRMM Era constellation includes TRMM, Aqua, and 3 Defense Meteorological Satellite Program (DMSP) satellites. These 5 satellites provide an average revisit time of 3 hours or less over 34.6% of the globe. The right side of Figure 5 shows the simulation for the proposed 8-satellite configuration of the GPM Era, including the GPM Core and Constellation satellites, JAXA's GCOM-W, NPOESS (3), ESA's EGPM, and the Megha-Tropiques mission, a joint collaboration between Centre National d'Etudes Spatiales (CNES), and the Indian Space Research Organisation (ISRO). This proposed constellation covers 100% of the globe with average revisit times of 3 hours or less, fully satisfying the mission requirement for average revisit times of less than 3 hours over 80% of the globe.

3.2. Orbit Maintenance

Due to the tight orbital constraints imposed by the operation of the DPR, a calculation of estimated times between orbital maintenance maneuvers was performed [6]. This study showed that depending on the solar activity level, an orbit correction maneuver could be required every few days to maintain the orbit within its control box. In order to keep operations costs low, a trade was performed that resulted in a requirement being placed on the observatory to provide for autonomous orbit maintenance. Recently, the analysis has been refined and the orbit control requirement has been slightly adjusted to allow for an orbit maneuver once per week in the worst case. It was felt that this level of ground intervention for orbit maintenance was acceptable, and therefore, it was decided that ground-based orbit maintenance procedures would be used for GPM.

Future trade studies will include looking at the on-board fuel cost versus operations of the solar arrays. A study will examine the effect on mission lifetime and fuel usage versus the ability to keep the array's cross-sectional area parallel to the velocity direction while allowing for adequate solar array current input to the electrical power system. Typical space-based power systems have large margins at launch to account for various aging effects as well as capacity to recover from certain failures. This margin could be used to save fuel by feathering the arrays.

3.3. Orbital Debris

NASA requirements for limiting orbital debris dictate that spacecraft developers show by analysis that most of the spacecraft burns up when it re-enters the Earth's atmosphere. If this is not the case, and considerable debris is estimated to re-enter, then a controlled re-entry is required. For GPM, a study looked at the survivability of the observatory design to re-entry. Typically, high strength metals like titanium and stainless steel are shown to largely survive the trip through the atmosphere. This is particularly true if the part is surrounded by other materials that must burn away before the atmosphere can begin ablating the surviving metal part. For GPM, a strategy was selected to scrub the design and remove these survivable materials where possible. Several areas of study were undertaken to look at increasing the likelihood that the design would "demise" before reaching the ground.

Flexures. One design area studied was the use of titanium flexures to support the large radars. Titanium has the beneficial properties of being high strength as well as thermally isolating. Analyses were performed to examine changing this interface material to aluminum, and the results of this study were that the thermal isolation requirement was relaxed in order to bring down the total survivable debris.

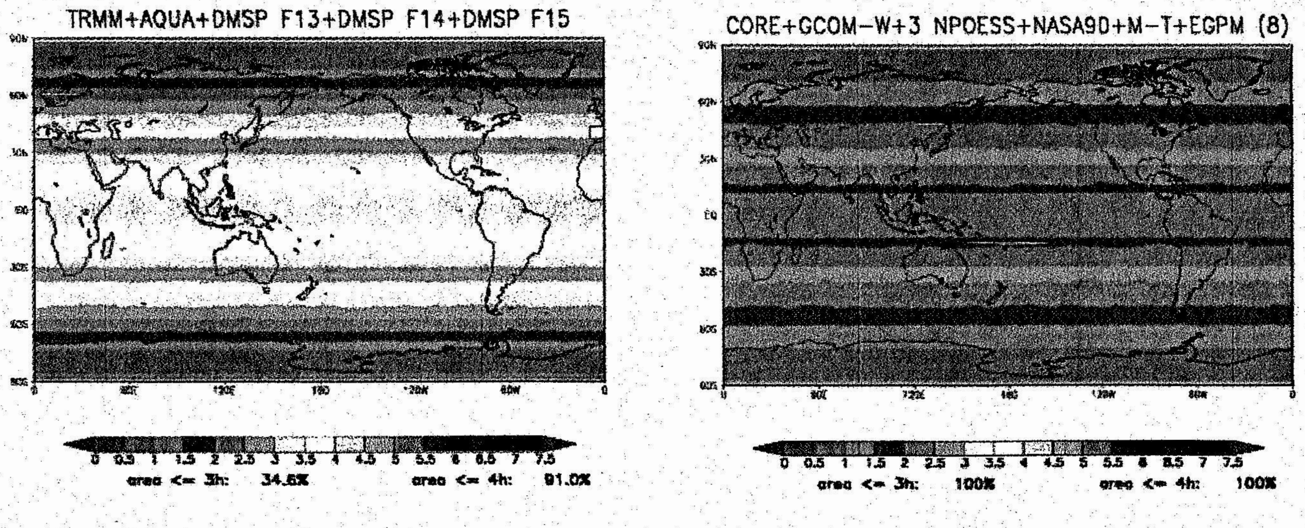

Figure 5. Global Coverage Results - TRMM Era vs. GPM Era

The parts were redesigned with aluminum and baselined for use on the mission.

Reaction Wheels. Reaction wheels typically contain an ablation-resistant material as the rim loading material of the wheel to maximize momentum capability while minimizing size and weight. A development effort underway at NASA GSFC is attempting to qualify a "demisable" wheel by essentially replacing the material of the wheel with aluminum, a highly demisable material. This wheel is currently planned to undergo environmental qualification testing by the end of 2006. If the wheels pass the tests, they will become part of baseline design for the mission.

Propulsion Tank. Propulsion tanks have typically been constructed of Titanium with a composite overwrap for strength. Again, a development effort is underway to qualify an aluminum tank. One of the challenges of this design is the fact that the aluminum oxide that forms on the tank prevents good wetting of surfaces, which interferes with the performance of the tank. This issue is under study now, with results expected early next year. Again, depending on the successful qualification of this demisable tank design, the mission can continue to meet the overall orbit debris requirements without requiring that mission be de-orbited.

4. CONCLUSIONS

The GPM mission architecture and operations concept have been reviewed, and some of the system trade studies that have been conducted have been described. The in-house development team at GSFC has been assembled to meet the requirements of the increased in-house portion of the core observatory development. Planning is underway for the GPM Mission Preliminary Design Review in Summer 2006.

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BIOGRAPHY

David Bundas is the Mission Systems Engineer for the GPM Mission. Prior to that, he served as the Swift Systems Manager from January 1999 to the March 2005. He has provided systems analysis and engineering expertise to a variety of space and earth science missions since joining the GFSC in 1983. He received his Bachelor's and Master's degrees in Aeronautics and Astronautics from M.I.T.