1. INTRODUCTION

System engineering principles and methods are very useful in large-scale complex systems for developing the engineering requirements from end-user needs. Integrating research into system engineering is a challenging task. The proposed Global Precipitation Mission (GPM) satellite will use a dual-wavelength precipitation radar to measure and map global precipitation with unprecedented accuracy, resolution and areal coverage. The satellite vehicle, precipitation radars, retrieval algorithms, and ground validation (GV) functions are all critical subsystems of the overall GPM system and each contributes to the success of the mission. Errors in the radar measurements and models can adversely affect the retrieved output values. Ground validation (GV) systems are intended to provide timely feedback to the satellite and retrieval algorithms based on measured data. These GV sites will consist of radars and DSD measurement systems and also have intrinsic constraints.

One of the retrieval algorithms being studied for use with GPM is the dual-wavelength DSD algorithm that does not use the surface reference technique (SRT).

The underlying microphysics of precipitation structures and drop-size distributions (DSDs) dictate the types of models and retrieval algorithms that can be used to estimate precipitation. Many types of dual-wavelength algorithms have been studied. Meneghini (xxxx) analyzed the performance of single-pass dual-wavelength surface-reference-technique (SRT) based algorithms. Mardiana (xxxx) demonstrated that a dual-wavelength retrieval algorithm could be successfully used without the use of the SRT. It uses an iterative approach based on measured reflectivities at both wavelengths and complex microphysical models to estimate both No and Do at each range bin. More recently, Liao (xxxx) proposed a solution to the Do ambiguity problem in rain within the dual-wavelength algorithm and showed a possible melting layer model based on stratified spheres. With the No and Do calculated at each bin, the rain rate can then be calculated based on a suitable rain-rate model.

This paper develops a system engineering interface to the retrieval algorithms while remaining cognizant of system engineering issues so that it can be used to bridge the divide between algorithm physics and overall mission requirements. Additionally, in line with the systems approach, a methodology is developed such that the measurement requirements pass through the retrieval model and other subsystems and manifest themselves as measurement and other system constraints. A systems model has been developed for the retrieval algorithm that can be evaluated through system-analysis tools such as MATLAB/Simulink.

2. SYSTEM ENGINEERING APPROACH

One objective of system engineering is to maximize performance or output of a system while minimizing total costs or complexity. Figure 1 shows a simplified block diagram of some of the system-level interactions to meet the GPM objectives.

![Figure 1. Simplified view of the interactions between the major GPM systems.](image)

This is not meant to be all inclusive but to show that algorithms and microphysics-based models are linked to both the GV and satellite systems. GV systems will have input to the algorithms and satellite systems. Each subsystem contributes, in conjunction with the other subsystems, to the overall success in meeting the GPM science objectives.

3. METHODOLOGY

Normally, to provide for a better systems engineering solution, it is necessary to understand the subsystems: how they perform; their strengths; their...
weaknesses; and how they interact with each other. The present work is beginning this process of complete systems understanding and is focused on the microphysics of the hydrometeors and the dual-wavelength algorithm.

3.1 ALGORITHM

The dual-wavelength algorithm iteratively solves for Do and No at each range bin based on microphysical models for each region of assumed hydrometeors: top, melting; and rain. A simplified schematic is shown in figure 2. A detailed explanation can be found in Mardiana (xxxx).

As shown, the algorithm works by estimating path-integrated-attenuation values, Ai, where i = 1 or 2 for wavelength one and two), at the bottom bin for each frequency, and using those values to correct measured reflectivity, Zmi, at each frequency to obtain the effective radar reflectivity factors, Zei. The algorithm starts at the bottom bin and works upward. With the calculated Zei factors, the Do at the selected bin can be calculated using a \(\delta\text{Zei-Do} \) look-up table. Integral equations are used to calculate No and specific attenuation, ki at each bin.

...maybe add lbi, lli equations?
...maybe add ki, Ai equations?

3.2 CONTROL SYSTEM VIEW

The non-SRT dual-wavelength algorithm convergence process can be thought of in control-system terms. A simple block diagram is shown in figure 3. The inner loop feeds back and converges on PIAi and the outer loop converges on Zmi. The algorithm converges and stops iterating by meeting a pre-defined error tolerance either on Zmi or PIAi.

Initially, with early simulations, convergence was done on Zmi with no inner-loop feedback on PIA. However, when Zmi converges, so does the PIAi values, and a mathematically equivalent solution is to feedback and converge on PIAi. Also, it was found that this method incorporates an integrator as the feedback control element with a gain of one. Adding a small amount of proportional term has decreased convergence time and remained stable. As this is on-
going work, the model presently only uses the inner loop.

The diagram shows that the inner loop operates as a simple proportional-integral controller with integral gain of 1.0 and proportional gain of 0.1. Adding the inner-loop P term decreased convergence time with some data sets.

4. RESULTS

The algorithm has been successfully tested with synthesized radar reflectivity data, Zmi, of known Do and No for regions of only rain and of rain/melting/snow. In each case, models were made for the δZei-Do, ki and Ai relationships. Liao (yyyy) also made such models for the snow region.

An example of the rain output for synthesized Do = 1.50 mm, and No = 2041 is shown below in figure 4.

![Figure 4 Plot showing...](image)

The shaping factor, µ, is equal to one. Many other Do/No combinations have been synthesized and run with the algorithm. It has been found that with certain combinations of Do/No that the algorithm converges but does not yield a straight vertical line for Do and No as it should. This is shown in figure 5.

The green diamonds are Do/No combinations that converge and yield unique solutions. The red asterisks are Do/No combinations that converge but do not yield unique solutions. With those synthesized data sets, the Do and No retrieved values tend to curve at the bottom of the range. From the synthesized data, a line has been calculated and drawn that appears to define the regions between unique and non-unique convergent solutions.

5. SUMMARY

The paper has presented an overview of a systems engineering approach for optimizing GPM performance based on subsystem response. To fully optimize a system, a thorough understanding of the subsystems is necessary. This paper has described the operation of the dual-wavelength algorithm along with its response under controlled conditions.

The results should be considered preliminary, and work is on-going in several areas: 1) to fully characterize and understand the dual-wavelength algorithm in rain, melting and snow regions based on hydrometeor assumptions and types; 2) analyze the response of the algorithm to noise at the top and bottom of the rain region; 3) add in a fully developed

References

Liao, L., et al., (xxxx),
Liao, L., et al., (yyyy),
Mardiana, R., (xxxx),
Meneghini, R., et al., (xxxx),