Development of the NPOESS Microwave Imager/Sounder (MIS) Instrument Concept

Introduction

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) is developing a replacement for the Conical-scanning Microwave Imager/Sounder (CMIS), the Microwave Imager/Sounder (MIS). The MIS will perform key measurements for the NPOESS system including Soil Moisture and Sea Surface Winds. Other environmental parameters related to conical-scanning microwave radiometers and MIS include Atmospheric Temperature and Moisture Profiles, Sea Surface Temperature, integrated atmospheric moisture and precipitation measurements. The importance of MIS-related measurements to meteorology, weather forecasting and climatology is demonstrated by the role of measurements from several MIS-legacy sensors including the DMSP Special Sensor Microwave Imager (SSM/I) and Imager/Sounder (SSMIS), as well as the TRMM Microwave Imager (TMI), the EOS Advanced Microwave Scanning Radiometer (AMSR-E), and the Satellite-based Vector Winds Measuring System (WindSat). These sensors provide important insight regarding the design, operation and utility of the future NPOESS MIS in areas of RFI mitigation techniques, sensor calibration and stability, and channel selection; algorithm development and cal/val considerations; the impact of SSMIS measurements for improving NWP forecasts, and improvements to sea surface wind vector, sea surface temperature and soil moisture measuring capabilities. Drawing heavily on these experiences and the diverse background they supply, a trade space for the MIS was defined and several sensor configurations were evaluated in order to determine the best sensor concept to develop for MIS.

Trade Study Description

In order to define the CMIS replacement sensor, the NPOESS Integrated Program Office initiated a comprehensive trade study to determine the most viable strategy and sensor concept to pursue in order to ensure 1) continuity of legacy environmental measurements assigned to CMIS 2) meet the NPOESS key Performance Parameters assigned to CMIS and 3) achieve validated user requirements while accepting a reduction in capabilities. A trade space of capabilities for cost estimation and performance comparison was developed based on the capabilities of the MIS legacy sensors. The trade study further assessed the industrial capability to develop the nominal sensor designs and the technology readiness level of the key aspects each design concept.

The trade study was conducted over a period of six months and included several user and expert reviews throughout the effort. The trade study began with the following assumptions:

1. Affordable and lower risk microwave sensor development required (through reduced complexity or design reuse)
2. F2 Launch (sensor delivery to prime in 1Q2014)
3. Operational Sensor (with 7 year design life, reliability, fault tolerant)
4. KPPs must be met
5. Soil Moisture sensing depth: deeper than 0.1 cm
6. Sea Surface Wind Speed accuracy: 2 m/s or 10%
7. Heritage/legacy performance must be maintained (DMSP)
8. Legacy is defined as the specified legacy performance, not on-orbit performance
9. Atmospheric Sounding KPPs can be provided by Advanced Technology Microwave Sounder (ATMS) and Cross-track Infrared Sounder (CrIS) suite
10. No Solo-flyers, NPOESS-based instrument
11. Wind direction and sounding capability is tradable
12. Upper air sounding capability is tradable

Legacy sensors relevant to this study include a sounding capability, which enables a vertical profile measurement of the atmosphere for temperature or moisture. NPOESS has two KPPs associated with sounding, AVMP and AVTP. These KPPs are provided on NPOESS by the ATMS. Hence for this study the MIS sensor concepts without sounding channels were considered.

MIS Heritage Performance defined from DMSP SSMIS

Heritage capability for the NPOESS MIS is defined from data provided by DMSP and POES. The relevant aspect for MIS is based the DMSP SSMIS sensor. The first SSMIS sensor was launched on DMSP F16 on October 18, 2003. The SSMIS continued imaging measurements provided by the SSM/I and added the first operational conical-scanned temperature and moisture profile data. The SSMIS utilizes a 0.6m main reflector with 24 channels covering a frequency range from 19.35 GHz to 183.31 GHz (channel center frequencies). Continuity of the SSMIS and SSM/I operational capability is of highest importance for the MIS. Figure 1 depicts the SSMIS sensor on-board the DMSP F-16 spacecraft.

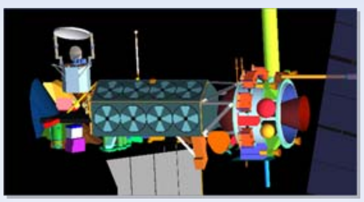

Figure 1. The Special Sensor Microwave Imager/Sounder (SSMIS) on the Defense Meteorological Satellite Program (DMSP) F16 spacecraft.

Key Performance Parameters for the NPOESS MIS

The second set of 'capabilities' for the NPOESS MIS are the NPOESS key Performance Parameters (KPPs) that were assigned to CMIS: Soil Moisture and Sea Surface Temperature. The Soil Moisture KPP is its sensing depth attribute. The sensing depth must be at least 0.1 cm (into the soil) based on a horizontal cell size (HCS) of 50 km. The MIS heritage DMSP EDR is computed using a measure of 'previous' precipitation called the Anticedent Preciptation Index (API). In order to obtain a direct measurement of Soil Moisture as referenced in the NPOESS integrated Operational Requirements Document (IORD), it is generally accepted that the minimum essential capability includes microwave measurements at 10 GHz or lower in frequency. The original Soil Moisture Requirement indicated capability over Bare Soil and known soil types which leads to a very limited area of the globe (Figure 2a). However, in order to achieve direct Soil Moisture measurements with reasonable utility over the global environment a sensor with a 6-GHz capability is required.

Figure 2a shows global regions defined by 'bare soil' (areas in green). In contrast, Figure 2b shows the regions where Soil Moisture retrieval can be performed with the addition of a 6-GHz measurement capability (areas in green) defined by regions of vegetation cover < ~1.5 kg/m^2 (in general, excluding only dense vegetation and forested regions). The advantage of 6-GHz measurement capability is clearly justified (Images are provided by the US Army)

Figure 2a. Bare Soil Regions Soil Moisture Capability

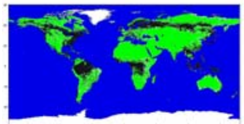

Figure 2b. CMIS Soil Moisture Capability

The second KPP for the MIS is Sea Surface Wind Speed. The associated KPP attribute is its measurement accuracy which is required to be less than the "greater of 2 m/s or 10%" (of the measured value). The Sea Surface Wind (SSW) EDR attributes are based on a spatial resolution of 20 km. This accuracy requirement is not a demanding one based on demonstrated performance of similar sensors. The addition of 10-GHz channels on meteorological microwave sensors (e.g. TMI) has shown that this channel improves the performance of many EDRs including Wind Speed so it is expected that this EDR can be easily met and exceeded.

Sea Surface Wind Direction (SSWD) is not an NPOESS KPP; however, direction retrievals support improvements to the SSWS KPP and Sea Surface Temperature (SST) . Sea surface wind vector (speed and direction) measurements are currently provided by NRL's WindSat and JPL's QuikSCAT, both of which are experimental sensors whose life will likely not last until the NPOESS C2 launch. An operational scatterometer is scheduled for launch on the MetOp satellites with data availability expected through 2020. SSWD capability provided by WindSat (polarimetry) have shown significant utility for improving forecasts and represents an important capability that can be provided by an operational MIS sensor on NPOESS.

MIS Performance compared to IORD II requirements

The third set of 'capabilities' for the NPOESS MIS are performance goals relative to the NPOESS IORD II EDRs originally assigned to CMIS. This set of EDR thresholds include significant performance improvements compared to the current DMSP EDR characteristics. Most notably, improved horizontal cell size (related to spatial resolution), and measurement uncertainty. Further, new EDRs such as Cloud Ice Water Path, and Total Water Content (vertically resolved vapor, liquid and ice) are required by the IORD compared to heritage DMSP. In order to limit the scope of the MIS compared to the original CMIS design goals, the MIS will not achieve all of the IORD II thresholds for the EDRs assigned to the sensor. However, the MIS design approach is required to accommodate growth to achieve near IORD II capability after the initial flight unit if capability falls significantly short of the IORD.

Trade Space

The trade space associated with the MIS study is defined by the heritage SSM/I and SSMIS sensor s (0.6m main reflector; channel frequencies > 18 GHz) and the CMIS design (2.2m main reflector; channel frequencies from 6.2 – 183 GHz). This is a significant range of sensor capability, cost, and associated mass and power requirements for accommodation on the NPOESS spacecraft. The one of the goals of the MIS trade study was to explore the relative performance that could be obtained from sensor configurations that spanned the range from current DMSP (SSMIS) to the CMIS design. The approach was to define two increments in the size of the main reflector: A=1.2m and B=1.8m and three general channel sets: the basic capability includes core imaging (10 – 89 GHz), type 1 includes core imaging with polarimetric capability (10 P/M; 18 P/M and 18 L/R; and 37 PM) and finally type 2 adds sounding (+50 and 183 GHz channel suites).

For each combination of sensor attributes, a top level performance assessment was collected from a team of experts familiar with the EDR performance. Figure 3 shows a summary of the assessments of the Horizontal Cell Size and measurement accuracy/precision/uncertainty (APU) for the set of existing conical-scanning radiometers and 7 conceptual sensors with CMIS. The assessments are made with respect to IORD II thresholds of the original 20 CMIS EDRs and grouped into four categories: exceeds EDR requirements (Blue), meets EDR requirements (Green), doesn't meet requirements but has significant utility (Yellow), and essentially no performance (Red). Gray cells indicate that an assessment was not available.

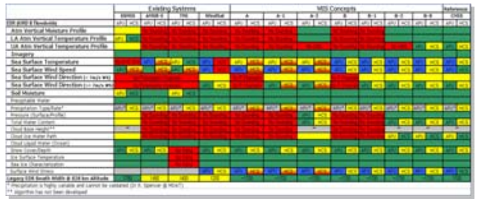

Figure 3. Assessment of EDR performance for several conical-scanning radiometer designs spanning the range between DMSP SSMIS and NPOESS CMIS.

There are several points from Figure 3 that are important with respect to the MIS definition trade study. First, note that only SSMIS, A-2, B-2, B-8 and CMIS include atmospheric sounding capability. Second, sensors in class "A" generally show more sever deficiencies in HCS (noted by the red/yellow cells). And third, CMIS did not meet IORD II thresholds for all EDRs. This summary chart provides an overview of how the larger reflector (B-class) and extended channel sets (1 and 2) provide improved performance compared to IORD II thresholds.

MIS Point Design

Using the results from the detailed assessments that are summarized in Figure 3, a detailed point design was developed using detailed simulations of the antenna and receiver parameters consistent with the B-2 sensor concept. The model was assembled using information from the WindSat and CMIS radiometer designs and coupled with parameters of the NPOESS spacecraft. With development of the point design, additional trade studies were carried out in order to confirm swath width, receiver performance, fields of view, and beam efficiency requirements could be met with the design. These additional detailed assessments were considered to be a critical part of the MIS sensor definition, and ensured to viability of the top level MIS sensor and EDR requirements for achievable and affordable requirements. An example of the 'B-2' sensor antenna simulation is shown in Figure 4.

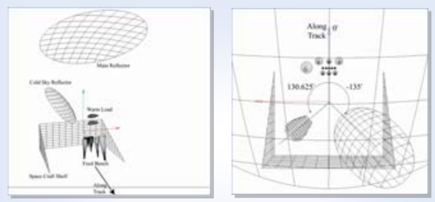

Figure 4. Graphical depiction of the B-2 antenna simulation using the General Reflector Antenna Software Program (GRASP) analysis. The figures show the main reflector, cold sky reflector, warm load, and antenna feed bench locations with respect to the edge of the NPOESS spacecraft.

Conclusion

This poster summarizes two important aspects of the NPOESS MIS development 1) evaluation of the available trade space defined by existing DMSP heritage and the NPOESS CMIS and 2) importance of a detailed engineering point design in order to ensure a viable sensor concept that meets new goals of NPOESS.

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