ASSIMILATING MULTIPLE METEOROLOGICAL SENSOR DATA

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ABSTRACT

The first of several Meteorological Measuring Set - Profiler(MMS-P) Proof-of-Concept calibration tests was conducted 99 August 3-5. The focus of this test was on the meteorological sensors selected for generating a timely local met profile. Post-Test analysis of the final data acquisition period reinforced the importance of understanding the individual sensor data processing assumptions, as well as the local atmospheric dynamics before assimilating the multi-sensor resources into a single met profile. An examination of this challenging measurement set is presented, as well as the subsequent 'lessons learned'.

1. Background

The 1990 Jun 1 - Field Artillery Accuracy Improvement Analysis reported that "43% of the bias error for unguided cannon and 94% of the bias error for unguided rocket can be attributed to weather".[1] Based on this fact, the Army Research Laboratory(ARL) has been pursuing an enhancement to the artillery accuracy by developing new meteorological(met) application technologies and concepts that influence doctrine on the battlefield. One of the 'new' met technologies was the Meteorological Measuring Set-Profiler(MMS-P). See Figure 1. In 1997, the Artillery Meteorology Branch of ARL created a Development Plan for engineering the construction of an MMS-P that would be housed in an Army High Mobility Multi-Wheeled Vehicle(HMMWV).[2] In its most basic concept, the MMS-P Unit would input near real-time local and/or regional met data into a mesoscale model, which would forecast met conditions along the trajectory and in the impact area of the artillery projectile. The original design was purposefully drawn with modular components, thus allowing room for technological improvements both during and after the construction phase. The two primary modules included the 'Local Meteorological Profile(LMP)' and 'Computer Assisted Artillery Message(CAAM)'. The first module focused on the met sensors selection, data acquisition, and timely data fusion of the local met profile. The latter couples a mesoscale weather forecasting model with the already fielded CAAM software. In November 1998, the physical construction of the first

HMMWV-Integrated MMS-P was completed.[3] In April 1999, this novel prototype was demonstrated at the Senior Fire Support Conference at Fort Sill, OK. From August through November 1999, field tests were conducted on the modules and sub-modules, as well as the entire MMS-P system. In this paper, a unique data set drawn from the initial field test and rich in 'lessons learned' is presented.

Figure 1. First HMMWV-Integrated MMS-P Proof-of-Concept constructed 1998 Nov.

1.1 MMS-P Proof-of-Concept Unit

The first of two MMS-P Proof-of-Concept Unit modules, the Local Met Profile, was composed of a suite of met sensors that included a surface point source unit (Campbell CR21X), a Radiometer, a 924 MHz Wind Profiling Radar, and a Met Satellite Data Receiver with a Global Positioning System(GPS). Table 1 presents the LMP met sensors, the data variables each sensor acquired and the range of heights of the raw (unedited) data. The CAAM Module used the Battlescale Forecast Model. In the original design, the final met message produced was radioed to artillery units via an Army SINCGARS radio.

Table 1. MMS-P Met Sensors.

Sensor Unit	Met Variable Acquired	Data Heights Reported
Surface Sensor(CR21X)	P, T, RH, WS/WD	2 m (single point)
Radiometer	Temperature Profile	0 - 10000 m
Wind Profiling Radar	Wind Speed/Direction Profile	150 - 7000 m
Met Satellite/GPS	P, T, Td, WS/WD Profile	125 - 31000 m

1.2 Local Met Module Calibration Test

The Local Met Module Calibration(LMMC) Test was conducted from 3-5 August 1999 at the ARL Radar Site, White Sands Missile Range, New Mexico. The mission of this test was to collect and compare simultaneous measurements from the LMP sensors and a GPS/LORAN rawinsonde observation(raob) system. The test site was in the Tularosa Basin, at the base of a mountain range rising approximately 1200 m above the 1265 m-MSL desert location. All sensors were positioned within an area of approximately 25 m by 10 m.

2. Research Accomplished

The hazards of comparing point source met data with volumetric measurements have long been the catalyst for many animated discussions within the met sensor community. Never was the heart of this debate made clearer than in the final data set acquired in the LMMC Test. The presentation of the LMMC Test case study will first examine the primary met sensors, followed by the atmospheric conditions during the case study, and finally the data analysis.

2.1 1999 August 05 Case Study - Met Sensors

The primary data resources were the rawinsonde, wind profiling radar and meteorological satellite(met sat) systems. Each system makes assumptions when processing the acquired data into meteorological variables. The major assumptions are described below.

2.1.1 Rawinsonde

The raob is a balloon-borne package of sensors that transmits point source met measurements sampled as it ascends through the atmosphere. The resulting data are assembled into vertical profiles representing the Pressure, Temperature, Relative Humidity, Wind Speed and Wind Direction over the balloon launch site. The assumption made by the raob data acquisition system is that the atmospheric conditions are homogeneous from the ground-zero balloon launch point through the final, down-wind measurement reported at the maximum height, 40-60 minutes later. Given an ascent rate of 5 m/s, an average horizontal speed of 6 m/s, and a 60 minute flight, the volume represented by this assumption would be 21.6 km in the horizontal and 14 km in the vertical. A second assumption made by the raob acquisition method stems from the timestamp given to the resulting profiles. While most raob systems have 'time from launch' data available, the general practice is to use just the initial launch time for the entire set of vertical profiles reported. Thus, the assumption becomes that the atmosphere is homogeneous throughout the duration of the entire raob flight.

2.1.2 Meteorological Satellite

Profiles gleaned from the LMMC Test Meteorological Satellite(Met Sat) polar orbiting passes were based on a radiative transfer equation and a weighting technique imposed on the infrared and microwave met sat data. The resulting Pressure, Temperature, Dewpoint Temperature, Wind Speed, Wind Direction profiles represented volumes in the atmosphere. The assumption made with this data acquisition method was that the atmosphere was homogeneous throughout the cube of air being sampled. For TIROS-Operational-Vertical-Sounding(TOVS) data, the horizontal dimension was approximately 75 km.[2] The vertical resolution varied from 1.4 to 4.7 km. The timestamp given to the data was taken from the initial time the pass reaches the receiver. The assumption made was that the atmosphere was homogeneous throughout the duration of the passes (10-15 minutes).

2.1.3 Wind Profiling Radar

The Wind Profiling Radar used in the case study employed an Advanced Signal Processing(ASP) module. Unlike the traditional 60-minute consensus radar processing, the ASP generated an output every 5 minutes. Within these five-minute wind speed/direction profiles was an analysis of 1 vertical and 4 near-vertical, cone-shaped atmospheric volumes(radar beams). Each volume(beam) was sampled for approximately 30 seconds. The atmospheric volume represented in the case study was initiated at 298 m AGL and reached a maximum height of 3745 m (resolution was 150 m). The total volume of the profile was approximately 7010 m^3. The timestamp of the output data was defined as the starting time of the 5-minute sampling. Any previously acquired data with a timestamp of up to 25 additional minutes were also incorporated in the data processing, when available.

2.2 1999 August 05 Case Study - Atmospheric Conditions

The large scale atmospheric conditions during the 5 August 1999 Case study consisted of a Low Pressure system over the western United Sates and a large High Pressure over the southeastern United States. A continuous stream of subtropical moisture fed the atmosphere over southern New Mexico, supporting the local diurnal monsoon pattern of late afternoon thunderstorm buildup. Precipitable water measured 1.3 inches over the test site.

Chronologically, the test day began with cloudy skies in the morning. Partly cloudy skies characterized the mid-day hours. By late afternoon, 'scattered' conditions were reported and evolved into a local heavy thunderstorm impacting the Test site from the East-Southeast. Heavy rains over the site ended by 1910 MDT.

The cast selected for this article began at 1750 MDT. The data resources, their data timestamp and the data heights reported are listed in Table 2.

Table 2. 99 Aug 05, 1750 MDT Case.

Sensor Unit	Acquisition Timestamp (MDT)	Data Heights Reported
Raob	1751	0 - 12381 m
Radiometer	1752	0 - 10000 m
Wind Profiling Radar	1750,1755,1800,1805,1810	298 - 3745 m
Met Satellite/GPS	1818	127 - 31583 m

2.3 1999 August 05 Case Study - Data Analysis

Assimilating multi-sensor met data begins with a data comparison. Figure 2 displays the temperature profile measurements for the 1750 MDT case study. From about 1 km and above, the raob consistently reports a cooler atmosphere than the radiometer and met sat. Examining the wind speed profiles of the raob and the 5-minute radar profiles collected during the raob's ascent, also yield a curious independence between sensors. In fact, when one compares the raob chronologically with each of the radar 5-minute profiles, the correlation coefficient values peak (.966) at launch plus 10 minutes. Calculating the average radar-raob wind speed differences reenforces this finding. A chronological comparison of the raob vs 5-minute radar wind direction profiles also shows the peak correlation coefficient to be at launch plus 10 minutes (.870).

For an explanation of this apparent disagreement between sensors, one must return to the time of the test and take a closer look at what each sensor is reporting. The rawinsonde was launched at 1751 MDT. The path of the balloon, based on the wind direction, began as Northerly, turned Easterly at 395 m, Southerly at 1426 m, South-Westerly from 2068 m through 6903 m, and finally South-Easterly by 11000 m. (No wind data were reported between 7200 and 11000 m.) When viewing this path from above, an a-typical hook-shaped ascent captures one's attention.

The cause for this unusual pattern can only be explained by the late afternoon monsoon thunderstorm that was approaching the site from the East-Southeast at launch-time. Not surprising, the steering dynamics of the storm were evident by the 395 m raob sample.

In contrast to the 'mobile' raob, the radiometer and radar are stationary sensors. From their perspective, the data reported described the approach of the monsoon thunderstorm. Their measurements represented atmospheric volumes sampled. While the met sat also sampled volumes, the magnitude of the volume was significantly larger than the stationary ground sensors. Thus, the met sat data yielded temperatures more reflective of the region. And, the monsoon thunderstorm was a subset of that region.

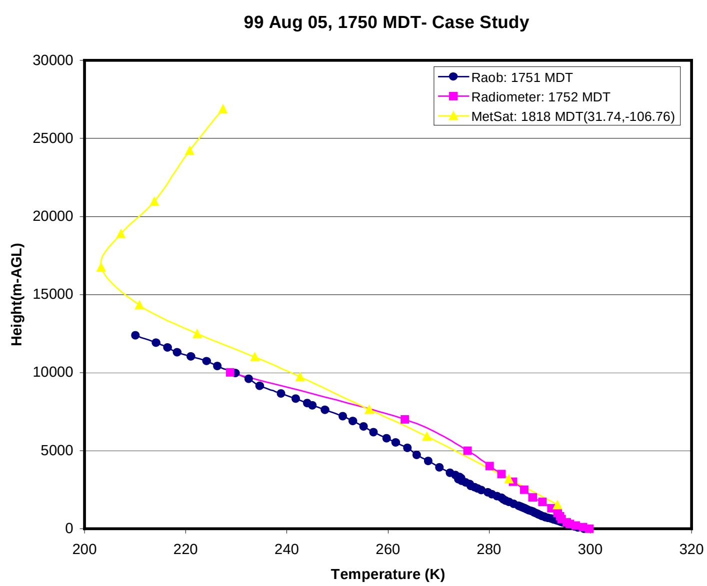

Figure 2: 1999 August 5, 1750 MDT Case Study - Rawinsonde, Radiometer and Met Sat temperature profiles display measurement variations in and around an approaching monsoon thunderstorm.

3. Conclusions

The 'lessons learned' from the 1999 August 5, 1750 MDT Case Study were old but still significant. First, when two met sensors have the same timestamp that does not necessarily mean their reported parameters represent the same atmospheric conditions. Second, two sensors reporting measurements at a common height may actually represent significantly different volumes of atmosphere. And finally, in conclusion, this case has re-enforced the fact that knowledge of the sensor location, atmospheric volume or location being sampled, data processing assumptions and local dynamic atmospheric conditions are critical input when assimilating multi-sensor meteorological data.

References:

[1] *Field Artillery Accuracy Improvement Analysis*, Fort Sill, 1990 June 1.

[2] Vaucher, Gail-Tirrell and Bob Brown, *MMS-Profiler Development Plan*, 97 Oct 2; 97 Nov 21.

[3] Vaucher, Gail-Tirrell, *MMS-P HMMWV Integration Exercise: 27 Oct-10 Nov 98, Summary of Successes*, 99 Nov 12.

[4] Dr. Lei Shi, Personal Correspondence - 99 Oct 27.