The Real Time Mission Monitor - A Situational Awareness Tool For Managing Experiment Assets

Richard Blakeslee[1], John Hall[2], Michael Goodman[1], Philip Parker[3], Larry Freudinger[4] and Matt He[3]

[1]NASA Marshall Space Flight Center, [2]Science Applications International Corporation, [3]University of Alabama in Huntsville, [4]NASA Dryden Flight Research Center

Abstract - The NASA Real Time Mission Monitor (RTMM) is a situational awareness tool that integrates satellite, airborne and surface data sets; weather information; model and forecast outputs; and vehicle state data (e.g., aircraft navigation, satellite tracks and instrument field-of-views) for field experiment management. RTMM optimizes science and logistic decision-making during field experiments by presenting timely data and graphics to the users to improve real time situational awareness of the experiment's assets. The RTMM is proven in the field as it supported program managers, scientists, and aircraft personnel during the NASA African Monsoon Multidisciplinary Analyses experiment during summer 2006 in Cape Verde, Africa. The integration and delivery of this information is made possible through data acquisition systems, network communication links and network server resources built and managed by collaborators at NASA Dryden Flight Research Center (DFRC) and Marshall Space Flight Center (MSFC). RTMM is evolving towards a more flexible and dynamic combination of sensor ingest, network computing, and decision-making activities through the use of a service oriented architecture based on community standards and protocols.

I. INTRODUCTION

The Real Time Mission Monitor (RTMM) is a situational awareness, decision-support system that integrates satellite remote sensing, aircraft position and weather state information, airborne and surface instrument observations for Earth science research investigators. The integration and delivery of this information is made possible through data acquisition systems, network communication links, and network server resources built and managed by the authors at the NASA Marshall Space Flight Center (MSFC) and the NASA Dryden Flight Research Center (DFRC).

The RTMM integrates satellite and radar imagery, surface and airborne instrument data sets, model output parameters, lightning location observations, aircraft (including balloon) navigation data, soundings (e.g., dropsonde), and other applicable Earth science data sets. The RTMM uses the Google Earth application as the user visualization.

The genesis of RTMM dates back about a decade at NASA MSFC and NASA DFRC. Both groups independently developed methods to better ingest, process, and distribute aircraft and instrument data in support of NASA Earth science field campaigns. The RTMM, developed at MSFC, builds upon the solid heritage of earlier mission and weather monitor applications implemented during the 2002 Altus Cumulus Electrification Study [1] and other airborne and ground-based missions. An interactive Java-based web prototype emerged in mid-2005 and was used to support the Lightning Instrument Package (LIP) during the Tropical Cloud Systems and Processes (TCSP) campaign in Costa Rica [2]. This prototype RTMM was primarily used by the LIP instrument team with only ancillary use by other scientists in TCSP. However, it was during the 2006 NASA African Monsoon Multidisciplinary Analyses (NAMMA) field experiment in the Cape Verde Islands off the coast of Senegal in West Africa when the widespread use of RTMM by multiple instrument scientists, mission scientists, and program managers was fully realized. In anticipation of its broader user-base with NAMMA science operations, the RTMM was redesigned to utilize Google Earth and its constituent Keyhole Markup Language (KML) as an integration interface for real-time displays. What emerged from these iterative improvements was the capability to leverage a single, easy to use visualization tool that supports science and logistics decision-making by merging disparate and geographically distributed information that is constantly changing. Behind the scenes, we designed a sustainable infrastructure able to grow and support virtually any airborne science campaign, anywhere, anytime.

A key addition and advanced capability added during NAMMA was providing, for the first time, a local RTMM capability on the DC-8 aircraft itself during the flights. This provided on-board scientists and aircraft operators access to imagery and data sets unavailable in prior airborne campaigns.

Figure 1 illustrates how airborne and ground-based network resources are tied together to create a sub-orbital tele-presence that constitutes the beginnings of a sub-orbital sensor web. The bidirectional transmission of data and information between the aircraft and redundant RTMM servers are made possible through a dynamically configurable embedded data system and network gateway called the Research Environment for Vehicle Embedded Analysis on Linux (REVEAL) [3] developed by the NASA Dryden Flight Research Facility. REVEAL connects to the network using Iridium satellite data links.

The existing core functionality of RTMM enables any user with internet access (e.g., at the NAMMA mission operations center in Cape Verde, aboard the NASA DC-8 aircraft, or at a remote site back in the United States) to monitor – in real-time – multiple field observation assets including but not limited to multi-spectral geostationary satellite imagery (e.g., GOES, Meteosat), polar orbiting satellite tracks and instrument field of views (e.g., NASA satellites and instruments), derived NASA satellite products (e.g., AMSR-E sea surface temperatures), surface weather radar, global lightning observations, radiosondes and dropsondes, aircraft flight tracks, airborne instrument observations aboard the DC-8, and forecast model output parameters. All of these data sources were utilized during the NAMMA field campaign.

Figure 2 depicts some of the observations during a NAMMA flight on 12 September 2006 off the coast of West Africa. The NASA DC-8 is sampling a tropical depression that is the precursor to Hurricane Helene. In the figure, the airplane icon represents the current position of the NASA DC-8 as it follows the planned flight track (green "figure-8"). The actual aircraft track is represented by the red line which for the most part is following the green pre-planned flight track. Another feature to note is the broad red swath oriented southwest to northeast which represents the track of the TRMM satellite with the 1-minute field-of-view of TRMM Microwave Imager overlaid in green.

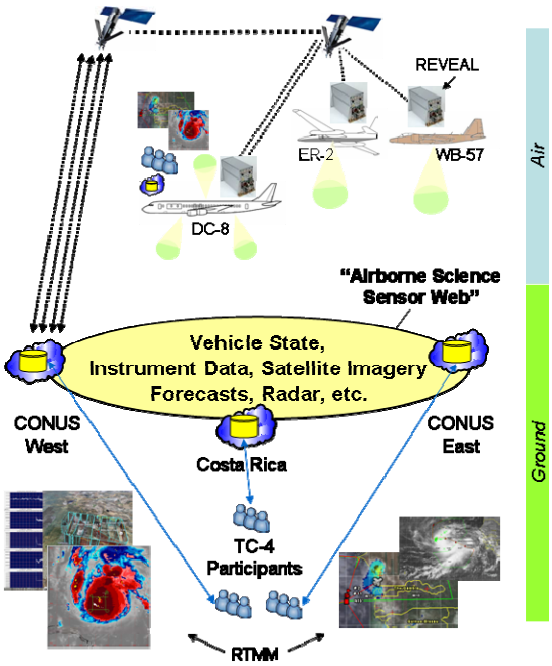

Figure 1. Airborne and ground-based network resources linked together to form a sub-orbital sensor web.

These graphics are superimposed upon a background image of a color enhanced infrared Meteosat image. Cloud-to-ground lightning strikes are denoted by the yellow cross hatching embedded in the most intense convection within the storm. Along the red aircraft flight track can be seen red flag markers depicting the location of dropsondes that were deployed from the DC-8. Another feature to note is the aircraft altitude graph in the upper left corner. The strength of RTMM is its ability to continually provide the user with animated satellite, aircraft flight level and surface state information. Although Fig. 2 is a still photographic image, a wealth of information is readily conveyed in a concise and easy-to-use interface. It is important to remember that all these data sources and information are integrated in near real-time and presented to the end-user. The animated geostationary satellite images are updated every 15-minutes while the other observations described above are continuously updated to enhance situational awareness and optimize the scientist's decision making capabilities. To see an animated view of past airborne missions please go to the RTMM home page at http://rtmm.nsstc.nasa.gov.

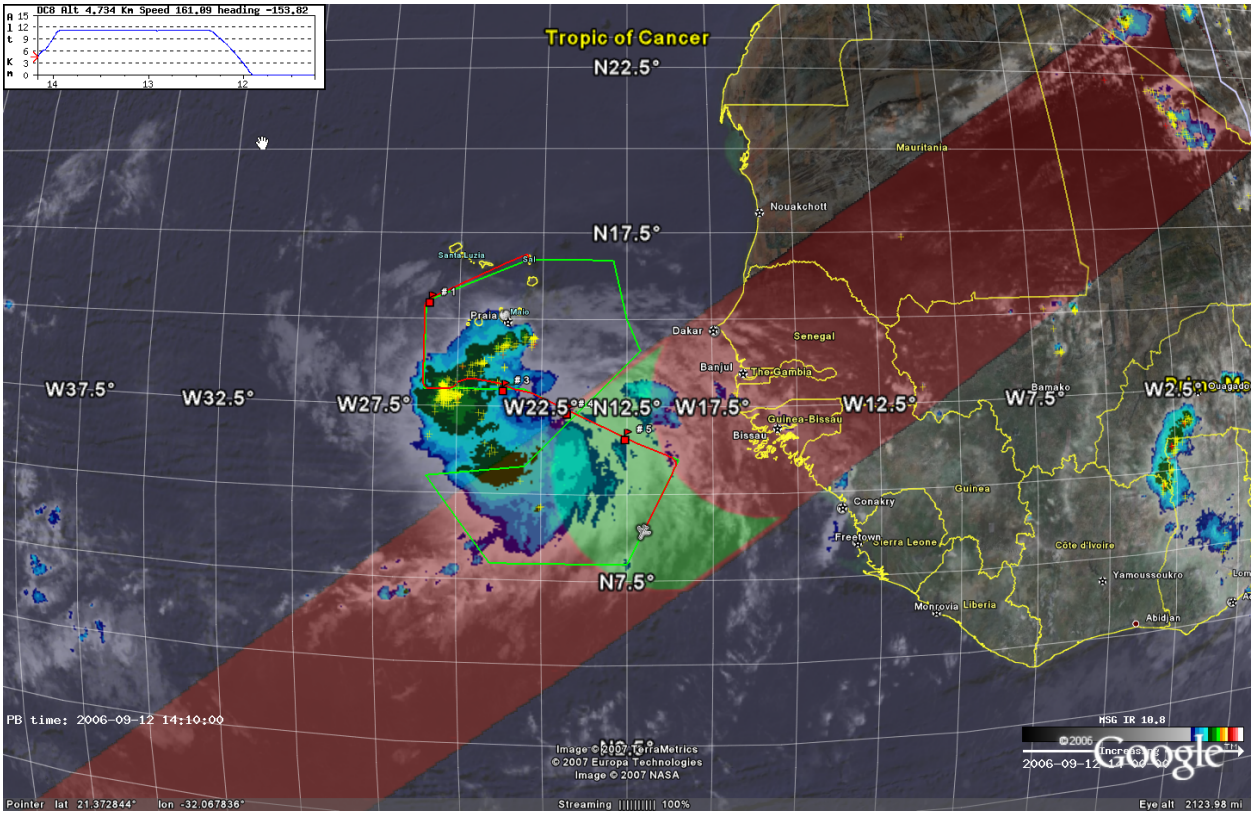

Figure 2. Screen shot of Real-time Mission Monitor of the NAMMA DC-8 flight on 12 September 2006 off the West African coast.

II. RTMM Architecture and Interface Standards

From a user's perspective the Real Time Mission Monitor seamlessly integrates multiple data sources into a single interface. The RTMM is built upon a loosely-coupled, Web-based, service oriented architecture (SOA). The term loosely-coupled implies that the service client is independent of the service. The client doesn't have to know *a priori* the details of the service provider (e.g., the service platform, operating system, or language). A Web-based SOA is predicated upon a well defined set of interface standards and protocols that enable interoperability between the component pieces. As previously noted, the RTMM utilizes uses Google Earth's client to display an integrated set environmental parameters to the viewer. Google Earth incorporates the KML standard to define where, when, and how often to gather the data and information into the service. These data are created and/or ingested at MSFC and placed on servers accessible by the end-user.

The RTMM data are accessible by a standard Apache web server to the client's Google Earth display using the HTTP protocol. A large number of software packages run on the distributed RTMM servers to provide these data (Fig. 3). The servers may be located at both ground and/or airborne sites. These data packages ingest satellite, lightning, radar, navigation, and dropsonde data. The data are processed and converted to a form that is compatible with the Google Earth display software (e.g., PNG images geolocated in a cylindrical equal-angle projection). Weather forecast model output parameters and other imagery are created by external data providers and are downloaded to the RTMM servers for visualization by the client.

As illustrated in Fig. 3, the RTMM user may be located on the (upper left) ground or in the air aboard an aircraft (e.g., the NASA DC-8; lower right). The RTMM user invokes Google Earth using a predefined KML file. After initiating the RTMM, the user can

exercise full control over the data sets selected.

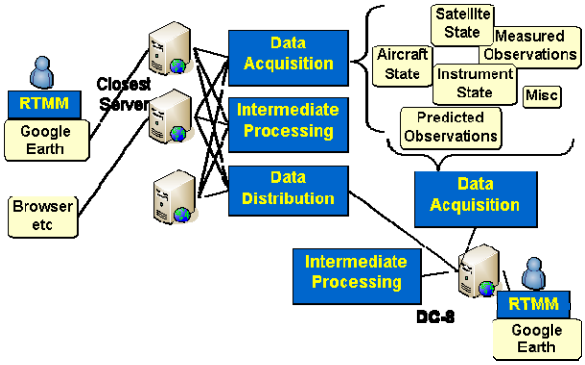

Figure 3. A distributed network architecture in a typical RTMM field deployment. Data acquisition servers can be located at remote locations including aircraft and field operations sites. Communications between the airborne servers and the surface servers is provided by the REVEAL network gateway.

The RTMM also provides an exciting new capability to review data previously captured. The user selects a date/time range and playback speed (e.g., review 5-minutes of flight time per ~2-sec interval of current time) and then animates the selected data sets in a fast forward mode. The playback capability enables any user to interrupt a real-time visualization and dynamically review an in-flight sequence and then resume the real-time viewing. Another use of playback is to review a completed mission in post-mission analyses. An example of this feature is demonstrated in a review of a NAMMA flight mission months after it was completed. In this NAMMA review scenario, the user selects the flight day and can playback the entire 6-hr mission in a few minutes by adjusting the playback speed, accordingly. Throughout the playback, the individual data sets (e.g., infrared and visible satellite channels, cloud-to-ground lightning, airborne instrument observations, etc.) collected on a flight day can be dynamically turned on/off for viewing.

III. New Services and Functionality

We are adding functionality to RTMM by employing services that use the Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) environment [4]. Using a Sensor Observations Service (SOS), the RTMM accesses an historical tropical storm database that describes the location, date, time, and intensity of the storms. Another sensor web enabled service uses the Sensor Model Language (SensorML) to processes the satellite navigation ephemeris (two-line element sets) to produce the satellite tracks and associated instrument field-of-views. Adding functionality necessitates that we meet the complex challenge of automating the integration of data from multiple sensors, platforms, and models by implementing a sensor web enabled environment with common protocols and formats. The SWE protocols enable dynamic discovery and access of data and information. The suite of sensor web standards and protocols enable heterogeneous plug and play operations. Within the SWE framework, there is little distinction between an instrument, model and simulation, and data processing engine. They all are termed "sensor systems" and can be described in SensorML as process models or chains. As sensor systems, they all produce observations that can encoded in the Observations & Measurements specification and be advertised and accessed through a SOS. Many of these sensor systems can also be tasked or configured to meet the specific needs of the user and are thus candidates for web enablement through the Sensor Planning Service. We anticipate incorporating sensor web services to connect RTMM visualizations to data access.

IV. Conclusion

The RTMM is a situational awareness tool that was proven in the field as a mission essential asset during the NAMMA campaign. The RTMM enabled NAMMA airborne scientists and ground-based science operations and program managers to simultaneously have access to flight status information in order to facilitate mission execution. The RTMM supports mission planning and mission coordination and execution through the inclusion of weather forecast model output parameters, aircraft waypoint tracks, and predicted satellite nadir track and instrument field-of-views.. Post-mission analyses are aided by playback capabilities. The RTMM development effort represents an evolutionary step toward a general set of "sensor web" and "intelligent airborne observation system" capabilities targeted by Earth science technology insertion investments.

References

[1] R. J. Blakeslee, C. L. Croskey, M.D. Desch, W. M. Farrell, R. A. Goldberg, J. G. Houser, H. S. Kim, D. M Mach, J. D. Mitchell, and J. C. Stoneburner, The ALTUS Cumulus Electrification Study (ACES): A UAV-based science demonstration, *Preprints, 12th Int. Conf. on Atmos. Electr.*, 143-146, June 2003.

[2] Halverson, J., P/ Azofeifa, M. Black, S. Braun, D. Cecil, M. Goodman, A. Heymsfield, G. Heymsfield, R. Hood, T. Krishnamurti, G. McFarquhar, J. Molinari, R.Rogers, J. Turk, C. Velden, D-L. Zhang, E. Zipser, R. Kakar, 2007, NASA's Tropical Cloud Systems and Processes (TCSP) Experiment: Investigating Tropical Cyclogenesis and Hurricane Intensity Change, *Bull. of Am. Met Soc*. June, 2007

[3] C. Sorensen, S. Yarborough, L. Freudinger, P. Gonia, "Research Environment for Vehicle-Embedded Analysis on Linux", , *Proceedings of the 39th Int'l Telemetering Conference*, paper 03-11-04October 2003.

[4] M. Botts, A. Robin, J. Davidson, I. Simonis, editors, 2006 *OGC 06-021, 2006*