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MANAGING THE INFRASTRUCTURE OF A 21st CENTURY METEOROLOGICAL SERVICE: SYSTEMS ENGINEERING, MANAGEMENT AND SUSTAINMENT (SEMS) AND THE AIR FORCE WEATHER AGENCY (AFWA)- A GOVERNMENT/PRIVATE SECTOR PARTNERSHIP

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1. INTRODUCTION

Generation and delivery of weather products for military applications and users has taken on ever increasing complexity in light of continual developments in the field of meteorology, and increasingly complex user needs. Operational fine scale numerical weather prediction models, new satellite based sensors, global requirements and operational demands have increased the demands on processing power and bandwidth. This trend will accelerate with new generation mesoscale modeling systems, sensor systems, and derived products from next generation geostationary and polar orbiting satellites. New weapon systems are highly weather dependent and produce an increased demand for highly tailored weather products.

The Systems Engineering, Management and Sustainment (SEMS) program provides systems support for the Air Force Weather Agency (AFWA), the strategic center for weather for the U.S. Air Force and supplies all weather-related information to the Air Force, Army, and many federal agencies. AFWA provides meteorological analysis and forecast support to Army and Air Force units worldwide, supports weather forecasting and severe weather prediction by civilian agencies, and participates extensively in the meteorological community's advanced weather research. AFWA is the largest supplier of weather data for military users worldwide in supporting front line combat operations and mission support, mission planning, and routine flight operations support.

This paper describes the current state of support provided to AFWA under SEMS, providing an overview of the enterprise. The overview will take the perspective of systems management and examine aspects of systems engineering needed to maintain, advance, and enhance complete global, military weather support.

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2. THE WEATHER OPERATIONS PROCESS

The weather operations process can be viewed as a five-step process (Figure 1). This five-step process covers all of the activities from collecting raw environmental data to creating and distributing products to end users in the field. Observations and forecasts must be available on a real time basis to users worldwide. This information is supplied to users in the field to support operations, to mission planners, executors and to decision makers. Weather data collected and processed by AFWA serve as a backup source for NCEP.

The first step in the weather operations process is to acquire the data. The weather data that we ingest comes from many sources, including standard and special surface observations, upper air observations, pilot reports, satellite observations, and ship reports. Data that are received are verified for completeness and accuracy. Data are transmitted for subsequent processing by other enclaves within Air Force Weather, and by external users of the data we collect. The data that are collected are dynamically changing with advances in new sensor systems and data sources. Included in these are NPOESS (National Polar Orbiting Environmental Satellite System), GOES-R and OS-21 (the DoD equivalent of ASOS). Currently, preparations are underway to accept data from the NPOESS series of satellites by way of adopting the NPP (NPOESS Preparatory Project) sensor data into the AFWA data stream. Government, military, and private sector members of the AFWA community are involved in, and actively pursuing these new data sources, planning for the future, and developing new applications for the data as they become available.

Next, the data are ingest and decoded by resident AFWA systems. The raw data are parsed and conditioned for their intended uses within the AFWA enterprise. Data are routinely verified for their accuracy and completeness. A number of AFWA systems perform these functions, the primary being the Weather Data Acquisition enclave, which comes under the AFWA/SEMS umbrella in the next several months.

The data are then stored in common and specialized databases. The use of common databases reduces redundancy, thus lowering total operating cost, and provides for tighter integration of the component systems at AFWA. Because of the interdependency between data and the component enclaves at AFWA, the migration towards an enterprise view of the weather operations is highly desirable. The databases constantly evolve with needs and new data sources; recently we completed the first phase in the transition to a common database structure to serve the needs of all AFWA enclaves. Data storage is an AFWA wide function that falls directly under the SEMS umbrella of services.

Data are analyzed and forecast products generated. Data intended for model input are again verified. Completeness is assured and supplied to data assimilation routines such as 3DVAR, for use in the MM5 forecast system. The primary forecast system at AFWA is the Global Theater Weather Analysis and Prediction System (GTWAPS). Aside from GTWAPS, analysis and prediction are the key functions of the Cloud Depiction and Forecast System (CDFS-II), and Space Weather Analysis and Forecast System (SWAFS). The analysis function extends beyond the walls of AFWA to the next level, the Operational Weather Squadrons (OWSs). Analysis and display also falls under the Joint Environmental Toolkit (JET).

The final step of the process involves the dissemination, tailoring and display of weather data. In this step, graphical products are generated for the end user and made available to users worldwide. We also provide specifications, forecasts, warnings and alerts. Processed data are also verified (verification of data occurs along each of the five steps) before products are distributed. Increasingly important is the product tailoring process. Product tailoring is essential in that weather effects can be represented to decision makers, and with the trend in increased volume of meteorological data, we can make effective use of available bandwidth by distributing to end users just what they need, and provide a drill down capability for more detailed information upon demand. Dissemination primarily occurs through the Joint Air Force & Army Weather Information Network (JAAWIN), through OPS2 (OWS), Joint Weather Information Service (JWIS), and, in the future, through the Joint Environmental Toolkit components.

SEMS is responsible for AFWA systems including the Global Theater Weather Analysis and Prediction System (GTWAPS), Satellite Data Handling System (SDHS), the Joint Air Force & Army Weather Information Network (JAAWIN), the Space Weather Analysis and Forecast System (SWAFS) and Cloud Depiction and Forecast System II (CDFS-II). SEMS provides integration, sustainment and engineering support for these enclaves, providing an integrated depiction of global weather from earth's surface out to space, and from data collection to product dissemination. Presently, over 92 GB of weather products are generated per day, with almost 60 GB of satellite imagery being collected and processed from over 10 satellites. Nearly 10,000 surface and over 3500 upper air observations are assimilated, processed into the database, and shared among enclaves. SEMS integrates the functionality of AFWA systems that cover all five key weather operations functions including ingest, analysis, forecast, product tailoring and dissemination.

3. NUMERICAL WEATHER PREDICTION

SEMS is responsible for the entire life-cycle engineering of the Air Force Weather Agency's (AFWA) GTWAPS program. GTWAPS acquires data from a variety of sources internal to AFWA and externally from other agencies, including the US Navy's Fleet Numeric Meteorology and Oceanographic Center (FNMOC), NOAA's National Center for Environmental Prediction (NCEP), and the World Meteorological Organization, and produces fine scale atmospheric modeling worldwide to support DoD combat operations and mission planning. Aside from supporting the war in Bosnia, the Kosovo conflict, and support for both the Gulf War and Operation Iraqi Freedom, this AFWA system also provides emergency backup support to NOAA's

National Center for Environmental Prediction. This system of systems houses no less than six 'applications', which are models designed for very specific purposes meeting DoD, DOT, and other federal agency's needs.

The conglomerate system consists of two IBM massively parallel production systems, an applications server, data server, development system, and a High Performance Gateway Node (Figure 2). This system boasts some of the latest computing technology housing the Regatta class nodes. The two production systems currently in use employ a total of 34 nodes, with a total production capacity of over 1500 Gflops on the unclassified system. A total of 500 CPUs are resident on the two production systems. An additional 10 nodes /90 Gflops are available on the development side. GTWAPS was recently upgraded to this configuration in anticipation to the need for increased computing resources with WRF.

Since its inception, development of this system has gone through four major hardware refreshes to remain on the cutting edge of technology. In 1995 GTWAPS was conceptualized to use IBM scalable parallel architecture running the Penn State University developed Mesoscale Model 5 (MM5). Since then, GTWAPS has typically had two large production systems and was re-architected to house the smaller models on an applications server, while serving incoming and outgoing data via its data server. For several years the Community Coordinated Modeling Center (CCMC) was administered under the auspices of GTWAPS and enabled the academic, research, and DoD 'community' to test and run space models, the Weather Research and Forecast (WRF) model, and various data assimilation schemes. The Air Force Weather plan was to enable a compressed acquisition of the latest science via useful research grade code to rapidly 'operationalize' improved models. In its continuing evolution this system is taking a necessary step in the engineering of a Collateral Model Processing System (CMPS), which will ingest all standard data sets that the rest of GTWAPS ingests and provide parameterized meteorological data for specific operations *in a classified setting*.

Model runs for 21 theaters worldwide (Figure 3) are run 2- 4 times a day covering most of the globe. Meteorological output from this model are custom tailored to the end-user in a complex post processing system in GTWAPS. Typical MM5 configurations include 40 vertical levels, and horizontal grid spacings of 45, 15, and 5 km, with finer resolution (1.67 km) available for special needs. Boundary conditions are derived from the GFS model, and forecasts are available every 3 hours out to 72 hours, for a 45 km grid forecast. Longwave and shortwave radiation schemes are based on Dudhia (1989), the Grell convective parameterization, Reisner mixed-phase microphysical scheme, MRF PBL and multi-layer soil thermal diffusion parameterization used by most of the configurations. 3DVAR is used for the initialization at present. The finer scale 15 km forecasts are run out to 42 hours. No convective parameterization is used in the 5km and finer models.

In addition to the MM5, a number of specialized models support and comprise GTWAPS and are housed on the GTWAPS Applications Server. Satellite data are integrated to better depict the snow cover with the Snow Depth (SNODEP) module and surface moisture and vegetative characteristics via the Agriculture Meteorological (AGRMET) module. An adaptation of the NOAH Land Surface Model (LSM) has enabled a better coupling of land and oceanic models for a seamless initialization of the earth's surface.

GTWAPS also provides for visualization using the Gridded Analysis and Display System (GRADS). Visualization is also possible for obtaining tailored products using an interactive version of GrADS known as IGrADS. In order to better serve numerous customers of this data, a data trimming scheme has been adopted to remove parameters or portions of geography to tailor data sets to customer needs. This utility has allowed tailored geographical and parameterized data sets to be created and distributed to many disparate users worldwide. A novel concept in model processing employed by this system is the incremental processing and distribution of data sets. Incremental processing has permitted a greater than 50% reduction in time to get global and theater analysis and forecast data into the hands of support personnel, mission planners, and decision makers.

Currently, a transition from MM5 to the newer state of the art Weather Research and Forecast Model (WRF) is in progress. We anticipate that the migration to WRF will be complete late April 2005, with full operational capability. On site research continues with the four-dimensional variational (4DVAR) assimilation scheme. This advanced technique will enable the integration of numerous 'non-standard' weather observations to be integrated into next generation physics models. For the needs in the immediate future, the 3DVAR approach is being adapted for use by WRF. As data from NPOESS and GOES-R come online between 2009 and 2012, we will be expending considerable effort toward exploiting the additional environmental data records and applying these data toward model initiation. Currently, WRF is being run in parallel with MM5. As details are worked out regarding the interface of the model output with the display utilities, AFWA continues to operationally run MM5 over most of the surface area of earth.

4. SATELLITE DATA

Satellite data are processed primarily on two resident systems: the Satellite Data Handling System (SDHS) and Cloud Depiction and Forecast System (CDFS-II). The former primarily displays satellite products (example, Figure 4), but also functions to supply satellite data (processed and raw) to the other component AFWA systems. The latter's primary function is to provide for accurate and timely cloud forecasts and analyses for military needs, globally.

Within the past 12 months, capability has been added within SDHS to ingest and process imagery from the Meteosat 7 and 8 satellites. Imagery processed by SDHS includes visible, infrared, water vapor and multispectral imagery from most polar orbiting and geostationary satellites worldwide. Satellites processed currently include NOAA polar orbiters, the DMSP series, GOES-E and GOES-W, the GMS series (currently the GOES-9 satellite, repositioned over the Pacific), the current Meteosats (5, 7, and 8), giving worldwide coverage.

The primary purpose of CDFS-II is to produce worldwide worldwide merged cloud analyses (WWMCAs) and short range cloud forecasts (SRCFs). Atmospheric Environmental Research Inc developed the primary functionality of CDFS-II, and SEMS personnel sustain the functionality.

With the planning for NPOESS and GOES-R, several engineering studies are focusing on the utility for the new data sources on board this next generation of satellites, and handling the vastly increased volume of data expected due to additional sensors and increased resolution. We anticipate a 2-5 order of magnitude increase in the volume of satellite data processed will result from these enhancements. Accordingly, the ground-based data processing will become more complex within the next 6-10 years. Enhanced monitoring of changes in the earth system will take place. Additional products derived from these satellites used to characterize the earth's surface and other environmental events will present a more complete depiction of conditions at the earth's surface and in the overlying atmosphere.

5. SPACE WEATHER

Within the past 5 years, increased level of effort has been given to the inclusion of a space weather component in depicting environmental conditions for military users of meteorological data. The SWAFS component was a relatively recent add-on to SEMS functionality with the move from Schriever AFB to HQ AFWA, Offutt AFB. Space weather effects include global positioning errors, ionospheric events that affect HF and UHF propagation, optical line of sight, scintillation effects, the effects of solar flares, geomagnetic disturbances, high altitude dosage, auroral clutter (radar interference), and charged particles.

A complex network of ground and space based sensors continually monitor the effects of space weather across the globe. In addition to observations, a dedicated space weather modeling component is integral to SWAFS. These models run on AFWA enclaves managed by SEMS. In the future the CMPS will house the Space Weather Analysis and Forecast System (SWAFS). The result of cooperation between academic, the government and private sector, SWAFS processes include the Parameterized Real-time Ionospheric Specification Model (PRISM), and Global Assimilation of Ionospheric Measurements (GAIM). The PRISM will be replaced by the GAIM model, which is programmed to run on the CMPS also. A portion of SWAFS processes is also run on the Applications Server to include the previously mentioned PRISM and the Ionospheric Forecast Model (IFM).

6. ENVIRONMENTAL DATA AND GIS

Currently sensed environmental hazards are also observed and forecast with present capabilities. These include volcanic plume analyses, environmental dust analyses and transport of dust and volcanic plumes. Both are hazards to aviation and military operations. While these phenomena are normally easily observed using satellite based sensors, they may also be forecast with dispersion models. These dispersion models are integrated with conventional meteorological data to present an accurate and complete 3-dimensional data cube, depicting conditions from the surface of the earth to space.

Display of data is evolving as well, with increased reliance on geographic information systems (GIS) as a basis of integrating geographically based environmental data

7. PRODUCT DISSEMINATION

Data are distributed from the various applications running on the AFWA subsystems to users in several ways including subscription service (WDA), the internet (JAAWIN) and by direct transmission via communications modes such as through satellite feeds. In the past decade, the amount of data ingested, processed and distributed has increased by over an order of magnitude, requiring advances in communications and information processing technology to be implemented as soon as they become available. This trend is expected to not only continue into the future, but to accelerate as new data sources come on line. Aside from the processing systems described above, SEMS has integrated into its enterprise view the subsystems responsible for distributing the data to the end users. SEMS and NGMS personnel are integral in performing the trade studies and ensuing recommendations necessary to take advantage of and incorporate emerging technologies to maintain AFWA's capabilities at the leading edge.

JAAWIN is AFWA's primary web site for meteorological information requests. Averaging approximately 8 million hits per month, JAAWIN provides a one-stop source for METSAT imagery, alphanumeric data, TAFs, lightning / NEXRAD radar data, model visualizations, space weather information, interactive applications, and aviation hazard depictions. As part of the AFWA enterprise, JAAWIN relies heavily upon the other subsystems operating under the AFWA umbrella for raw and processed data to be distributed to Operational Weather Squadrons, Combat Weather Teams, and users in the field and at fixed base operations. The system is available in unclassified, secret and SCI (Sensitive Compartmentalized Information) environments.

8. CURRENT CHALLENGES

SEMS is a partnership between the government and the private sector to sustain, enhance and modernize weather operations at the Air Force Weather Agency. The project covers the five basic steps in weather operations: ingest, process, store, analyze and predict, and disseminate.

SEMS is actively involved in the incorporation of new emerging technologies in order to advance the state of the art in weather support. Currently, we are planning for the next series of meteorological satellites including Meteosat Second Generation (MSG), NPOESS and GOES-R. While MSG has been successfully integrated into our enterprise, NPOESS and GOES-R have been the subject of engineering studies to determine the impacts on and need for future information systems, as well as employing these new data sources to derive novel products for the operational community. We have evaluated the potential use of all of the projected new (and existing) environmental data records expected from the next generation of weather satellites, as NPOESS replaces both the current NOAA polar orbiters, and the DMSP satellites.

In addition, within the current calendar year, we will be transitioning from the current MM5 mesoscale model, to the state-of-the-art Weather Research and Forecast (WRF) model. Integration of the space weather component into the "environmental data cube", provides complete "mud to sun" support for warfighters around the globe, and for mission planning.

Acknowledgments

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FIGURES

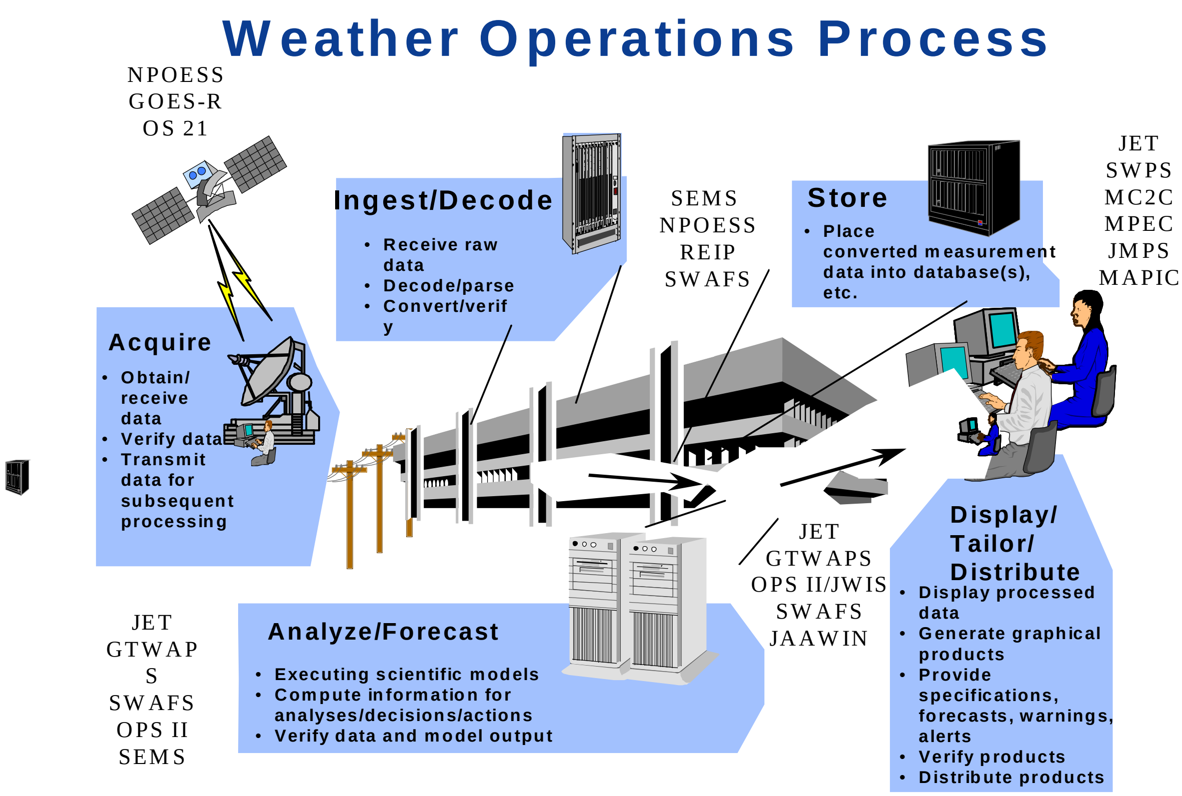

Figure 1: Overview of the weather operations process as it applies to AFWA/SEMS

GTWAPS Configuration (2,773 GFLOPS) – Dec. 2004

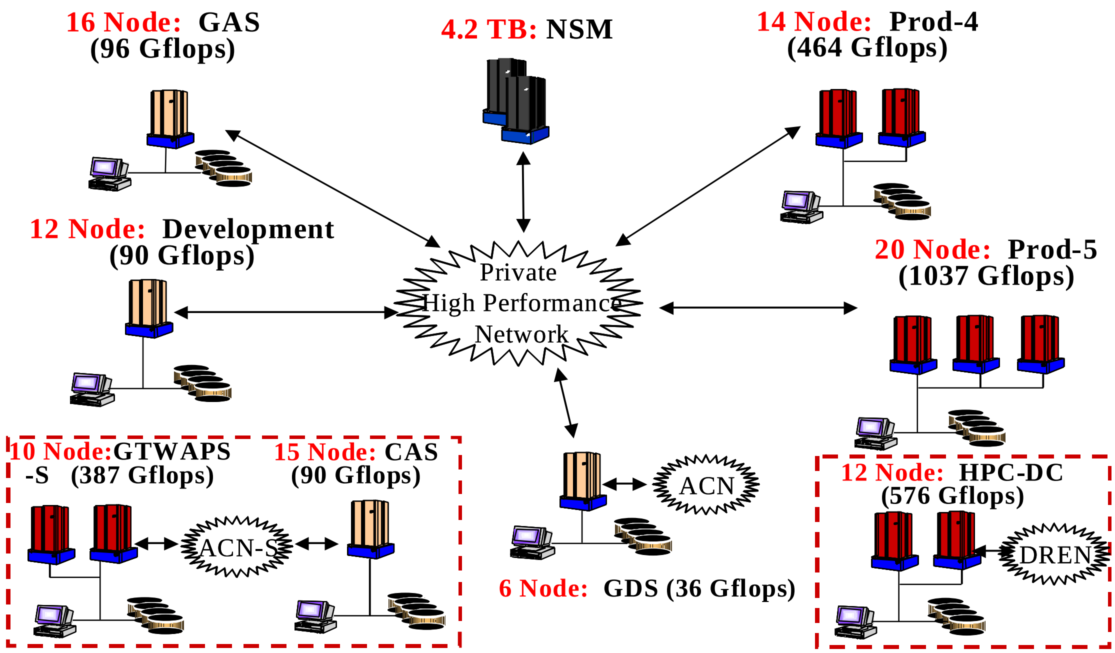

Figure 2: Current GTWAPS hardware configuration

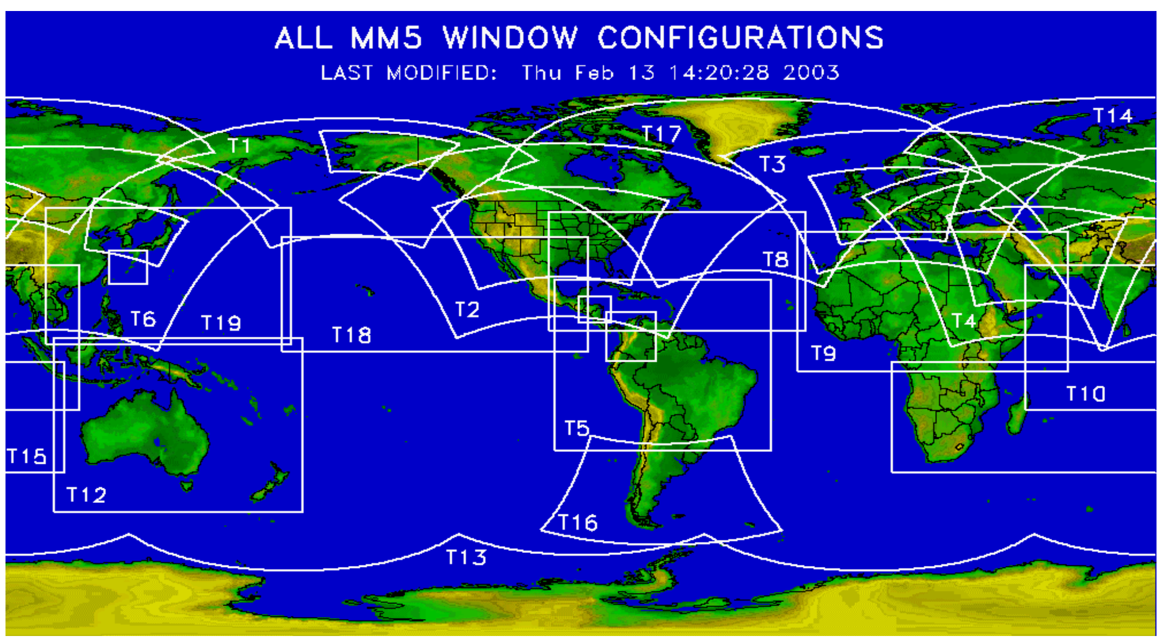

Figure 3: Current GTWAPS modeling configuration showing theaters (domains) with scheduled daily forecast cycles.

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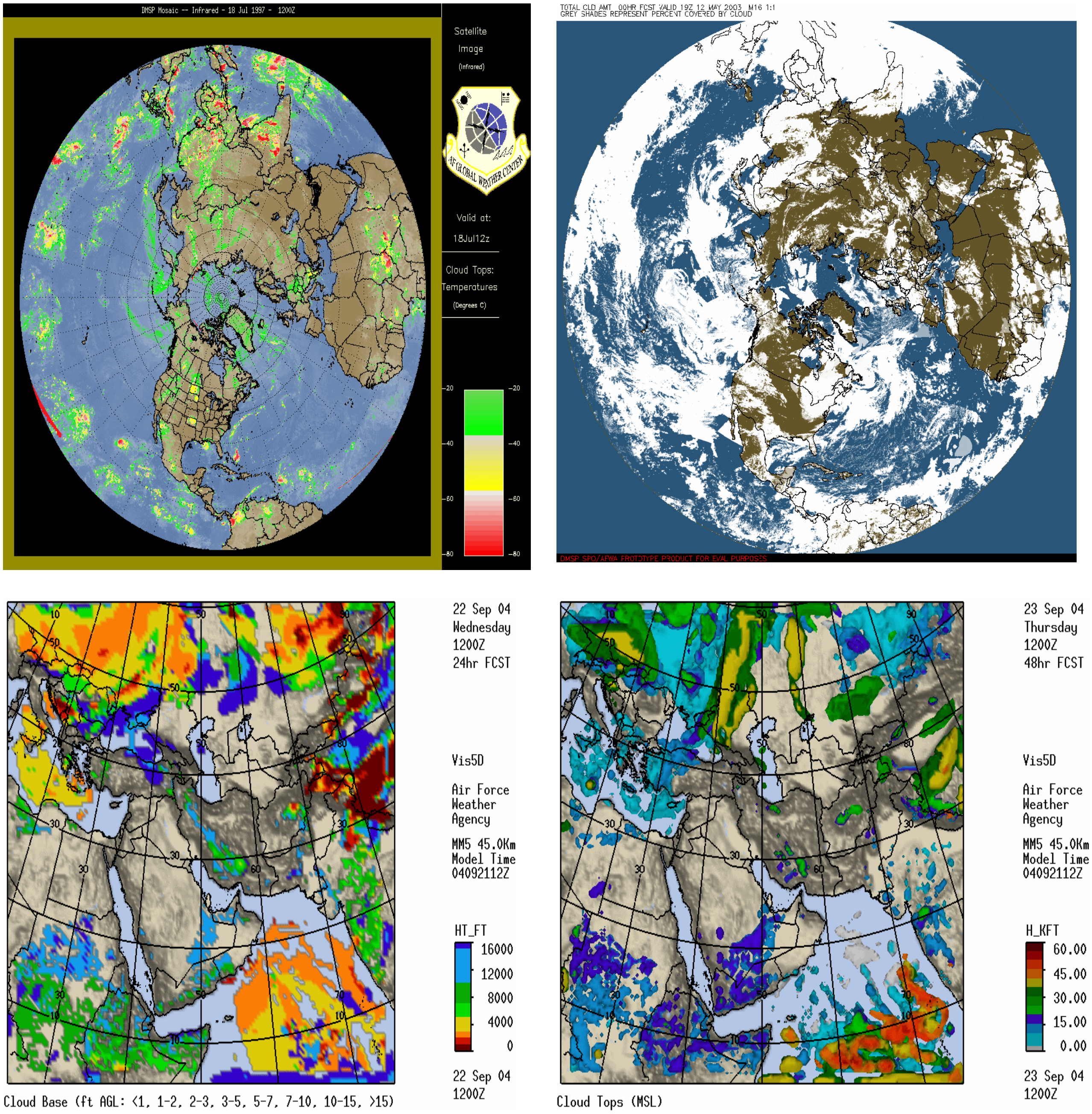

Figure 4: Sample CDFS-II and GTWAPS products. Top left: Colorized cloud top temperature image. Top Right: Worldwide Merged Cloud Analysis (WWMCA) Bottom left: Vis5D image of forecast cloud base from GTWAPS Bottom Right Vis5D image of forecast cloud top from GTWAPS, both of the lower forecast products were derived from MM5 output.