3.2 USES OF SATELLITE DATA IN AIR FORCE WEATHER

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1. INTRODUCTION

Environmental satellite data comprise a vital element of Air Force Weather (AFW) support to U.S. Department of Defense (DoD) and allied military operations. This paper provides an overview of the satellite data types, ingest and processing systems and operational methods used to generate products from satellite data for AFW customers worldwide. Operational applications using satellite data at AFW's strategic data processing centers, at regional weather squadrons, and by weather teams in the field will be discussed.

2. THE NEW AFW ORGANIZATION

The AFW Strategic Plan, approved by the Chief of Staff of the Air Force in August 1997, charted a course which systematically re-engineers AFW's products, processes, organizations, training, and technical tools consistent with the Aerospace Expeditionary Force concept and changes in the broader DoD mission. The end-state AFW structure is based upon a three-tiered concept replacing the legacy decentralized forecast structure at individual bases with a centralized regional forecasting structure. Realignment of weather functions has occurred at all levels (tactical, theater, and strategic).

The resulting operational AFW organization (Fig. 1) consists of Strategic Centers, Operational Weather Squadrons (OWS) and Combat Weather Teams (CWT). Three Strategic Centers accomplish data ingest, processing, and product distribution supporting national programs and global missions. Nine OWSs are aligned with numbered Air Forces and Air Force Major Commands to provide theater-scale forecasting and resource protection functions, and 162+ CWTs support Air Force and Army operators directly by tailoring OWS generated forecasts to meet specific mission needs. Satellite data are heavily employed at all levels in this "forecasting funnel." The following sections highlight some typical applications of satellite data across the spectrum of AFW operations.

3. STRATEGIC CENTER APPLICATIONS

AFW has three Strategic Centers; the primary data processing center is at Headquarters Air Force Weather Agency (AFWA), Offutt AFB, Nebraska; the Air Force Combat Climatology Center (AFCCC) in Asheville, North Carolina; and the Joint Typhoon Warning Center (JTWC) at Pearl Harbor, Hawaii.

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AFWA and JTWC use satellite data as a primary data source for their strategic missions. Both of these centers ingest geosynchronous (GEO) satellite data directly and by retransmission from NESDIS or domestic communication satellite (DOMSAT) relay. AFWA is the primary DoD ingest site for Defense Meteorological Satellite Program (DMSP) data. These data are down linked from recorders on the DMSP satellites to Air Force Satellite Control Network ground stations. The data are relayed to AFWA via DOMSAT. AFWA also ingests National Oceanic and Atmospheric Administration (NOAA) polar orbiting environmental satellite (POES) data through DOMSAT relay. Satellite data paths into AFWA are shown in Fig. 2. JTWC has the ability to ingest DMSP and POES data in real-time using the Small Tactical Terminal (STT) and Mark IV field systems.

Although the AFCCC does not use satellite data directly in its operations, they do incorporate satellite soundings and derived analyses of global clouds and soil moisture into their comprehensive global climatological databases. These derived products are created at AFWA and transmitted to AFCCC.

3.1 Data Ingest, Processing and Distribution

AFWA is able to ingest six GEO and eight combined DMSP and POES data streams through its Satellite Data Handling System (SDHS) ingest subsystem. Fig. 3 shows ingest and processing data flows and operational applications that use satellite data at AFWA. During ingest, calibration and earth-curvature correction algorithms are applied as required and the satellite data are stored in the AFWA satellite databases as images and in "simple" format. Data are available to users from the satellite database via manual or automated retrievals within just a few minutes of ingest.

The Weather Product Management and Distribution System (WPMDS) at AFWA transmits Defense Meteorological Satellite Program (DMSP) data to the Fleet Numerical Meteorological and Oceanographic Center (FNMOC) and to the National Environmental Satellite Data and Information Service (NESDIS) for satellite sounding generation via high speed ATM connections. DMSP data are also provided to the National Geophysical Data Center (NGDC) for long-term archiving. AFWA ingests various research data streams in pseudo real-time via the WPMDS, including TRMM, QuickSCAT, and MODIS. These data flows are shown in the lower-left corner of Fig. 3.

Generation of automated products from satellite data consumes a major portion of AFWA's computing resources. Product lines include worldwide and target-scale cloud analyses and forecasts, user-tailored enhancement and animation of imagery, space weather analyses and forecasts, tropical cyclone intensity estimates, troposphere wind estimates derived from GEO imagery feature tracking, and analyses and forecasts of volcanic ash plumes. Numerous environmental data records (EDRs) are also automatically generated using data from the DMSP Special Sensor Microwave/Imager (SSM/I). These include soil moisture, snow depth, surface temperatures, vertical temperature and moisture profiles, sea-surface wind speeds, and many more. The myriad AFWA processing applications and user outputs is shown on the right side of Fig 3.

3.2 *Human Interactive Analysis*

AFW Meteorologists rely heavily upon human interactive analysis of satellite imagery in their production processes. Such hands-on analysis is especially important to the tropical storm analysis, and forecasting functions at AFWA and JTWC, and AFWA's severe weather forecasting and cloud analysis bogus functions. Human interactive analysis at AFWA and JTWC is done primarily on Satellite Imagery Display and Analysis System (SIDAS). JTWC also uses the STT and Mark IV systems.

A screen shot of the SIDAS interface is shown in Fig. 4. The SIDAS can utilize any of the satellite data available in the AFWA satellite databases plus data from other satellites such as TRMM and QuickSCAT (McCrone, 2001). The SIDAS includes robust tools for image display, enhancement, animation, multi-channel mosaics, tropical cyclone intensity estimation, as well as plotting of observations and model output over satellite images, and plotting derived profiles. Holliday and Conner (2001) provide an in-depth description of existing SIDAS capabilities and planned enhancements.

3.3 Modeling Applications

Many operational modeling applications at AFWA use satellite data as primary inputs; most notably, the global cloud analyses and forecasts. Currently these are produced by the legacy Cloud Depiction and Forecasting System (CDFS) running on a Unisys mainframe. CDFS produces gridded cloud analyses at 25 n mi horizontal resolution with five vertical cloud layers. Input data to the legacy CDFS come only from DMSP and POES, which can introduce significant latency problems into the resultant analysis over portions of the globe. Cloud forecasts are done using an advective cloud model (ADVCLD) that produces forecasts out to 48 hours (McDonald, et. al., 2001).

By the end of 2001 a major upgrade to the CDFS, known simply as CDFS II, becomes operational. It will provide hourly global cloud analyses at 12 n mi horizontal resolution incorporating data from all GEO and POES in the AFWA satellite databases. Fig. 5 provides a functional view of the CDFS II. Through a series of complex processing steps incorporating advanced cloud analysis algorithms (Gustafson and Pesuzza, 2001), cloud gridded data records (GDRs) are produced for each class of satellite (DMSP, POES, GEO) and combined into an hourly worldwide merged cloud analysis. This product is manual quality controlled via the human interactive analysis tools described earlier Output products from CDFS II will support national programs, as well as mission planning and execution across the spectrum of military operations.

In the late 1990s AFWA developed a proof-of-concept target-scale cloud analysis and forecasting prototype to satisfy combat mission needs during operation "Allied Force" in Serbia. This system uses 3 n mi resolution DMSP "fine" imagery data as input to the CDFS II cloud analysis algorithms. The resultant high-resolution gridded cloud analysis is input to the ADVCLD model along with wind forecasts from AFWA's MM5 fine-scale model to generate target-scale cloud forecasts out to 30 hours (Fig. 6).

Satellite data provide critical input to several other AFWA analysis and forecast models. Derived soundings are assimilated into the MM5 fine-scale forecasting system using a multi-variant optimal interpolation scheme (Ritz, et. al., 2001). Special Sensor Microwave/Imager (SSM/I) data and worldwide GEO imagery are used in the Land Surface Model to specify precipitation rates, soil moisture content, vegetation conditions as well as snow depth and snow water content. Specially enhanced GEO, DMSP, and POES infrared imagery are used to establish initial plume conditions for driving the ash dispersion model "PUFF". Finally, data from the various DMSP and GEO space environment sensors feed AFW's space weather analysis and forecasting models.

3.4 Shared Data Processing

AFWA partners with other national processing centers through the Shared Processing Program (SPP) to help distribute its tremendous data processing volume. The SPP is comprised of AFWA, NESDIS, the National Centers for Environmental Prediction (NCEP), the Naval Oceanographic Office (NAVO), and FNMOC and is overseen by the Office of the Federal Coordinator for Meteorology. The SPP concept allows each center to focus effort, fiscal and computing resources toward generation of products for which it is identified as the lead center.

AFWA is the lead center for visible and infrared imagery, global cloud analysis, and land surface modeling. Under the SPP, AFWA provides DMSP data to NESDIS and FNMOC, and global cloud analyses along with land surface model output to NCEP. AFWA receives derived satellite soundings from NESDIS; satellite sea surface temperature analyses from NAVOCEANO; global model forecasts from FNMOC, and all NCEP global and regional forecast model data.

4. FIELD APPLICATIONS

AFW's nine OWSs provide theater level weather support. Fig. 7 shows where OWSs are located in the world and their parent Numbered Air Force or Major Command. The four continental U.S. (CONUS) OWSs also provide forecasts and resource protection warnings for their CONUS AORs. Specialized OWS-like forecasting centers are located at Vandenberg AFB, CA and Patrick AFB, FL to provide space launch support.

There are 162+ CWTs distributed worldwide providing tailored support to DoD at the tactical level. At the OWS and CWT primary operational applications of satellite data involves human interactive analysis similar to what is done at AFWA and JTWC. There is some limited automated production of satellite imagery visualizations for dissemination via web pages. Products generated by AFWA from satellite data (cloud analyses/forecasts, soundings, LSM output, etc.) are applied to theater level forecasting at the OWS and tailored for specific missions by the CWTs.

The human interactive analysis done at OWSs is accomplished on the OWS Production System (OPS). The OPS is based on a server-client architecture that incorporates the LEADS as it's primary forecaster interface. Fig. 8 depicts a typical OPS configuration. Data inputs/outputs to/from the OPS occur via the unclassified military Internet (NIPRNET) and classified counterpart (SIPRNET), Very Small Aperture Terminal (VSAT) satellite broadcasts, and various dedicated circuits. Satellite data are ingested at OWSs via an STT (Fig. 9) or Mark IV system (Fig. 10), either of which can be networked into the broader OPS system for data sharing and merged product creation.

At CWTs GEO, DMSP and POES satellite data are ingested directly with STTs. STTs are robust, fully deployable systems consisting of multiple fixed and tracking antennae, a primary processing computer and a data processing/display system. Experienced troops can establish a working STT configuration in the field in less than 30 minutes. The VSAT broadcasts from AFWA and OWSs also contain satellite imagery and satellite derived products and model output to support the CWT forecasting and product tailoring mission.

5. LOOKING TO THE FUTURE

AFW's mission will continue demanding real-time access to the ever-increasing suite of satellite data from U.S., foreign and commercial environmental satellites. In the near term, AFW is preparing to operationally integrate data from the new Special Sensor Microwave Imager/Sounder (SSMI/S) when DMSP Flight 16 becomes operational late this year. SSMI/S will provide data needed to generate more and higher quality EDRs for DoD mission support. See Kopp (2001) for an overview of SSMI/S processing at AFWA.

As a member of the tri-agency National Polar Orbiting Environmental Satellite System (NPOESS) program, AFW is actively involved in the ongoing NPOESS acquisition efforts. Incorporation of the NPOESS data into AFWA's production process will increase the amount of satellite data processed and disseminated by roughly three orders of magnitude. When added to other expected increases in GEO and non-traditional meteorological satellite data, AFWA is anticipating a satellite data growth of 10 orders of magnitude by 2010. In preparation for this "data deluge," AFWA has embarked on a major database, processing system, and communications infrastructure modernization and expansion effort known as the Re-engineered Enterprise Infrastructure Program.

On the deployed front, more effective field satellite data processing capability will result from the Joint MetSat Ingest and Support Terminal (JMIST). JMIST will merge and enhance the capabilities of the STT, Mark IV and SIDAS into an AFW standard satellite ingest, processing, and display system for use at all tiers within the AFW enterprise.

6. ACKNOWLEDGEMENTS

The author acknowledges the many contributions from AFWA's technical staff toward this paper and the accompanying presentation. Special thanks go to Mr. Francis Bieker, Dr. Charles Holliday, Capt. Scott Hausman, Dr. Thomas Kopp, Capt. Darryl Leon, Mr. Paul McCrone, Dr. David McDonald, Mr. Michael Moore, Mr. Joe Nolin, and Mr. Richard Ritz for their contributions.

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Ritz, R. L., M. D. McAtee and R. T. Swanson, Jr., 2001: Data assimilation at Air Force Weather Agency. *14th Conference on Numerical Weather Prediction*, American Meteorological Society.

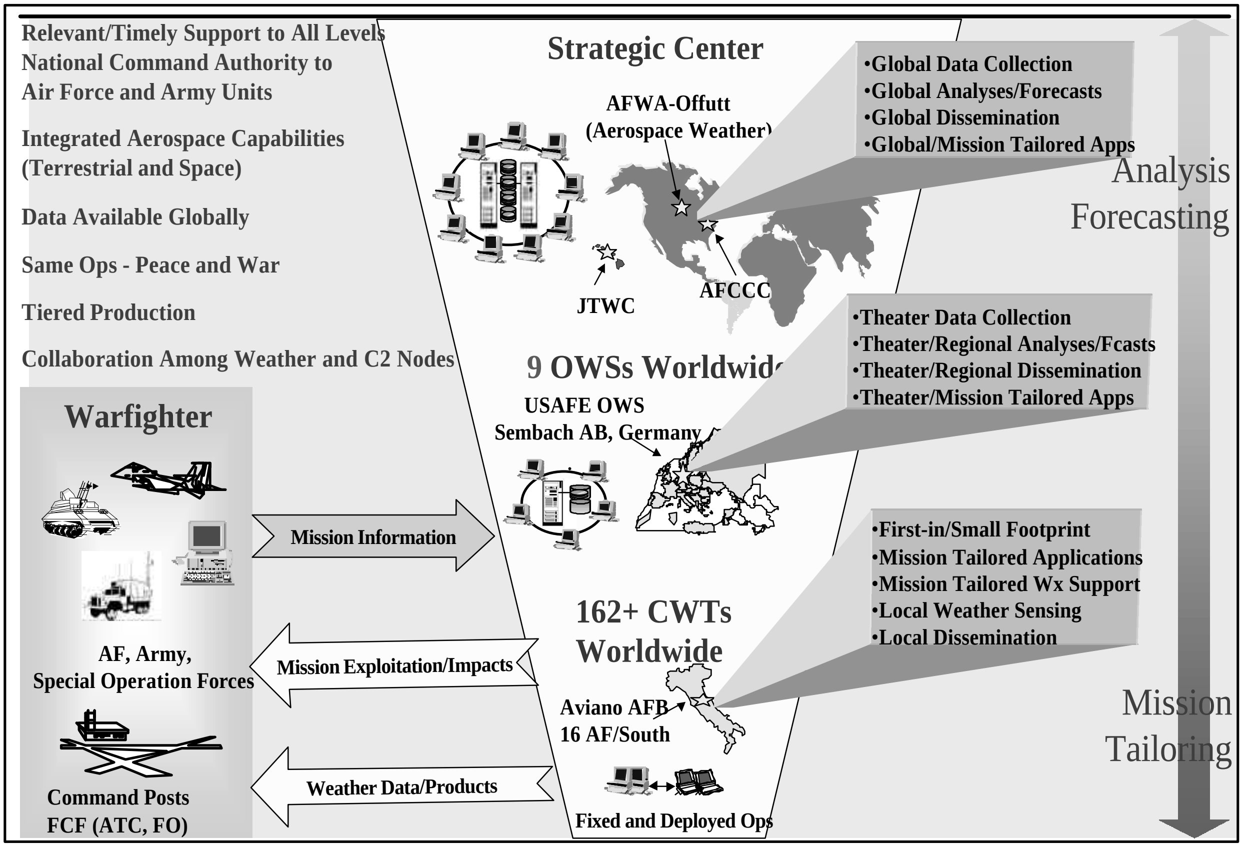

Figure 1. Air Force Weather organizational structure.

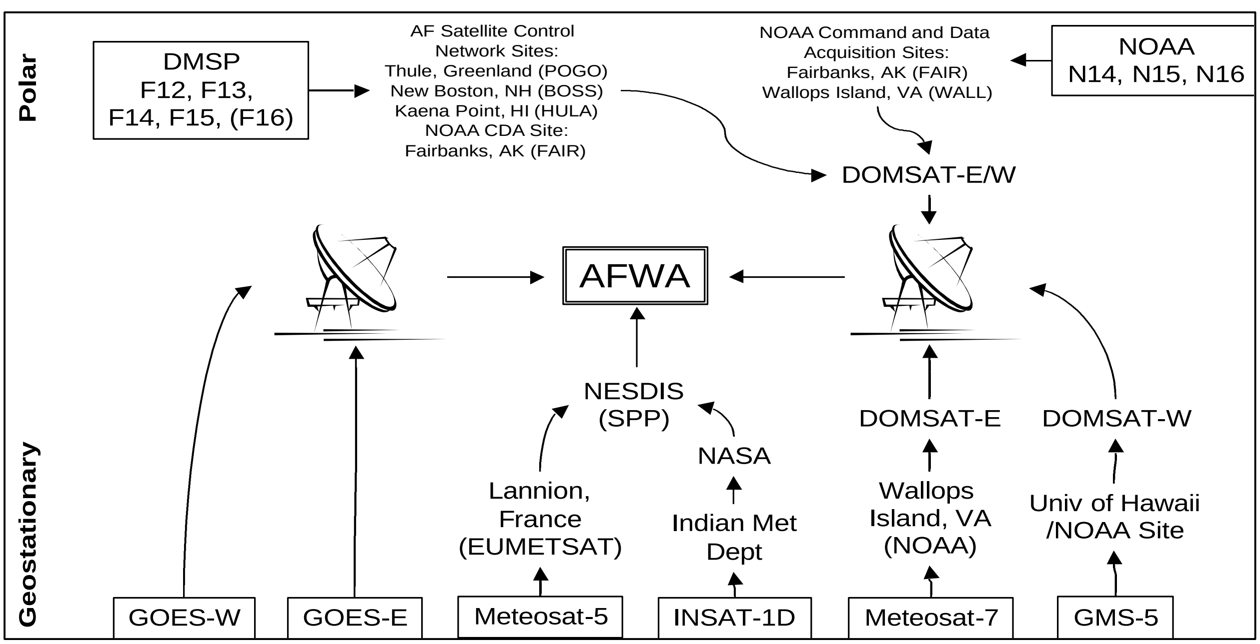

Figure 2. Satellite data ingest at HQ AFWA.

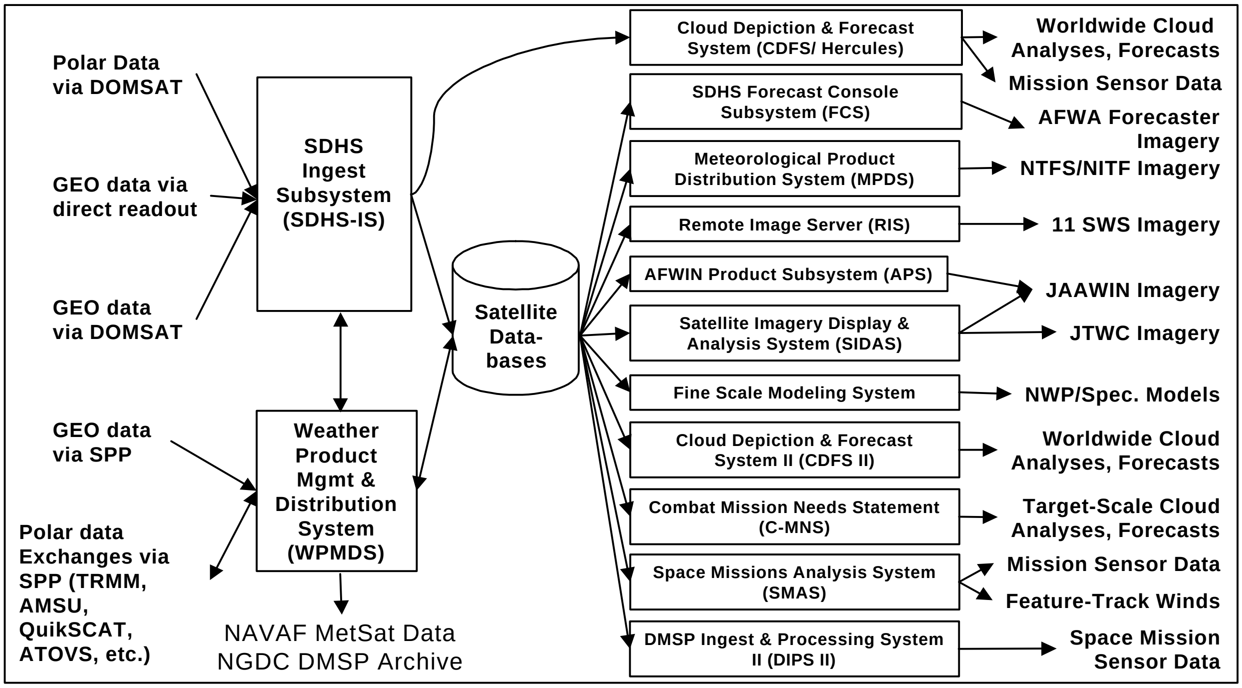

Figure 3. AFWA Strategic Center satellite data flow, processing applications, and product users.

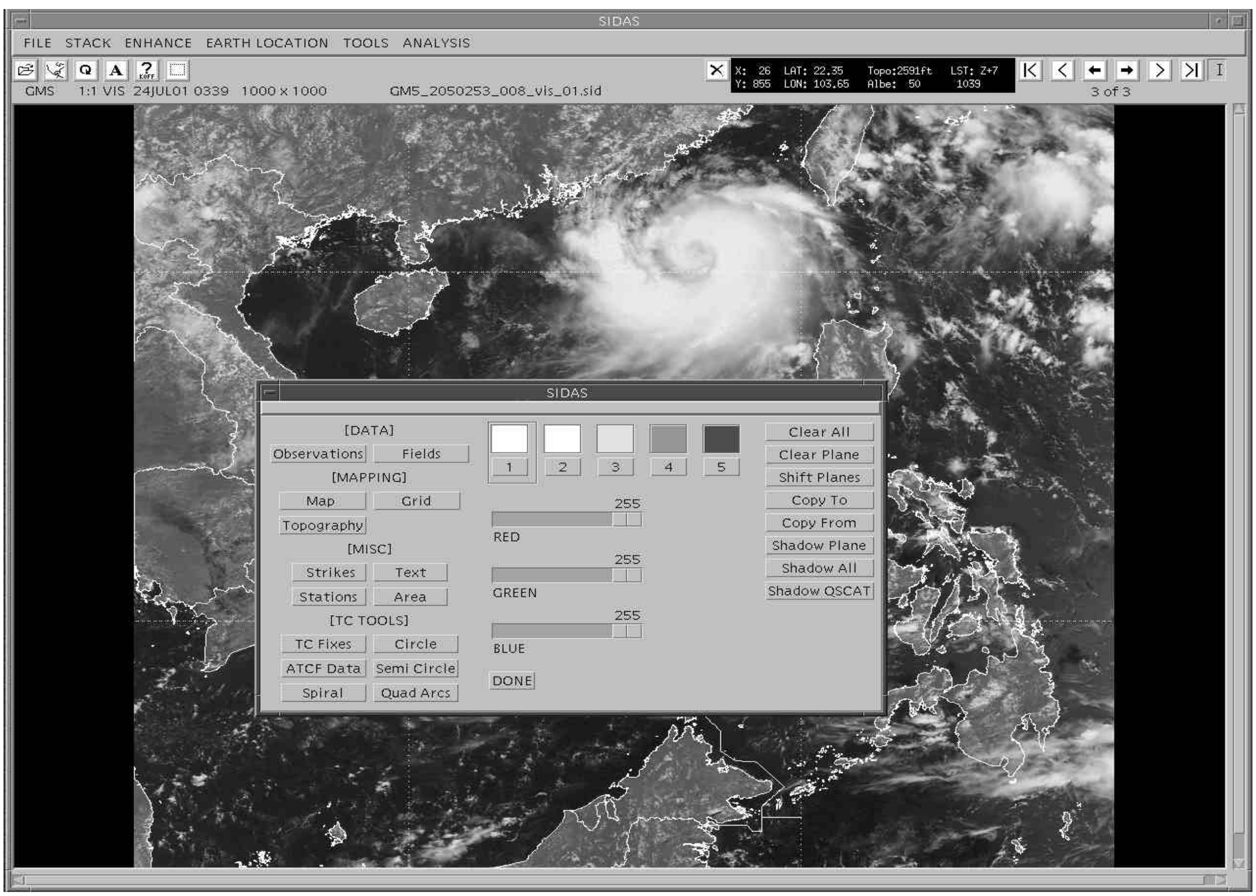

Figure 4. Screen shot from the Satellite Imagery Display and Analysis System (SIDAS).

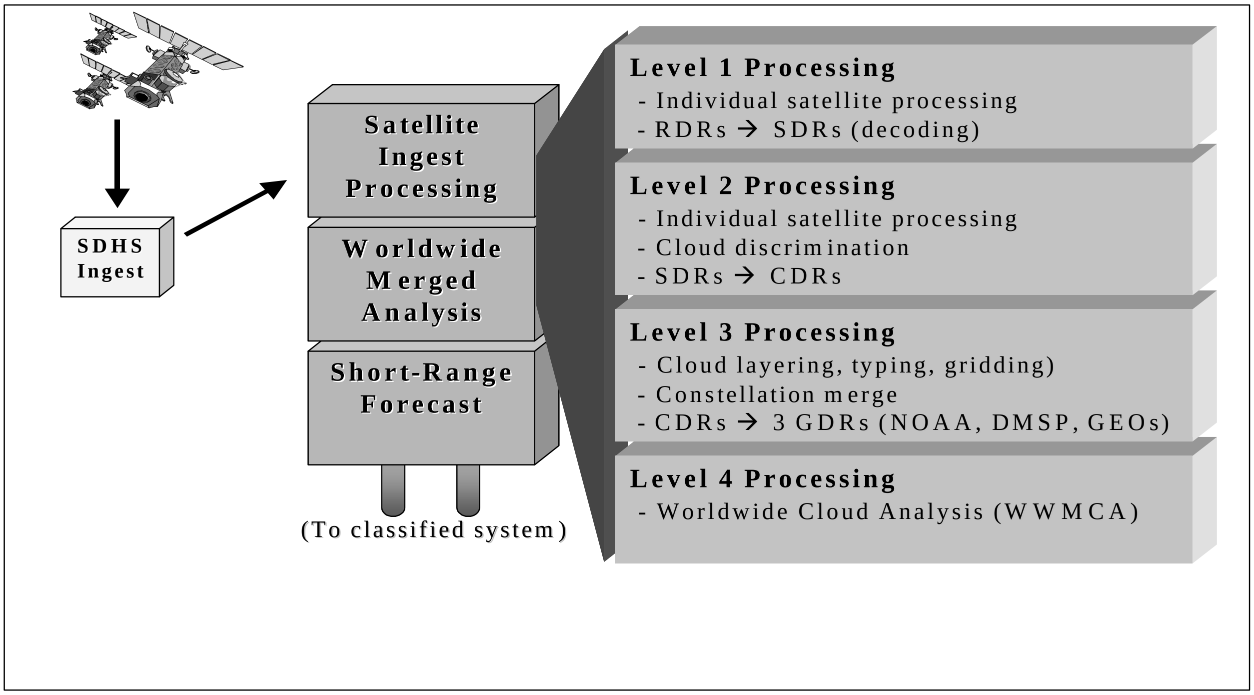

Figure 5. Cloud Depiction and Forecasting System (CDFS) II Functional Diagram.

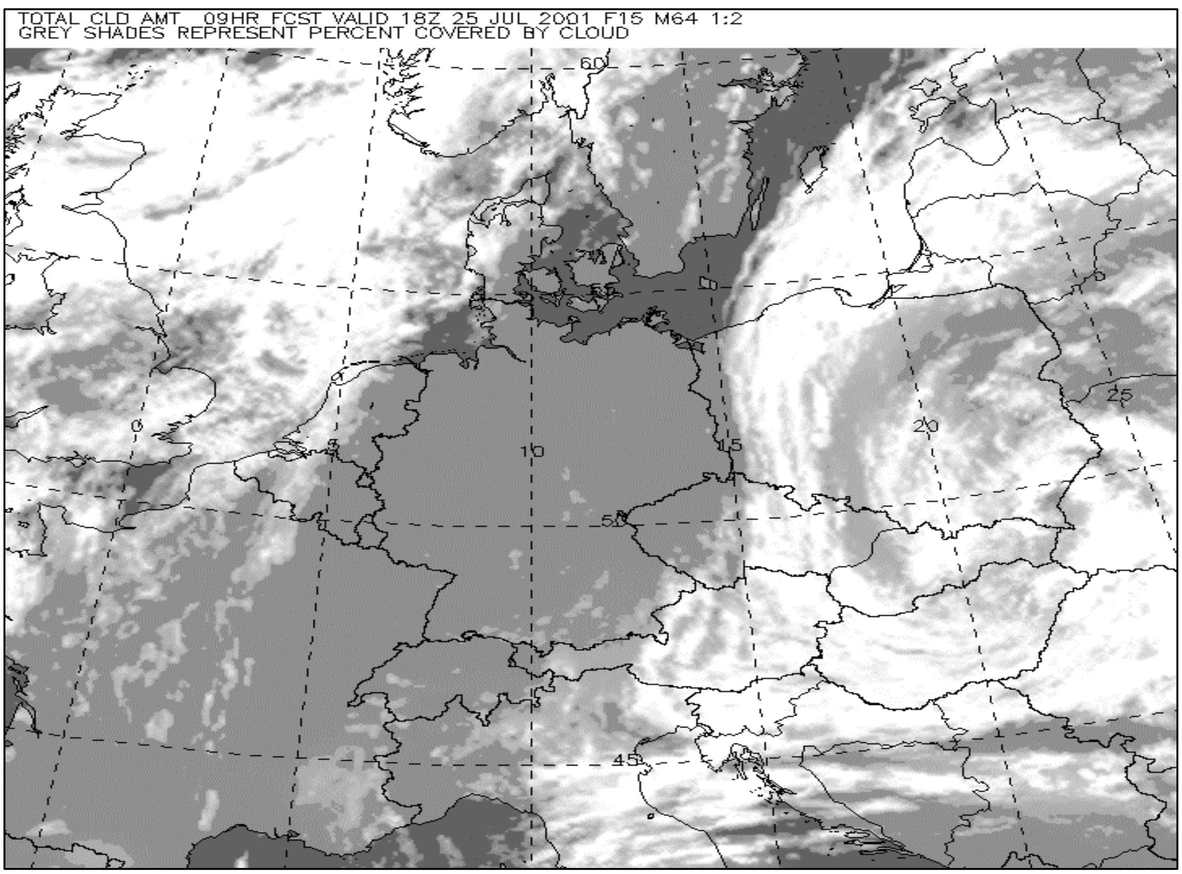

Figure 6. Nine-hour total cloud amount forecast based upon DMSP F-15 fine resolution imagery. Created using AFWA 64th-mesh (3 nautical mile) cloud analysis/forecasting prototype.

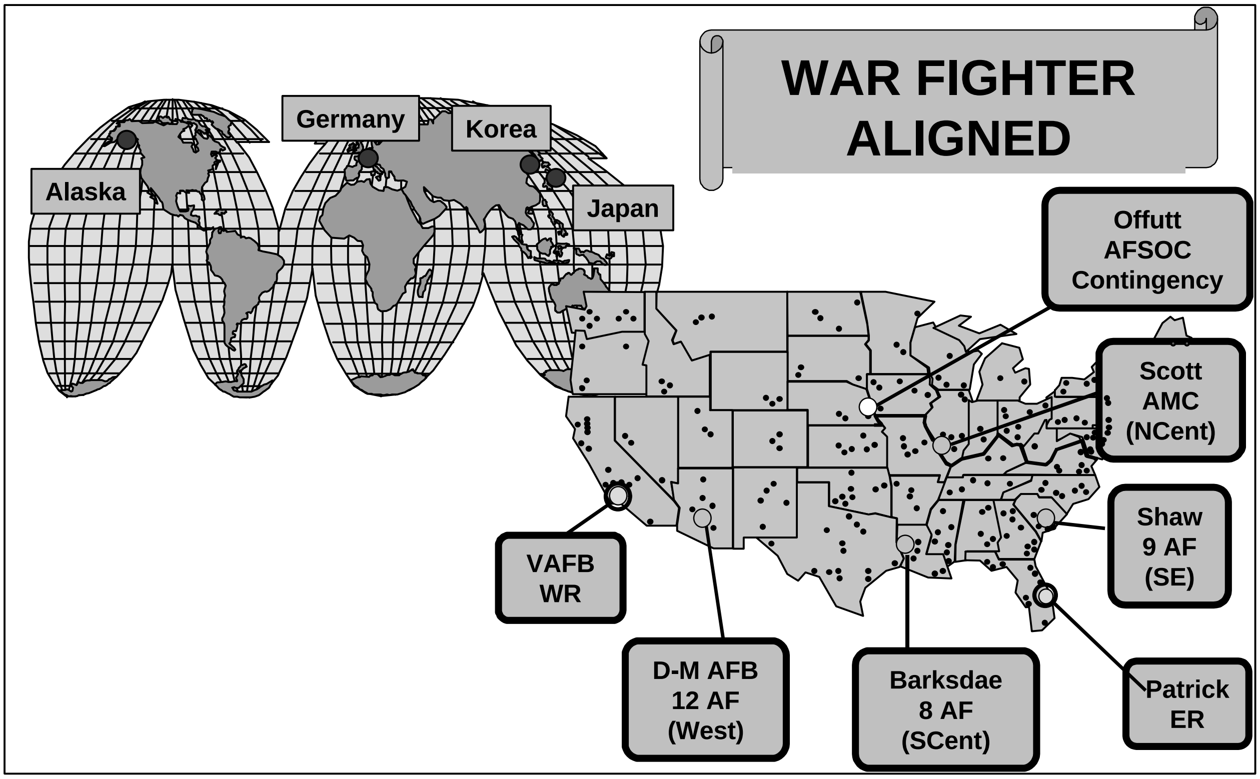

Figure 7. Worldwide Operational Weather Squadron (OWS) locations. Numbered Air Forces and Major Commands supported are indicated. For CONUS OWSs AORs are listed in parentheses.

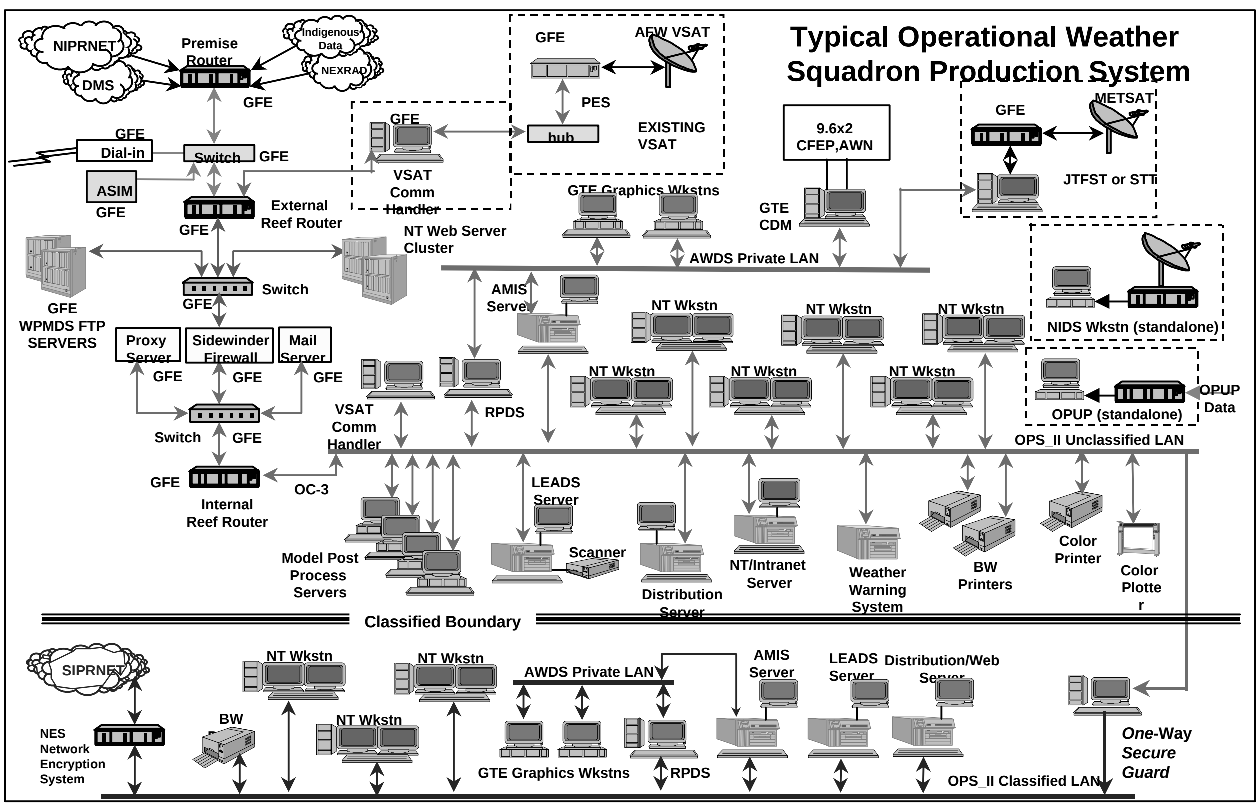

Figure 8. Typical Operation Weather Squadron Production System (OPS) architecture.

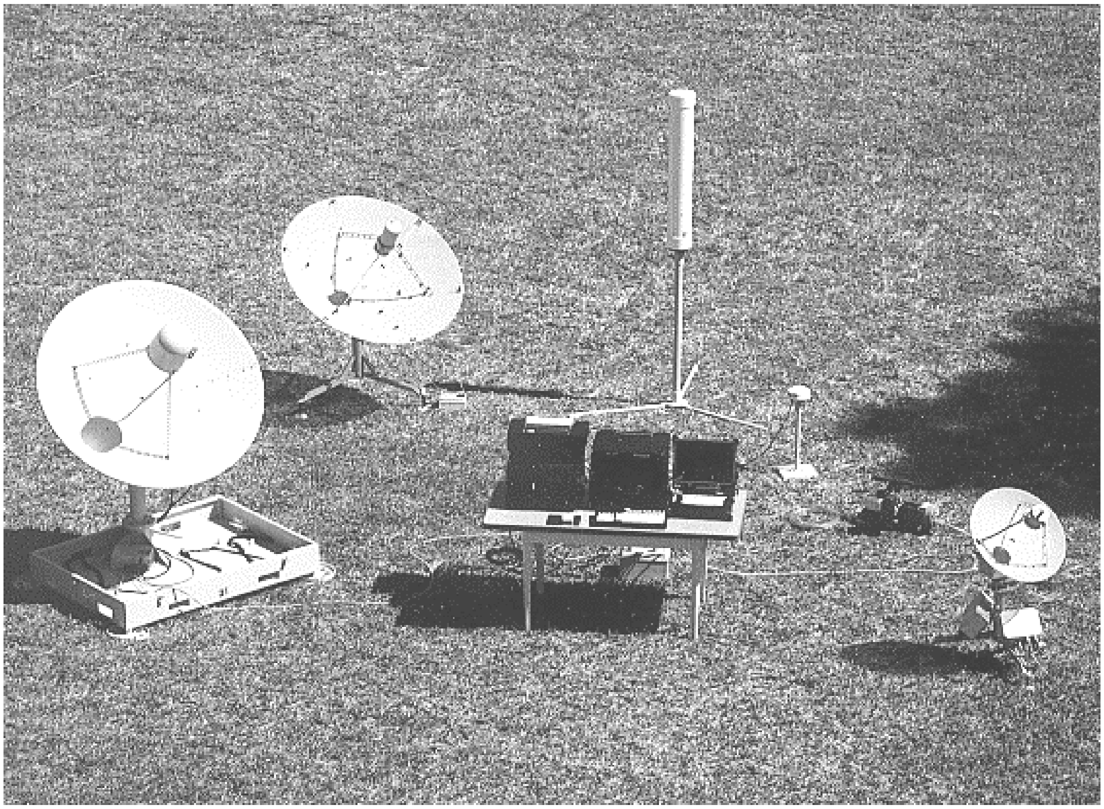

Figure 9. Enhanced Small Tactical Terminal (STT) system.

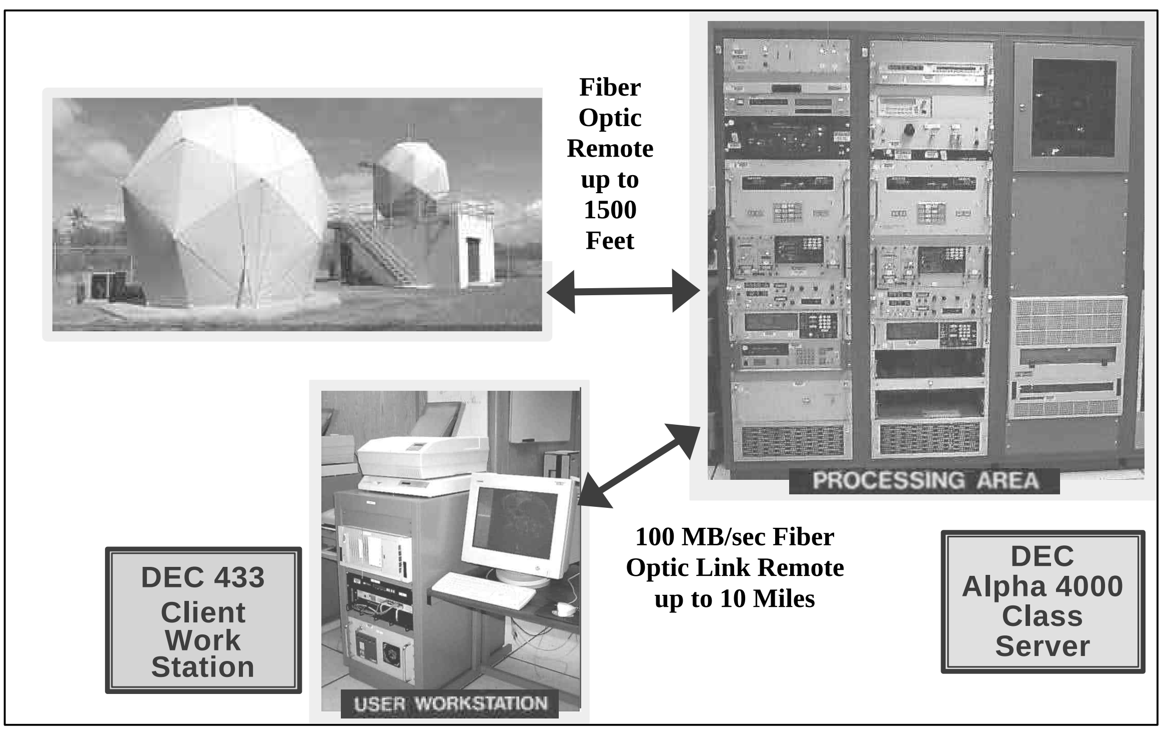

Figure 10. Mark IV system.