2.2 USE OF EOS DATA IN AWIPS FOR WEATHER FORECASTING

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1. INTRODUCTION

Operational weather forecasting relies heavily on real-time weather observations and modeling products for forecast preparation and dissemination of significant weather information to the public. The synthesis of this information (observations and model products) by the meteorologist is facilitated by a decision support system to display and integrate the information in a useful fashion. For the NWS this system is called Advanced Weather Interactive Processing System (AWIPS). Over the last few years NASA has launched a series of new Earth Observation Satellites (EOS) for climate monitoring that include several instruments that provide high-resolution measurements of atmospheric and surface features important for weather forecasting and analysis. The key to the utilization of these unique new measurements by the NWS is the real-time integration of the EOS data into the AWIPS system. This is currently being done at several of the Southern Region (SR) Weather Forecast Offices (WFOs) under the NASA Short-term Prediction Research and Transition (SPoRT) Program. NASA's SPoRT Center is located at the National Space Science and Technology Center (NSSTC) in Huntsville, Alabama that also houses the Huntsville (HUN) WFO (Lapenta et al. 2004; Goodman et al. 2004). The mission of the SPoRT Center is to accelerate the infusion of NASA Earth Science Enterprise observations, data assimilation and modeling research into NWS forecast operations and decision-making at regional and local levels (http://wwwghcc.msfc.nasa.gov/sport/). The principal focus is on research and transition activities emphasizing forecast improvements over the 0-24h period on the regional scale. The research concentrates on the integration of satellite data into operations, the use of regional forecast models and satellite data assimilation techniques to provide better short term weather guidance, and to use local lightning network data and high resolution imagery to improve the nowcasting of convective weather and provide a reduction in the lead time for severe thunderstorm warnings.

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This paper describes the use of near real-time EOS observations in AWIPS to improve the detection of clouds and fog, moisture variations, atmospheric stability, and thermal signatures that can lead to significant weather development. The SPoRT Center serves as a "testbed" for new products and capabilities and facilitates the transfer of these capabilities to the local WFOs. The HUN WFO has evaluated the utility of selected EOS products over a period of several months during the summer of 2003. The results of this assessment and a few example case studies are presented below.

2. BACKGROUND

2.1 The SPORT Center

The NASA Short-term Prediction Research and Transition (SPoRT) Center seeks to accelerate the infusion of NASA earth science observations, data assimilation and modeling research into NWS forecast operations and decision-making. The SPoRT Center was established in 2002 at NASA's Global Hydrology and Climate Center (GHCC) (part of the Marshall Space Flight Center). Shortly after its formation, a new NWS Forecast Office was opened to support weather forecast requirements in northern Alabama. The Huntsville NWS Forecast Office is collocated with NASA GHCC (both of which are housed in the National Space Science and Technology Center building), which provides a unique arrangement for collaborative interactions between these two government organizations.

Research activities during the first year focused on identifying unique forecasting problems of the local WFO that could potentially benefit from the infusion of unique NASA data, technologies, and scientific research. Working with the local WFO and other forecasters in the NWS Southern Region (Darden et al., 2002), three major forecast issues were identified; convective initiation, Quantitative Precipitation Forecasting (QPF), and aviation. The research of the SPoRT program concentrated on these forecast problems.

2.2 MODIS data in AWIPS

The Moderate Resolution Imaging Spectroradiometer (MODIS) is a 36 channel cross track scanner on NASA's Terra and Aqua polar orbiting satellites (King et al. 1992). Each satellite is in a sun-synchronous, nearly polar orbit, and provides global coverage every 1-2 days. The Terra satellite has an equatorial crossing time of 10:30am/pm (descending/ascending), while the afternoon Aqua satellite has a crossing time of 1:30pm/am (ascending/ descending). The polar orbits and the continuous collection of MODIS data around the globe provide imagery at a minimum of 4 times per day for a given region. The swath width of the scanner is 2330km and the ground instantaneous field of view (ifov) varies from 250m for the visible channels to 1000m for the infrared ones. MODIS was designed to collect a wide variety of information on the Earth's land, ocean, and atmosphere to monitor the global climate system. The MODIS science team, in support of various climate applications and research studies, has derived a host of science products for the entire MODIS data period.

MODIS data is available to the scientific community from several sources. All of the Level 1B (calibrated radiance data) and Level 2 & 3 derived and remapped products are available from NASA's archive system (http://daac.gsfc.nasa.gov). Real-time Level 1B radiance data is also available from a number of direct broadcast ground stations throughout the world (http://rsd.gsfc.nasa.gov/eosdb/). Some sites, such as the University of Wisconsin's (UW) Space Science and Engineering Center, not only ingest the real-time MODIS data but also use the EOS science team algorithms to produce near real-time Level 2 products. The SPoRT program gets its L1B and selected Level 2 science products from the UW Direct Broadcast (DB) site via a McIDAS ADDE server. This capability allows for the real-time subsetting of the large MODIS Level 1B data files (by channel and/or region of coverage) for faster data transfers.

Table 1 presents a list of MODIS data and products currently available at several WFOs in the Southern Region. The MODIS data is obtained by SPoRT from the UW DB system. Level 1b radiances are processed for various channels and sectored into the local, state, regional, and CONUS sectors used by AWIPS at each WFO. The atmospheric and cloud products such as total precipitable water (TPW), Lifted index (LI), cloud phase, height, and mask (Seeman et al. 2003), are obtained from the UW as well. These products are produced at the DB facility using EOS atmospheric science team algorithms. The resulting near real-time data is quite similar in quality to the archived EOS products available from the NASA online archive system. Additional products (color composite, LST, SST, and fog product) are created locally at the SPoRT Center. All of the L2 products are sectored (as with the radiance data), put into a NetCDF file format compatible with AWIPS, and sent to the SR server for dissemination to local forecast offices. Local offices issue ftp requests to obtain the desired EOS data and products. Timeliness of the data is important in the use of EOS data in the forecast process. Currently, the EOS L1B data from the UW DB is available to the SPoRT Center within 45 minutes of collection. All other products are available to AWIPS within 30 minutes of receipt of the L1B data at the SPoRT Center. The time delays are currently being reduced through software optimization procedures.

3. EOS DATA APPLICATIONS IN AWIPS

3.1 Image examples

The high spatial and spectral resolution of MODIS imagery allows for a variety of uses in the forecast preparation process. The visible and infrared imagery can be used like GOES data to provide a conceptual understanding of the role of surface and atmospheric features in driving current weather conditions (temperature, moisture variations, winds, etc.). Although the continuous evolution of these features is not captured as it is with GOES data, the high resolution (250m in the visible and 1000m in the infrared channels) provides a more detailed view of clouds, smoke, and atmospheric features as well as surface land use, vegetation and terrain variations, and the surface thermal structure over the land and coastal water regions.

Figure 1 provides an example of the utility of this high resolution MODIS imagery to identify tornado damage tracks. A series of tornadoes traveled through southeastern Missouri in the late afternoon on April 24, 2002. The left-hand image in Figure 1 shows the land surface structure identified by the 250m resolution MODIS imagery on the preceding day (April 23). Numerous land features are evident corresponding to roads, towns, rivers, etc. The MODIS visible image on the right shows the same region the day after the severe storms. Several linear features are readily apparent in the image that have no correlation to the surface features observed two days before. These west-to-east orientated linear features correspond to tornado track positions noted in the storm reports.

The additional spectral channels of MODIS (over that of other operational polar or geostationary satellites) allows for the derivation of unique products that can aid in weather forecasting. Detailed cloud information (at 1-5km resolution) such as type, height, and phase (ice, water, or mixed) provide information that is not normally available to the forecaster. This cloud information can provide insight into upcoming changes in visibility and other aviation related conditions.

The NWS currently uses GOES data to monitor the development of fog and low clouds that may also affect visibility. The night time fog product ($11\mu m$ - $3.9\mu m$ channels) derived from MODIS data provides an enhanced diagnostic and forecast tool with significantly better resolution and fidelity than the GOES product. An example of the MODIS fog product (displayed in the AWIPS D2D analysis package) is presented in Figure 2 for the nighttime pass of the Aqua satellite at 0728UTC

PARAMETER	RESOLUTION	SOURCE	DESCRIPTION
RADIANCES			
Band 1 (0.62-0.67μm)	**250m**	**UW DB**	**Visible channel**
Band 22 (3.96μm)	**1000m**	**UW DB**	**Reflected solar, fires, emissivity**
Band 27 (6.7μm)	**1000m**	**UW DB**	**Mid-troposphere water vapor**
Band 31 (11.0μm)	**1000m**	**UW DB**	**Thermal window**
Band 32 (12.0μm)	**1000m**	**UW DB**	**Thermal window (dirty)**
PRODUCTS			
Natural color image	**500m**	**SPoRT**	**Combination of bands 1, 3, and 4**
Precipitable water	**1km / 5km**	**SPoRT & UW DB**	**Total column integrated water vapor**
Lifted Index	**5km**	**UW DB**	**Stability, severe weather potential**
Cloud mask	**1000m**	**UW DB**	**Confidence level for cloud detection**
Cloud height	**5km**	**UW DB**	**Cloud top pressure (mb)**
Cloud phase	**5km**	**UW DB**	**Ice, water, or mixed**
Cirrus product	**1000m**	**UW DB**	**Band 31 - 32 with enhancement**
Fog product	**1000m**	**SPoRT**	**Band 31 - 22 with enhancement**
LST/SST	**1000m**	**SPoRT**	**Physical algorithm**

Table 1. MODIS data available in AWIPS. The source of the data is from the University of Wisconsin's Direct Broadcast system (UW DB). Some products are generated at the SPoRT Center using in-house algorithms (SPoRT).

on August 14, 2003. The robust calibration and precision of the MODIS data allows for the preservation of subtle variations in the difference image not seen in the GOES product. Special enhancements bring out these features in the AWIPS display.

Three of the MODIS high-resolution channels span the visible portion of the infrared spectrum allowing for the reconstruction of a "natural" color image of the surface. These three-band color composite images are available in AWIPS at 500m resolution. The image processing techniques used to optimize the information about the surface in these three bands also enhances atmospheric features such as clouds, haze, and smoke. Figure 3 presents an example of the three-channel color composite image (top picture) from an Aqua MODIS pass on March 24, 2003. In addition to the wide variety of land use and terrain features in the image, three prominent smoke plumes corresponding to regions of agricultural burning are apparent in western Arkansas. The 3.9μm thermal channel from MODIS displayed in the bottom picture of Figure 3 not only shows the "hot spots" associated with these smoke plumes, but a number of other burning regions where smoke is less evident. The single visible channel on GOES at 1km resolution does not detect these smoke plumes very well.

The MODIS imagery also helps the forecaster to better interpret what is being observed in the coarser resolution GOES data. Figure 4 presents total precipitable water imagery derived from GOES at 1546UTC and Terra MODIS at 1656UTC on August 14, 2003. The GOES water vapor product is derived from 10km Sounder data. The resolution of the MODIS precipitable water image is 1km. The MODIS data provides a higher quality product because of its improved calibration accuracy over GOES (note the striping in the GOES TPW). The higher resolution MODIS imagery detects finer scale moisture gradients than those apparent in the GOES imagery and allows for the delineation of moisture between clouds. This is exemplified by the gradient portrayed by MODIS over southern Missouri and northern Arkansas (the GOES product shows complete coverage with clouds).

3.2 Assessment of data utility

An assessment of the utility of MODIS data on the Huntsville NWS forecast operations was conducted during July and August of 2003. The assessment focused on the use of MODIS imagery for nighttime cloud and fog detection and for identifying regions of convective initiation. MODIS data from the morning and evening passes of Terra and the afternoon and early morning passes of Aqua were available to the forecasters, including the visible (250m) and infrared (1000m) data with about a 60 minute delay. An 11μm - 3.9μm difference image was generated to simulate the GOES difference image used in fog and nighttime cloud detection. Special image enhancement curves were generated in AWIPS for the MODIS data. A limited amount of training (two 15 minute sessions) was provided to three NWS forecasters who participated in the evaluation. Since these forecasters had a reasonable level of knowledge on the use of GOES data for these applications, only the differences in these products between GOES and MODIS were highlighted in the training sessions.

A web-based survey was developed to quantify the utility of the MODIS data for these forecast applications. The evaluating forecaster filled out the survey after viewing the MODIS data. The survey took just a few minutes to complete. Sixteen forecaster entries were made into the survey database over a 7-week period from July 7 - August 22. The results indicated that MODIS data was a modest benefit for nighttime cloud detection and fog. Several case studies were noted where the MODIS 3.9 micrometer channel and the difference image fog product provided improved resolution and sensitivity over that of GOES (which aided in the detection of fog and low cloud regions). The 250m visible data provided a unique view of small developing cumulus clouds and their patterns and orientation. The survey results indicated the high-resolution data was useful in this application, but its delay in getting into AWIPS and lack of time continuity was a hindrance. A typical survey comment when looking at the 250m visible data was "….. this image could give one a little better sense of where the initial convection was going to fire vs. the 1 km GOES image….. ". A drawback to the more regular use of MODIS data for these applications is the lack of time continuity and the latency of the products. Additionally, the overpass times often are out of sync with forecaster deadlines (e.g., too late to impact issuance of fog advisories).

It is generally felt that the utility of MODIS data for these applications varies seasonally and regionally. Convective initiation is mainly confined to the warm season where surface forcing and thermal discontinuities (brought about by differential heating of the surface due to the spatial variation of cloud cover, land use, etc.) are thought to play a role in the location of initial cloud field and storm development. The occurrence of early morning fog and low clouds is also seasonally dependent and is influenced by a variety of local factors. The evaluation of a few MODIS products at one NWS Forecast Office over this period many not be representative of the actual utility of MODIS data for these applications.

4. SUMARY AND FUTURE PLANS

The SPoRT Center currently provides a number of unique NASA EOS observations and products to several WFOs in the Southern Region. A preliminary evaluation of a few selected products at one office shows only modest improvement over current satellite data and techniques. As these offices become more familiar with the data and products the impact is expected to increase.

Not only does the SPoRT program transfer NASA data and technology to the NWS, it also serves to prepare forecasters for future data from the NPOESS and GOES-R satellite programs. The polar orbiting NPOESS satellites will replace the current NOAA and DMSP series, meeting the meteorological satellite needs of both NOAA and the DOD. The NPOESS satellites will contain imaging and sounding instruments. The VIIRS instrument will provide similar channels and resolutions to that of MODIS. Forecaster exposure to MODIS data as part of SPoRT will better facilitate the use of VIIRS data later this decade. MODIS data is also a precursor to the Advanced Baseline Imager (ABI) scheduled to fly on the geostationary GOES-R satellite in 2012. The ABI will provide imagery and resolutions similar to that of MODIS at 5 minute intervals. In support of these future instruments, the SPoRT program plans to increase the number of MODIS channels currently sent to the WFOs to include channels that will be present on the VIIRS and ABI instruments. This will increase forecaster exposure to these data and products.

The SPoRT program plans to expand its dissemination of MODIS data to other WFOs in the coming year. Collaborations have begun with coastal offices in the Southern Region to identify forecast problems that can be addressed with the use of MODIS data.

Several new applications of MODIS data are planned as well. Figure 5 shows a 1 km Aqua MODIS land surface temperature (LST) image in the early morning (0735UTC) on October 24, 2003 over the Huntsville WFO forecast area over northern Alabama. The product is generated using a modified version of a GOES split window retrieval algorithm (Suggs et al., 1998; Suggs et al. 2003). The LST values range from 276 - 287K (37-57F) over the Tennessee River Valley and the mountains and elevated plateaus in the northeast part of the state. These variations in early morning LSTs are reasonably well correlated with minimum (low) temperatures as reported by the COOP stations in the region. Research at the SPoRT Center will focus on developing a minimum temperature forecasting procedure based on MODIS data to populate the Interactive Forecast Preparation System (IFPS) grids.

Additionally, profiles of temperature and moisture retrieved from NASA's AIRS instrument on the Aqua satellite will be provided to local WFOs for diagnostic analysis and use in their forecast preparation process. The AIRS with its high spectral resolution measurements has the potential to provide increased observations of vertical and horizontal structure of the thermodynamic environment over that of previous satellite sounders. The 1:30am/pm coverage of the

Aqua satellite will provide asynoptic information at 50 km spatial resolution. The impact of this profile information will be evaluated by the SPoRT Center.

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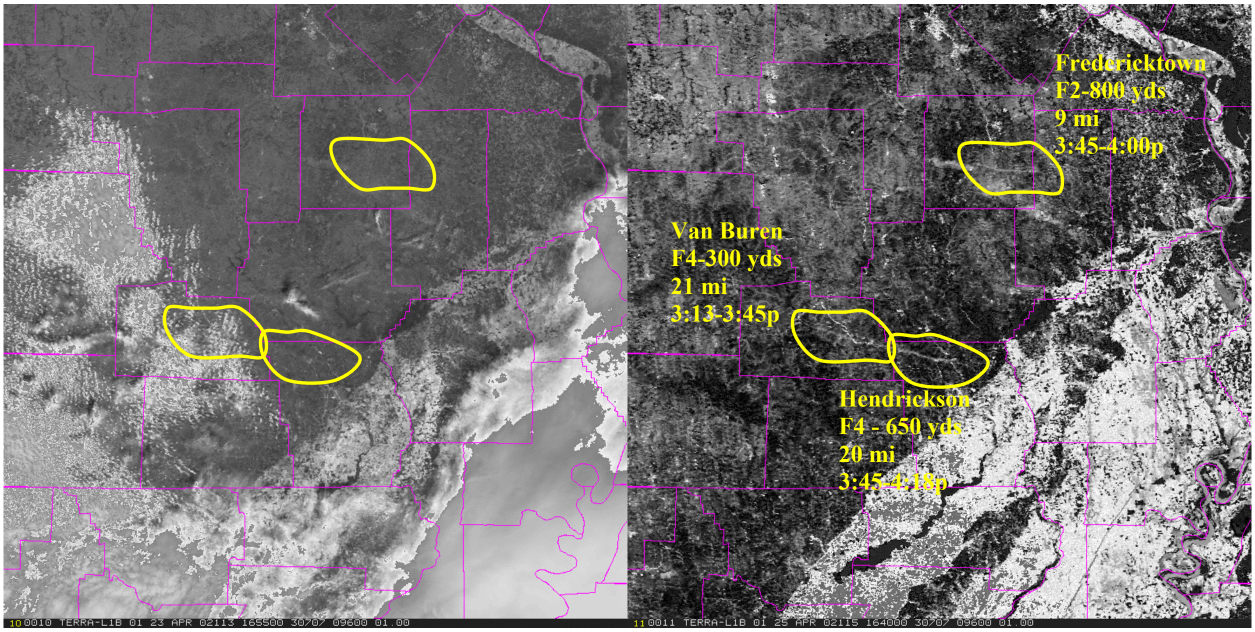

Figure 1. MODIS visible imagery showing tornado damage regions over southeast Missouri on a) 23 April (before), and b) 25 April (after) tornado events on April 24, 2002.

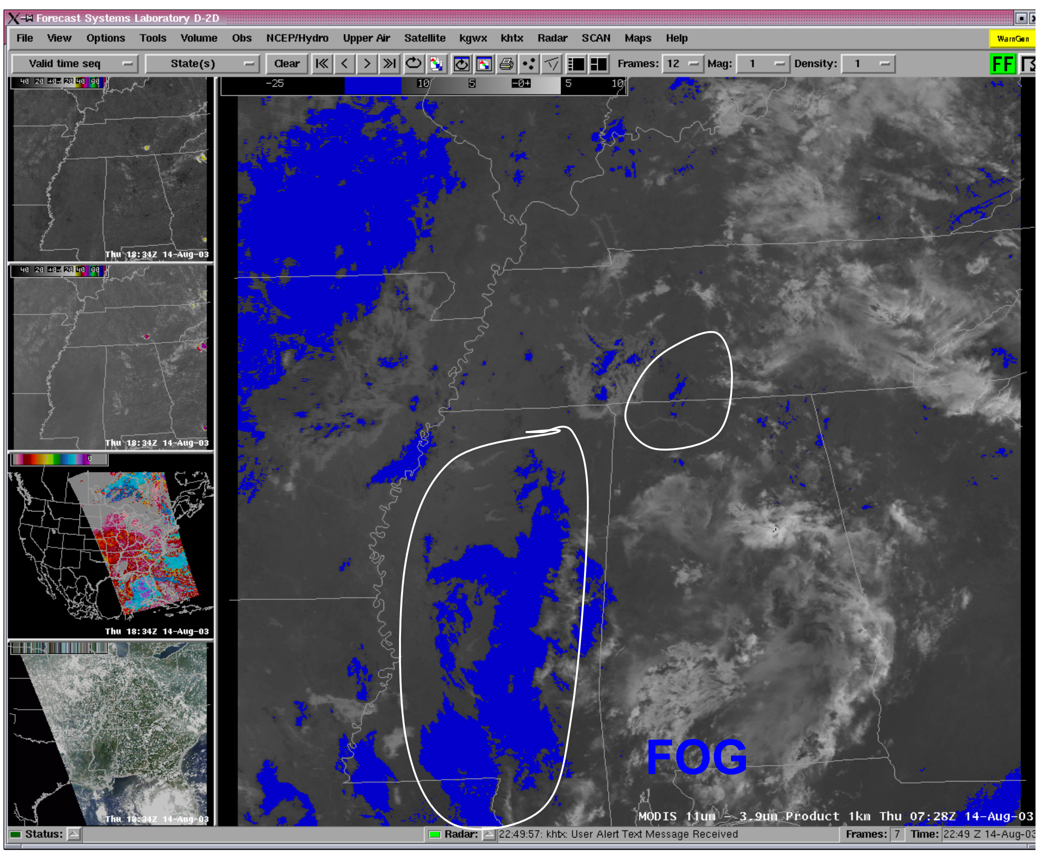

Figure 2. MODIS 11-3.9μm difference image at 0728UTC on August 14, 2003 displayed in AWIPS. The enhanced blue portions of the image indicate regions of ground fog. These regions correspond well with surface observations of reduced visibility (not shown).

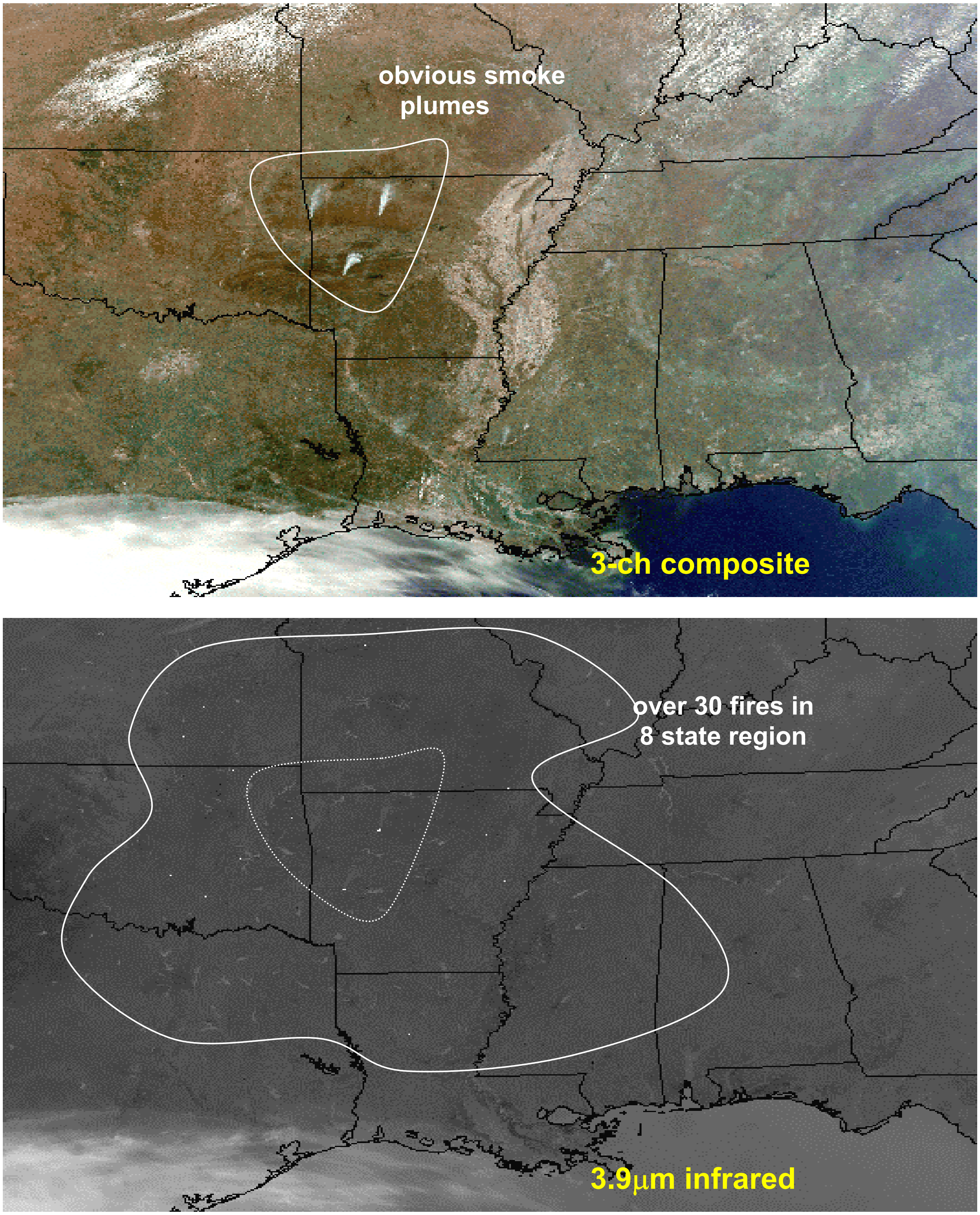

Figure 3. MODIS natural color composite image (top) and 3.9μm infrared image (bottom) for March 24, 2003. The color image highlights smoke plumes while the infrared image identify "hot spots" at the surface.

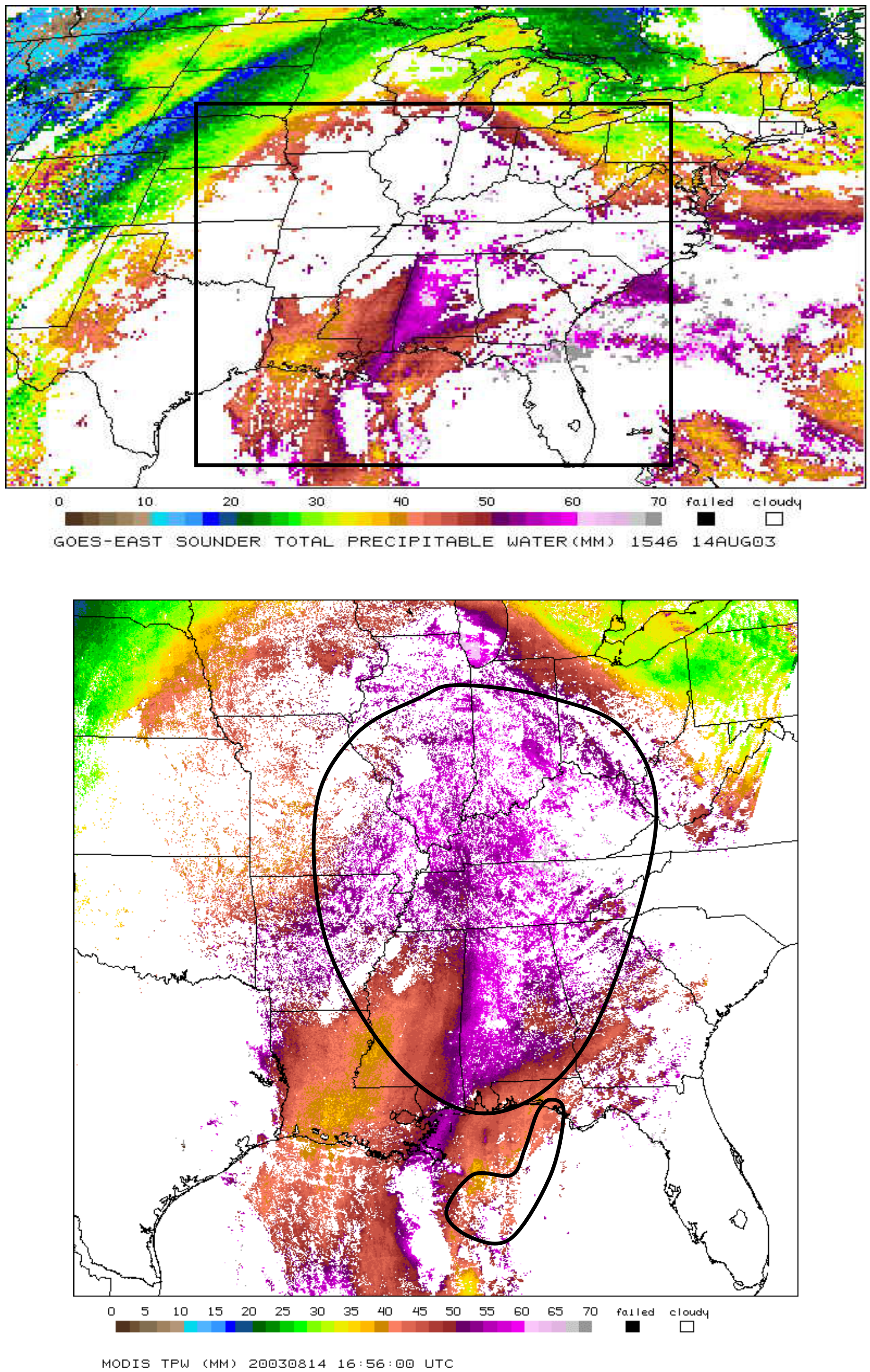

Figure 4. Total precipitable water (mm) derived from GOES (top) at 1546UTC and Terra MODIS (bottom) at 1656UTC on August 14, 2003. The GOES product is at 10km and the MODIS at 1km resolution. The highlighted box on the GOES product indicates the region of MODIS coverage.

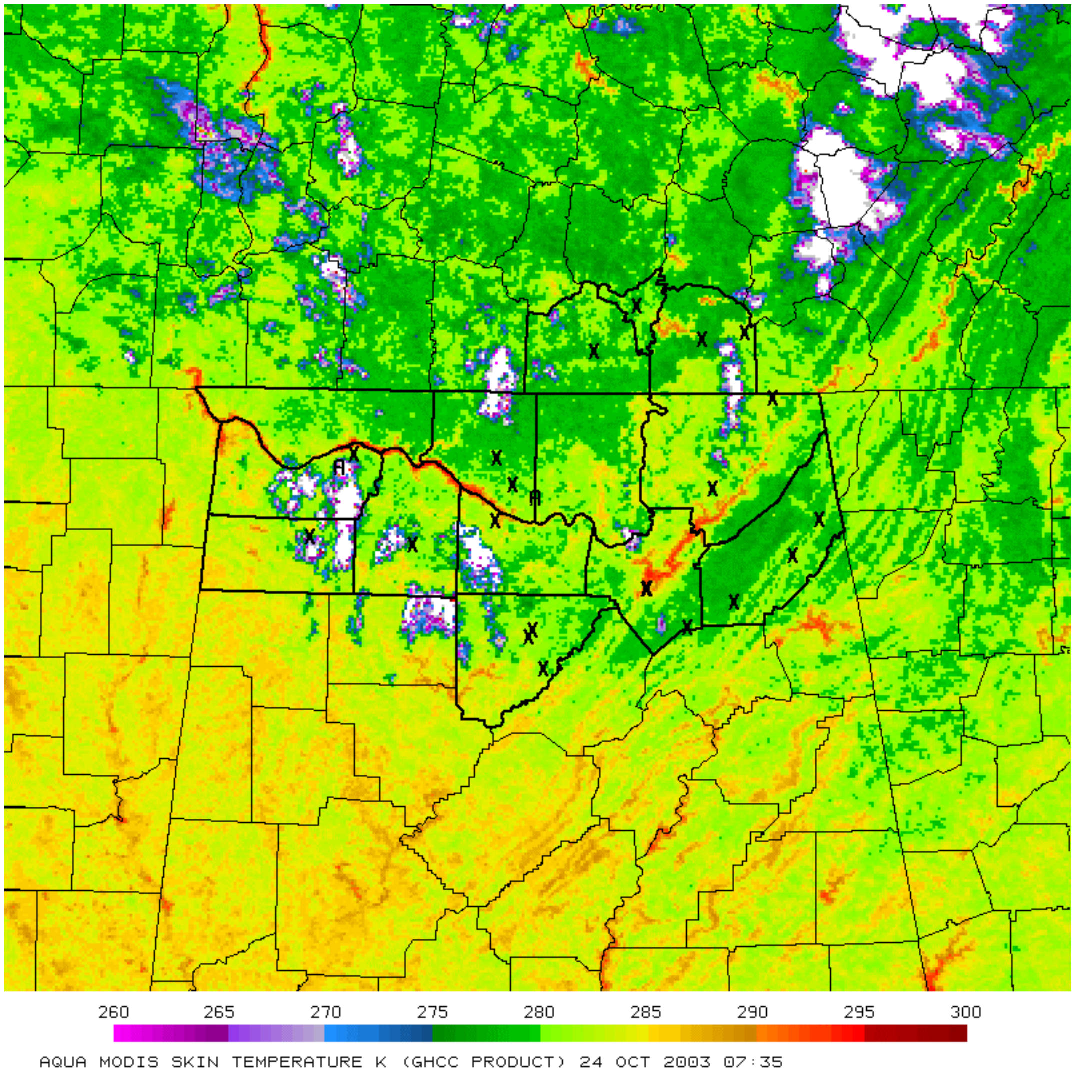

Figure 5. Land surface temperature (1km) derived from Aqua MODIS data at 0735UTC on October 24, 2003 over northern Alabama. The x's mark the locations of NWS COOP observer sites reporting minimum and maximum daily temperatures.