27 Communicating Timely Information on Convective Available Potential Energy (CAPE) using Geostationary and Polar Orbiting Satellite Sounders: Application to El Reno Event

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1. INTRODUCTION

The ability to measure vertical profiles of water vapor from space at times when ground based upper air soundings are not available can fill an important need in short-range weather prediction. New satellite observations allow for the retrieval of water vapor measurements with higher vertical resolution than was previously available. In order to demonstrate these new data opportunities, it's important to look at a practical application. Events like the Moore and El Reno tornados in 2013 are examples of just how dangerous and unpredictable tornados can be. These two natural disasters are also examples of the severity of human reactions to severe weather warnings (Gartzke et al 2014). The El Reno case study will be used to illustrate the potential value of satellite soundings.

National Weather Service (NWS) forecasters are using GOES sounder products for a range of applications, with positive results (Schmit et al 2002). These products include estimates of total precipitable water vapor (TPW) and atmospheric stability indices, such as convective available potential energy (CAPE) and lifted index (LI). Infrared observations from geostationary orbit capture the diurnal cycle of surface skin temperature with data collected over the continental United States every hour. These geostationary data can contribute to future warn on forecast approaches (Stensrud et al. 2009). However, the limited number of infrared spectral channels fundamentally limits the vertical resolution of the existing GOES sounder thermodynamic products.

Unlike the current GOES sounder, new high spectral resolution infrared sensors on polar orbiting weather satellites (POES) can sense the atmospheric boundary layer at specific times of day (about 10:30 am/pm and 1:30 am/pm). For example, the Atmospheric Infrared Sounder (AIRS) has been used to provide quantitative information about the lower atmosphere (Chahine et al. 2006). Software to process AIRS data in near real-time has been included in the IMAPP direct broadcast software package (Smith et al. 2012; Weisz et al. 2013). Near real-time data assimilation of polar orbiting advanced sounder products into rapid update NWP models has the potential to provide positive impact for future warn on forecasts (Stensrud et al. 2009).

A common goal of the severe storm science community is to obtain accurate information in a timely manner regarding atmospheric stability. This information can be used to communicate predictions of severe weather events. The first objective of this paper is to illustrate the value of advanced polar sounder observations, through the El Reno event during the 1:30 pm polar satellite orbit. The second is to put this event in the context of the climatology of the southern Great Plains and assess the ability of POES satellites to provide reliable stability information.

In this paper, a nine year record of upper air sounding profiles from the Department of Energy Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site helps to create a climatology of Convective Available Potential Energy (CAPE). We then look at the ability of satellite observations to characterize the CAPE probability distribution function at the 1:30 am/pm overpass times as a function of distance from the SGP site. This paper begins with a description of the El Reno case study.

2. CASE STUDIES DESCRIPTION

A deadly EF5 tornado hit Moore, Oklahoma on May 20, 2013 killing 24 people. Two weeks later on May 31, 2013 nineteen tornados struck central Oklahoma. After hearing a forecast for these tornados, many citizens tried to escape the storm by traveling south towards Texas on interstate forty. The interstate soon became traffic jammed for miles. Unfortunately, a massive and unpredictable tornado traveled across the interstate and killed a woman and child in a car near El Reno, Oklahoma in the late afternoon.

Currently, soundings from the ground can give meteorologists indication on how water vapor behaves in the atmosphere vertically but not horizontally. These soundings are typically only made every 12 hours. Events like the El Reno tornado is an example of how untimely these measurements can be.

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The last in situ measurements of the atmosphere were at 6am while the 6pm sounding came too late to be useful. Having some measurements to fill in this twelve hour window could give forecasters the power to create more accurate forecasts and perhaps save lives.

Figure 1 is an AQUA MODIS image obtained at about 1:30 pm local time on May 31, 2013. The image shows a cloud free region west of El Reno with nearby developing convection. The AQUA satellite also has an instrument called the Atmospheric Infrared Sounder (AIRS) that provides coincident data for the afternoon overpass. Figure 2 is a plot of the locations of AIRS soundings for the 1:30 pm overpass with colors indicating CAPE values computed from the temperature and water vapor profile retrievals. Note the maximum CAPE values are found due west of El Reno and Oklahoma City at this time. The cloudy regions seen in Figure 1 are areas where no AIRS CAPE could be computed.

3. DATA

This paper uses data from in situ observations and satellite remote sensing. The in situ observations are from Vaisala RS92 radiosondes launched by the Department of Energy (DOE) at the Atmospheric Radiosonde Measurement (ARM) at the Southern Great Plains (SGP) site near Lamont, Oklahoma. The data was obtained from the ARM archive at http://www.archive.arm.gov. The files used in this analysis are named sgp10rlprofmr1turn.cdf. These files contain sonde pressure, temperature and water vapor interpolated in time to continuous 10 minute intervals and in the vertical to fixed height levels. The interpolated profiles closest in time to the satellite overpass were used in this analysis to represent the ARM sonde data.

The satellite data used in this analysis was from the NASA Aqua platform in a sun-synchronous orbit with local overpass times of about 1:30 pm and 1:30 am. As the satellite orbits from pole to pole the sensor maps out a swath using cross track scan patterns as shown in Figure 3. AIRS measures infrared wavelengths between 3.7 to 15.4 microns, while the sensor AMSU-A makes simultaneous measurements in the microwave. Each of these wavelengths is sensitive to the presence of a specific gas. For example it's possible to acquire information about carbon dioxide, carbon monoxide, ozone and particularly temperature and water vapor. The data product used was the official NASA AIRS Science Team retrievals downloaded from the NASA Goddard data archive (http://disc.sci.gsfc.nasa.gov/AIRS). AQUA overpasses at 1:30 pm local time were used to provide matched AIRS profiles of temperature and water vapor for the Oklahoma region. Both the closest AIRS profile to the DOE ARM SGP site (<50 km) and profiles within 150 km, 300 km and 500 km were used in this analysis.

4. ANALYSIS METHOD

The climatology of temperature and moisture profiles in the Southern Great Plains was estimated using radiosonde data launched from the DOE ARM site and interpolated in time to the Aqua overpass times (1:30 pm/am). The time series of CAPE values used in the climatology are shown in Figure 4. The seasonal dependence of CAPE is evident with zero CAPE values during the winter and the highest CAPE values in spring and summer. A time and space coincident matchup was made using NASA AIRS v6 retrievals by extracting AIRS profiles of temperature and water vapor in the region surrounding the DOE ARM SGP site.

A climatology of CAPE for both the ARM sonde and the AIRS retrievals was derived from the matchup temperature and moisture data set. Figure 5 shows the correlation of calculated CAPE values with coincident total precipitable water vapor and lifted index. The red dots indicate negative lifted index values. High CAPE values are associated with the most negative lifted indices. High CAPE is also associated with high total water vapor, yet the correlation between the two variables is not strong. The comparison of AIRS closest and ARM sonde CAPE in Figure 4 indicates the two climatologies are qualitatively similar, although there are more samples in ARM sonde distribution.

The probability distribution functions for both AIRS and ARM sonde CAPE were computed for CAPE values greater than 50 J/kg. The 50 J/kg threshold was selected to remove zero values and small AIRS CAPE values close to the noise limit. Figure 6 shows a comparison of the probability distribution functions for ARM sonde and the AIRS CAPE closest to the ARM site. Similar probability distribution functions were computed for the maximum AIRS CAPE within a radius of 150, 300, and 500 kilometers.

5. RESULTS

5.1 Climatology of CAPE at ARM SGP

Table 1 shows the result of the climatology analysis performed at the ARM SGP site between January 2005 and June 2014. By integrating the ARM sonde CAPE probability distribution function for values greater than 1000 J/kg, the likelihood of occurrence was found to be 19%. The sonde profile represents a small region close to the sonde launch site. For comparison, the AIRS profile closest to the launch site was extracted. The likelihood of occurrence of CAPE greater than 1000 J/kg for the closest AIRS

CAPE is only 9.9%. In this time period, only 48 of 485 samples exceeded the threshold for the AIRS CAPE, while 158 of 809 samples exceeded the threshold for the ARM sonde CAPE. The difference in sample numbers is explained by the fact that the AIRS level 2 version 6 product can not retrieve CAPE in overcast cloud conditions. This reduces the total number of samples by nearly one half and the number of extreme samples by two thirds. The percentiles in Table 1 for the closest AIRS CAPE show that the entire PDF is shifted to lower CAPE values. This is illustrated in Figure 7 which compares the cumulative sum of the ARM sonde and AIRS closest CAPE.

In general, the maximum CAPE derived from AIRS exceeds the CAPE derived from ARM sondes launched at the ARM site, as shown in Figure 8. This is due to the large spatial coverage of the AIRS sounder compared to the point measurement from the radiosonde.

5.2 El Reno Case Study

Figures 1 and 2 illustrate the polar orbiting satellite overpass of the southern Great Plains at about 1:30 pm on the day of the El Reno event. The circled region in figure 2 is due west of El Reno. It is evident that there are spatial deficiencies in the remote sensing of CAPE from the AIRS sensor due to cloudiness. Despite this, large values of CAPE were detected by AIRS in Western Oklahoma. For comparison, we computed CAPE from the operational radiosondes launched from Norman, Oklahoma. The morning synoptic sonde launch (12 UTC, 6 am local time) had a computed CAPE value of 1159 J/kg which represents the 85th percentile in the ARM site radiosonde climatology. While this sounding represents an extreme CAPE value even at 6 am, the solar heating during the morning hours would tend to increase the CAPE. The 10:30 am Metop satellite overpass with the IASI advanced sounder and the 1:30 pm AQUA overpass with the AIRS advanced sounder can be used to monitor the growth of CAPE during the heating of the day. For the 1:30 pm AQUA overpass a maximum CAPE value of 2233 J/kg was detected due west of El Reno and Oklahoma City. This represented an extreme value in the 98th percentile of the ARM site climatology. Thus, between 6 am and 1:30 pm the CAPE in the southern Great Plains increased from the 85th percentile to the 98th percentile. This information was potentially available for predictive forecasting about 4.5 hours before the tornado touchdown.

Figure 9 shows a comparison of AIRS maximum CAPE and ARM sonde CAPE for the two week period prior to the El Reno event. The black vertical lines indicate the time of the touchdown for the Moore and El Reno tornados. This figure shows that the AIRS sounder has comparable skill to the radiosonde in detecting extreme CAPE values. Meanwhile, the timeliness and spatial coverage of the satellite data complement the local radiosonde observations.

6. CONCLUSIONS

A radiosonde climatology at the Lamont Oklahoma ARM site was developed for the period January 2005 to June 2014. The probability of sonde CAPE over 1000 J/kg is found to be 19% at the ARM SGP site. While the probability of the closest AIRS CAPE over 1000 J/kg is 9.9% and the probability of the maximum AIRS CAPE within 150 km is 25%. The 99th percentile of the sonde climatology was found to be 2364 J/kg. While the 99th percentile of the closest AIRS CAPE is 1733 J/kg, the 99th percentile of the maximum AIRS CAPE within 150 km is 2802 J/kg. While the closest AIRS CAPE values tend to be less than the sonde CAPE extremes, the maximum CAPE near the SGP site is higher. This is consistent with the advanced sounder product limitations caused by cloudiness at the sonde launch site but the larger spatial coverage of the satellite data. In conclusion, the maximum AIRS CAPE values near the SGP site tend to exceed the time coincident sonde CAPE at the ARM site.

In the El Reno case study, the 6 am sonde at Norman, OK had a CAPE in the 85th percentile (1252 J/kg) .The maximum AIRS CAPE (2233 J/kg) at 1:30 pm was found just West of Oklahoma City with a CAPE exceeding the 98th percentile of the sonde climatology This result illustrates the potential value of the polar satellite observations. As stated earlier, POES satellites have broad special coverage and they can detect extreme atmospheric instability. The downside are spatial gaps due to cloud cover and limited time of day coverage and product latency.

These results show promise for use of infrared sounder retrievals in the nowcasting of local severe storms. Product latency has been reduced to a few minutes through use of the UW CIMSS Community Satellite Processing Package (CSPP) (reference). Future work will make use of CSPP algorithms to provide timely and accurate products for use in probabilistic forecasting.

ACKNOWLEDGEMENTS

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REFERENCES

Chahine, Moustafa T., et al. "AIRS improving weather forecasting and providing new data on greenhouse gases." (2006).

Gartzke, J., R. Knuteson, H. Revercomb, W. L. Smith, Sr., and E. Weisz (2014), The Invisible Variable Behind Tornadic Events: Sensing Water Vapor from Space, AMS Broadcast Meteorology Conference, 16–20 June 2014, Olympic Valley, CA.

Smith, W. L., A. M. Larar, H. E. Revercomb, M. Yesalusky, and E. Weisz (2014), The May 2013 SNPP Cal/Val Campaign – Validation of Satellite Soundings, Proceedings of the 19th International TOVS study conference (ITSC-XIX), University of Wisconsin, Space Science and Engineering Center, Cooperative Institute for Satellite Studies (CIMSS).

Schmit, Timothy J., et al. "Validation and use of GOES sounder moisture information." Weather and forecasting 17.1 (2002): 139-154.

Smith, W. L., E. Weisz, S. Kirev, D. K. Zhou, Z. Li, and E. E Borbas (2012), Dual-Regression Retrieval Algorithm for Real-Time Processing of Satellite Ultraspectral Radiances. J. Appl. Meteor. Clim., 51, Issue 8, 1455-1476.

Stensrud, David J., et al. "Convective-scale warn-on-forecast system: a vision for 2020." Bulletin of the American Meteorological Society 90.10 (2009): 1487-1499.

Weisz, E., W. L. Smith Sr., and N. Smith, 2013: Advances in simultaneous atmospheric profile and cloud parameter regression based retrieval from high-spectral resolution radiance measurements. Journal of Geophysical Research -Atmospheres, 118, 6433-6443.

ILLUSTRATIONS AND TABLES

Table 1. Climatology of extreme CAPE values at the Southern Great Plains ARM site for the time period 1 January 2005 to 30 June 2014.

	ARM Sonde SGP site	AIRS			
		Closest CAPE <50 km	Max CAPE <150 km	Max CAPE <300 km	Max CAPE <500 km
CAPE >1000 J/kg	19%	9.9%	25%	32%	37%
25th	187.5	130.7	226.2	225.7	187.5
50th	402.4	290.9	577.4	655.1	698.2
67th	678.2	451.1	811.6	867.4	1052
75th	862.1	557.3	967.7	1202	1287
95th	1659	1252	2022	2295	2544
99th	2364	1733	2802	2997	3330

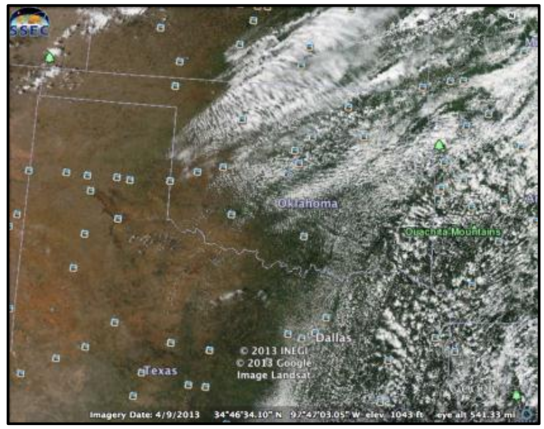

Figure 1. The satellite image above was taken 4.5 hours before the El Reno event.

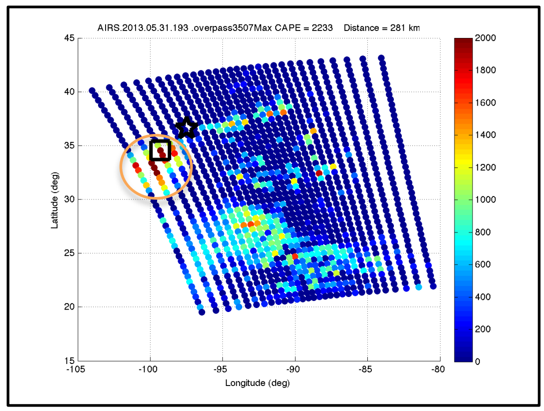

Figure 2. This figure shows the location of the highest CAPE value detected by AIRS (square) as well as the location of the ARM site (star). Each dot represents the calculated CAPE for the overpass on May 31, 2013.

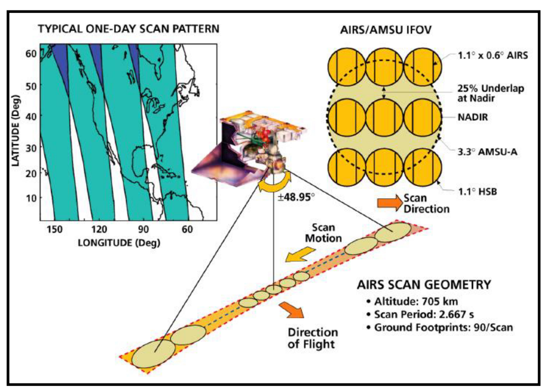

Figure 3. AIRS scan pattern of Earth observations.

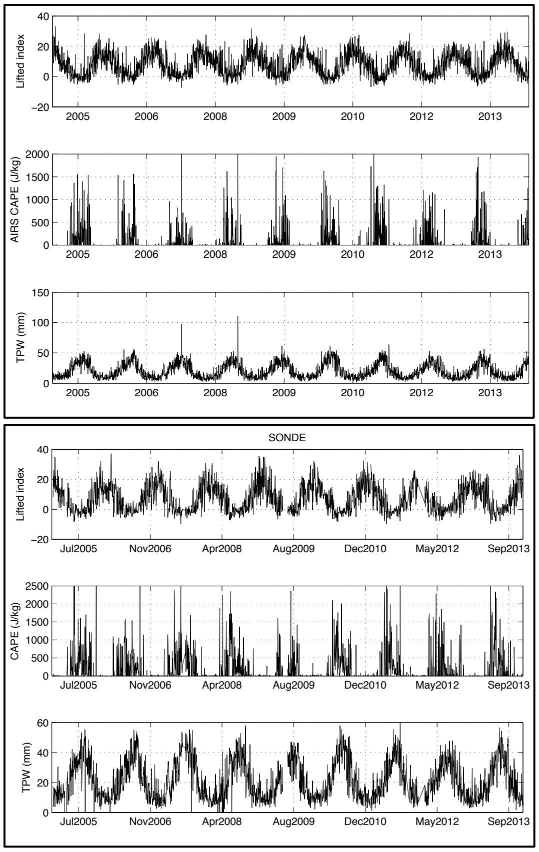

Figure 4. Time series graphs of lifted index, CAPE, and PWV for the AIRS closest (upper) and ARM sonde (lower) and from January 2005 and October 2013.

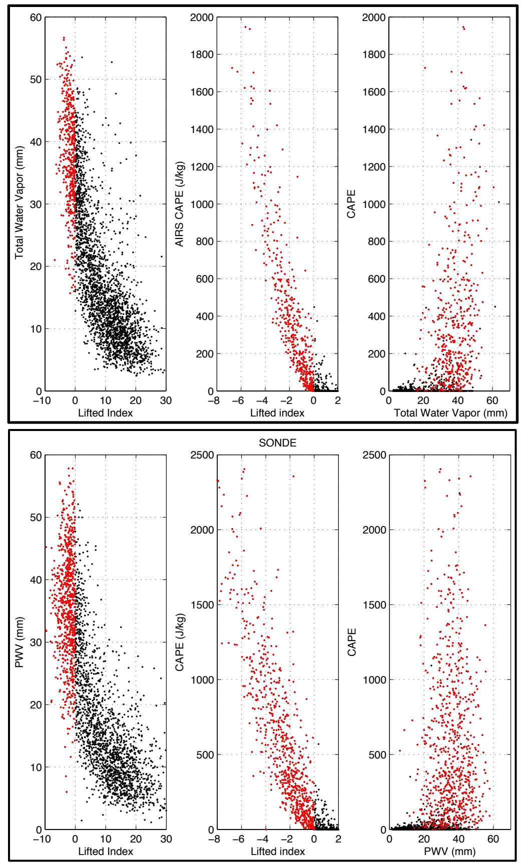

Figure 5. The relationship between CAPE, Lifted Index and Total Perceptible Water Vapor are shown for AIRS closest (left) and ARM sonde (right). Red dots indicate negative lifted index.

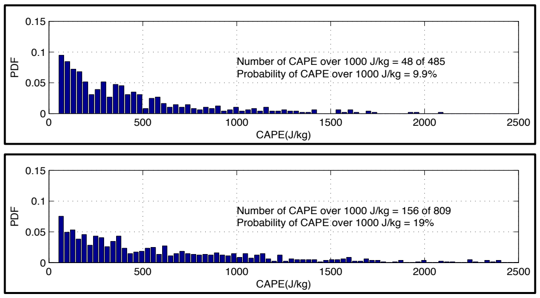

Figure 6. Probability distribution functions of AIRS closest CAPE (upper) and ARM sonde CAPE (lower) for CAPE values >50 J/kg.

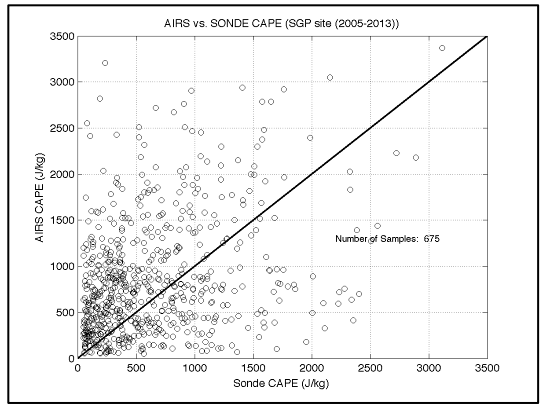

Figure 8. Time and space coincident matchups of sonde CAPE and the maximum AIRS CAPE within 150 km the ARM site.

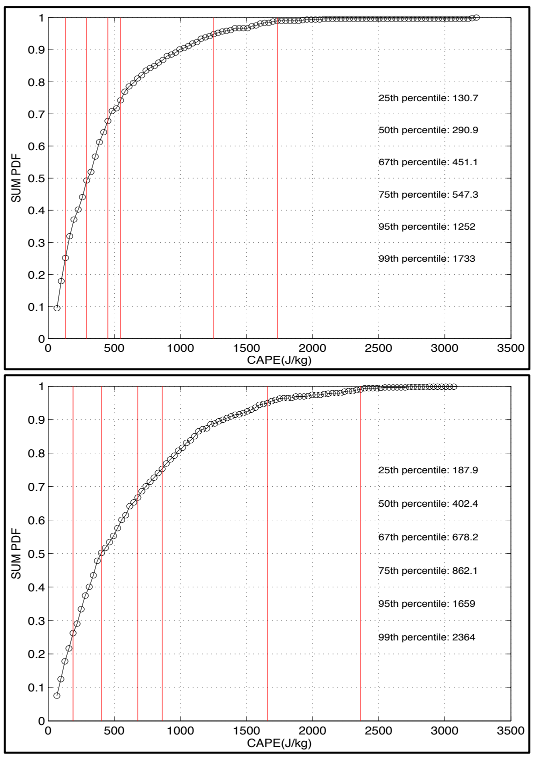

Figure 7. Cumulative sum of CAPE PDF for the AIRS closest (upper) and the ARM sonde (lower).

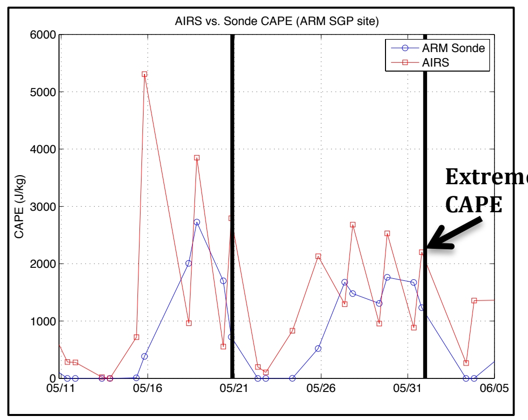

Figure 9. The CAPE values from May 11 to June 5, 2014. The two lines represent the Moore tornado (May 20) and the El Reno tornado (May 31).