11.2 THE INVISIBLE VARIABLE BEHIND TORNADIC EVENTS: SENSING WATER VAPOR FROM SPACE

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1. INTRODUCTION

The ability to measure vertical profiles of water vapor from space at times when ground based soundings are not available will prove to be invaluable in the weather prediction process. New satellite soundings 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 as well as the adverse human reactions to severe weather. These case studies will help demonstrate the role of water vapor in tornadic events and reveal a need for satellite soundings.
CrIS is a vital component that can improve NWP forecast skill and accuracy.

In this paper, section 2 describes the Moore and El Reno events in more detail. Section 3 presents some sociological questions brought up by the comparison between the two events. Section 4 and 5 describe the data used and the method of analysis. Section 6 presents the satellite measurements of water vapor highlighting the wife spatial coverage and vertical extent. To conclude, section 7 summarizes the points made and discusses the future applications for research.

2. CASE STUDIES DESCRIPTION

Unlike other forms of water, water vapor is invisible. It can't be detected by radar or the visible wavelengths. Yet, water vapor plays a very important role in the development of severe thunderstorms. Tornados develop when winds at different levels and different moisture contents cross and begin to rotate. This makes the state of Oklahoma the perfect place for severe thunderstorms to develop. Low level moist air from the Gulf of Mexico comes north below dry mid-level air, coming over the Rocky Mountains from the west. Although water vapor isn't entirely responsible for tornados, it is clear that it plays a crucial role in their rapid formation.

There were two very dangerous, very deadly EF5 tornados that struck Oklahoma in 2013. The first tornado struck Moore, Oklahoma on May 20th. At 2:56 pm local time the Moore tornado killed 24 people in 39 minutes, including 7 children. Winds measured up to 210 miles per hour. Only 11 days later on May 31st the second tornado struck El Reno. The widest tornado in history killed 8 people in 40 minutes, including the famous storm chaser, Tim Samaras. The tornado was unpredictable and changed direction with recorded winds up to 296 miles per hour.

These two case studies showcase how important water vapor is in the development of severe weather. Soundings from the ground can give meteorologists ideas on how water vapor behaves in the atmosphere vertically but not horizontally . These soundings are often only made every 12 hours. Events like the Moore and El Reno tornados are examples of how untimely these measurements can be. For the El Reno case, 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. Luckily, there are two important satellite overpasses at 10:30 am and 1:30pm that do just that. The Suomi NPP satellite has an instrument called the Cross Track Infrared Sounder and since April 2002 has provided fata for the afternoon overpass. The use of soundings from CrIS can be applied to Nowcasting and therefore lead to more timely and accurate warnings.

3. NWS WARNINGS AND SOCIETAL IMPACT

Severe weather not only causes loss of life and property but also serious social disruption. From a communication standpoint, the Moore and EL Reno tornados are perfect examples of varying human behavior during severe weather. First, forecasters knew about the possibility of severe weather on May 31st starting at 5:30 in the morning, yet the earliest warning was issued within a half hour of the event (see figure 2). Secondly, there is a significant difference in the amount of counties that were warned between the two events. Table 1 lists the very restrictive criteria for issuance of a tornado warning. Forecasters only warned 4 counties before the Moore tornado while before El Reno, there were upwards of 10 counties that were under a "tornado warning" at some point as shown in figure 3.

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Unfortunately, too many people panicked and many tried to drive south to Texas in order to escape the storm. Consequently, this caused a traffic jam on interstate I-40. The El Reno tornado tracked through that area and killed a woman in her car.

El Reno and Moore struck the same people, challenged the same forecasters and tore through the same area. Yet, people reacted very differently to these very similar events. The Moore tornado had fewer warnings that covered less area and 24 people were killed. While El Reno had more warnings that covered more area and still 8 people were killed. Can satellite soundings in the late morning and early afternoon help increase the timeliness of warnings, accuracy of the forecasts and save lives?

4.DATA FROM EARTH ORBITING SATELLITES

The Suomi NPP satellite is named after the University of Wisconsin professor, Verner Suomi. Professor Suomi is known as the father of satellite meteorology. CIMSS is continuing on his legacy by using an instrument called Cross Track Infrared sounder (CrIS) that takes ultraspectral radiance observations. The word ultraspectral means that it provides information of more than 1000 infrared spectral channels (Smith et al. 2012). As Suomi NPP orbits the earth from pole to pole, the sensor maps out a swath using cross track scan patterns. CrIS measures different wavelengths, each of which are sensitive to the presence of a specific gas. CrIS can acquire information about carbon dioxide, carbon monoxide, ozone and water vapor. Inverting the spectral channels produces vertical soundings of temperature and water vapor. CAPE products are one type of data that can be retrieved from University of Wisconsin Space Science and Engineering center (SSEC) when radiosondes are not available. Additionally, lifted index can be examined to create better forecasts as shown in Figure 5.

5. ANALYSIS METHOD

The term dual regression refers to the fact that two sets of regression coefficients are computed from ensembles of data. The dual regression method utilizes “clear trained” and “cloud trained” retrievals of skin temperature, surface emissivity, surface emissivity coefficients, carbon dioxide concentration, cloud top altitude, effective cloud optical depth and atmospheric temperature, moisture and ozone profiles above the cloud and below a thin cloud (Smith et al. 2012). Each set of coefficients is separately applied to an observed radiance spectrum to retrieve a clear and cloudy solution (Weisz et al.2013). The cloud trained regression relates the surface, cloud, and the atmospheric profile parameters to their associated radiance spectra calculated using a cloud radiative transfer model assuming cloud parameters diagnosed from the atmospheric humidity profiles. (Smith et al. 2012) The solution includes temperature and humidity profiles which are used to compute convective stability parameters such as lifted index.

6. RESULTS

Unlike from GOES, new sensors on polar orbiting weather satellites (POES) can see the low level moisture flow in the ultraspectral observations. CrIS can provide quantitative information about the atmosphere in combination with the visible imagery from VIRS. The software has been included in the CIMSS Community Satellite Processing Package (CSPP, http://cimss.ssec.wisc.edu/cspp/). The inclusion of these products into forecasts might have a positive influence on timely warnings.

7. CONCLUSIONS

Unfortunately, the effectiveness of severe weather warnings is very sensitive to the sociology of people. Warnings can sometimes cause panic and fear to the point where they are actually ineffectual. Because there were so many watches before the El Reno tornado, this may actually have led to more casualties. There is a definite gap in atmospheric knowledge between the 6 am and the 6 pm radiosonde in tornado alley. CrIS will fill in this gap by providing vertical profiles of the atmosphere at 10:30 am and 1:30 pm. CIMSS is producing products in near real time than can help to measure atmospheric instability when other data is unavailable. The integration of these products into the National Weather Service is currently being researched.

REFERENCES

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and cloud parameter regression based retrieval from high-spectral resolution radiance measurements. Journal of Geophysical Research -Atmospheres, 118, 6433-6443.

ILLUSTRATIONS AND TABLES

Figure 1. These images are of the Moore Tornado (May 20, 2013) and El Reno Tornado (May 31, 2013) after touchdown. The first warning given for the Moore tornado was only 16 minutes before it's touchdown at 2:56 pm local time. The first warning given for the El Reno tornado was 27 minutes before the tornado struck at 6:03 pm local time. These touchdown times are typical of tornados in the United States however; the warning times were not long enough to prevent casualties.

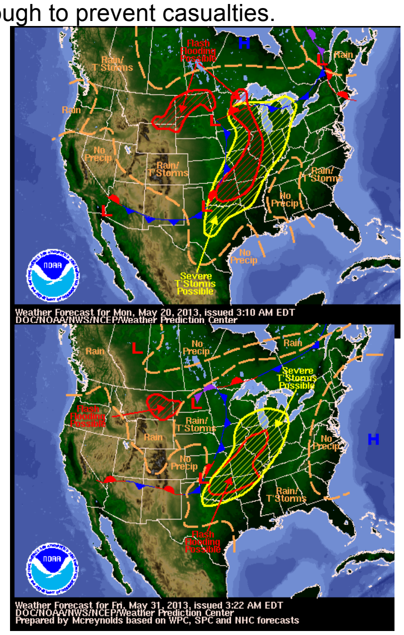

Figure 2. Figure 2 shows that severe weather was predicted for the both events early in the morning, yet warning times were less than a half hour for both events.

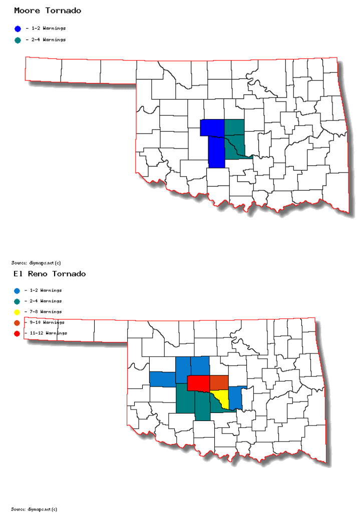

Figure 3. Figure 3 compares the amount of Tornado, Severe Thunderstorm and Flash Flood warnings given during the Moore and El Reno events. The image also gives a special representation of the area warned. It is apparent that the El Reno tornado produced a higher frequency of warnings for a larger area.

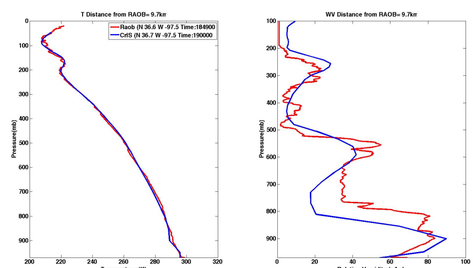

Figure 4. Inverting the spectral channels allows for the creation of vertical soundings. Figure 4 demonstrates the effectiveness of the retrieval method. The red line was taken from the Lamont Oklahoma radiosonde, while the blue was retrieved from Suomi NPP data. It's apparent that there's a deep level of moisture on May 20, the date of the Moore tornado, and capping inversion that is eroding.

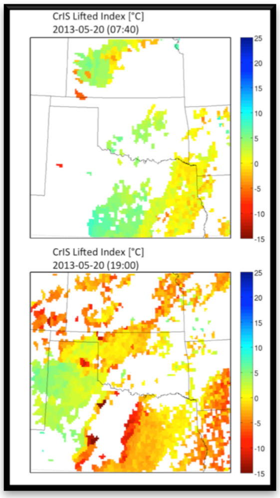

Figure 5. This is an example of the lifted index values for May 20, 2013. In the case of the Moore tornado, this type of analysis could have been very helpful to forecasters if it were available in a timely manner. Negative values, represented by red dots, means the atmosphere is extremely unstable. There are two overpasses pictured here. The first one at 1:40 am local time shows relatively no potential for severe weather. The second image shows values of -15 or extreme instability at the time of the event.

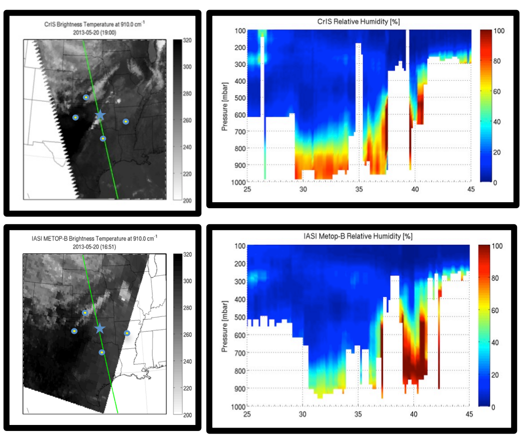

Figure 6. Figure 6 is a map of the satellite data for the late morning and early afternoon overpasses. The star shows the location of Oklahoma city while the yellow dots show the locations of the NWS operational radiosonde launch sites. The green lines give the location of the vertical slice shown on the right. The images on the right show the vertical cross sectional comparison of Relative Humidity for the Moore event in the late morning and early afternoon. Oklahoma City is around 35 degrees north. Within just a few hours, the relative humidity at Oklahoma City increased significantly.

Criteria for issuing Tornado Warnings
A cyclonic rotational couplet in the lower levels of the storm (approx. 1000 - 10,000 ft AGL). A gate to gate signature of maximum inbound and outbound wind is particularly dangerous, but *not* required.
A SRM velocity in either the inbound or outbound wind of the mesocyclone couplet of >40 knot at any distance from the radar.
A *VR shear* rotational velocity of >30 knot at any distance from the radar.
A *VR shear* rotational shear of .008 within 60 miles, or .006 beyond 60 miles.

Table 1. The tornado warnings given out for the Moore and El Reno events followed the warning criteria shown in Table 1.