P1.23 A CASE STUDY ANALYSIS OF THE CLOUD-TOP HEIGHT PRODUCT (CTOP) DURING THE LANDFALL OF HURRICANE FRANCES

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1. INTRODUCTION

The Cloud-Top Height product (CTOP) was developed by the Federal Aviation Administration Aviation Weather Research Program's (FAA/AWRP) Oceanic Weather Product Development Team (OW PDT). The CTOP is based on a combination of GOES IR emittance values with output from a numerical weather prediction model. The product diagnoses clouds above 15,000 feet and is intended to diagnose clouds that may be a hazard to aviation.

One of the challenges for the AWRP's Quality Assessment Product Development Team (QA PDT) in evaluating the CTOP is finding high quality data sets that are independent of those used in the creation of the product. It is important to note that none of the data sources compared and contrasted to the CTOP are a true measure of the cloud top height, but all are inferred values.

This paper presents a case study to evaluate how well CTOP corresponds with other cloud top observation platforms. The datasets used in this study include a GOES sounder-based cloud-top pressure product provided by NESDIS (NCTP), echo tops (ET) derived from NEXRAD radar data, and cloud top heights estimated from rawinsonde (RCTH) observations.

2. CLOUD TOP MEASURING TECHNIQUES

Because cloud-top height can not be directly measured, cloud-top heights were derived from weather variables measured by satellite, radar, and rawinsonde observations. The techniques used for each process is briefly described in this section.

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2.1 CTOP Diagnostic Product

The CTOP Diagnostic product utilizes the IR Window technique which combines brightness temperature, measured by the infrared channel of the GOES Imager, with a temperature profile from the Global Forecast System (GFS) numerical weather prediction model to estimate the cloud height for a given pixel. The CTOP product domains include the Pacific, Gulf of Mexico, North Pacific, and for this evaluation only, the CONUS. The CTOP product has a nominal resolution of 4 km, the same as the GOES Imager IR window channel scan.

2.2 NCTP Product

The NESDIS Cloud-Top Pressure (NCTP) product is described in detail by Schreiner et al. (2001). The algorithm primarily relies on the CO_2-slicing technique, derived from radiative transfer principles, to determine cloud top pressure (Menzel et al. 1983; Wylie and Menzel 1989). In cases where the CO_2-slicing calculation fails (which typically occurs for very thin, high clouds or low, opaque clouds) the algorithm adopts the IR Window technique to determine the pixel cloud top pressure. A brightness temperature, measured by the GOES Sounder, provides the value for lookup in the GFS temperature profile. The NCTP product has a nominal resolution of 10 km. The maximum cloud top pressure value for the NCTP is either 150 hPa (roughly 45,000 ft) in the standard atmosphere, or the tropopause, whichever height is lower in the atmosphere.

2.3 ET Product

The radar-derived echo top (ET) is the maximum vertical extent of precipitation-sized particles within a cloud, and thus, this height will always be less than or equal to the height of the cloud. This product is derived from the National Weather Service (NWS) WSR-88D radars and has a 4 km spatial and 6 min temporal resolution with a range of 230 km and a vertical resolution of 5,000 ft. The lowest detectable tops are those at 5,000 ft., while the highest are at heights of 70,000 ft. The precision of the echo top heights decreases with range due to beam broadening. Also, the 1 km resolution reflectivity data are mapped to a 4x4 km box and the highest of several possible tops is used in the ET product.

2.4 RCTP Product

The rawinsonde-derived cloud-top height (RCTP) product is a point based product, unlike the gridded products previously discussed. This product took advantage of a technique developed by Wang and Rossow (1995) to derive cloud-top height from those variables that are directly measured by the rawinsonde instruments. The cloud top is set at the highest level when the relative humidity with respect to water (RH_w) or ice (RH_i) either (a) exceeds 87% or (b) exceeds 84% and the level above had RH_w or RH_i that was at least 3% lower than the RH_w or RH_i of the layer in question. The rawinsonde vertical sounding can overestimate the cloud-top pressures, which results in an underestimate of cloud-top height. This overestimation occurs most frequently in regions where cloud tops are colder than -40°C, as in deep convective environments.

As the rawinsonde balloon rises it also drifts away from the launch site with the wind. To account for this, the observed winds were used and a 5.5 m/s ascension rate for the rawinsonde was applied and the accumulated drift of the instrument package from the starting point to a given level provides a measure of the horizontal drift from the station's surface location.

3. DATA ANALYSIS

3.1 Synoptic Setup

To evaluate the performance of the CTOP product on a visual, rather than a statistical, basis, a case study was performed to compare all the different products in the verification process. In order to have the greatest number and diversity of products for the comparison, the coastal region of Florida was selected for the case study. For interesting and significant weather to compare all the products, 5 September 2004, the day Hurricane Frances made landfall on the Florida Peninsula, was chosen.

Frances formed from a wave over the far eastern Atlantic Ocean off of the coast of Africa on 25 August 2004 and quickly became a tropical depression and then a tropical storm later that same day. Frances reached hurricane strength by 26 August and was a major hurricane on 27 August. The maximum wind speed during the life of the hurricane was 145 mph which occurred on 31 August as well as 2 September, which made it a category four on the Saffir-Simpson scale. Hurricane Frances made landfall as a category two storm over the southern end of Hutchinson Island, near Stuart, Florida, early on 5 September and then continued west-northwestward across the central Florida Peninsula, where it eventually weakened to a tropical storm.

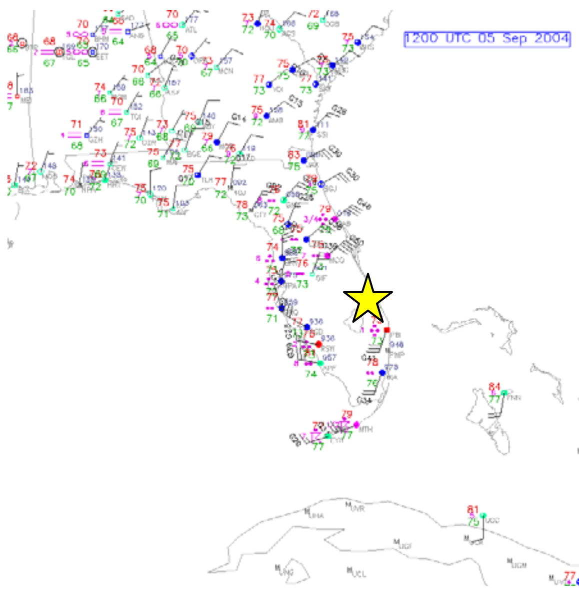

Fig. 1: *Surface observations from 12 UTC 5 September 2004. The yellow star marks the location of the land fall of Hurricane Frances.*

3.2 Satellite Analysis

The case study concentrates on 12 UTC so that recent rawinsonde data are available in addition to the NCTP product and ET data. Figure 1 presents the surface station map across Florida, Georgia and Alabama, showing the weather observations for 12 UTC. Note the hole of missing data over Florida closest to the center of the hurricane. This lack of data is most likely due to the extremely high winds occurring at that time and location. The automated weather stations do not indicate cloud top heights; however, they do give an idea of where clouds are present (with a base of less than 20,000 feet) and where it is clear (below 20,000 feet). The circles marking each station represent the cloud cover field. The circles are filled in by fourths corresponding to clear (open circle), few (1/4), scattered (1/2), broken (3/4) and overcast (solid circle). The plot shows that all the surface stations in the Florida Peninsula and southeast Georgia were reporting overcast skies. While a portion of the Florida Panhandle around Panama City was reporting clear skies, the reports are cloudy again over Pensacola. These general cloud conditions were similarly denoted in the NCTP (Fig. 2) and CTOP (Fig. 3) products.

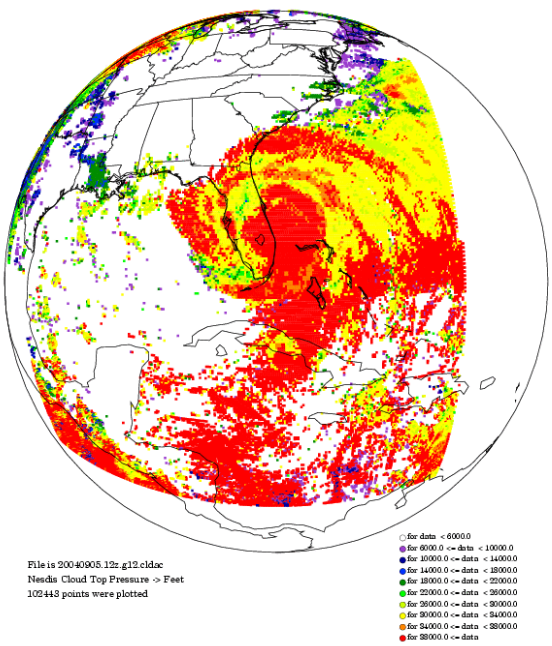

Fig. 2: *NESDIS cloud top pressure product from the Atlantic and Caribbean passes spliced together and converted to cloud top height in feet using standard atmosphere.*

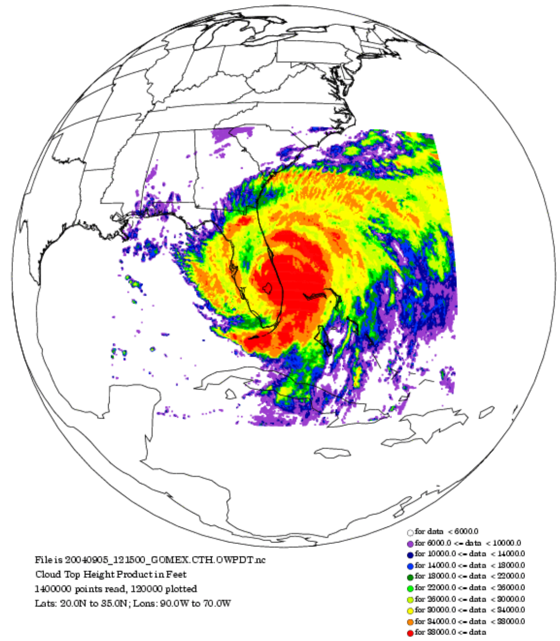

Fig. 3: *Cloud Top Height (CTOP) product in feet valid at 1215 UTC 5 September 2004.*

The GOES-12 IR (Fig. 4) and water vapor (Fig. 5) images from 1215 UTC on 5 September 2004 clearly illustrate bands of cold cloud top temperatures, which correspond to high cloud top heights, in the deeper blues to purple colors on the IR image and the brighter white on the water vapor image. A wave cloud structure is also evident around the periphery of Frances to the west and north. Both of these features are well represented in the CTOP product (Fig. 3) valid at the same time. The NCTP product shows the higher cloud top bands to an extent, but with a resolution of 10 km in this region, it cannot capture the fine details like the CTOP product can with 4 km resolution.

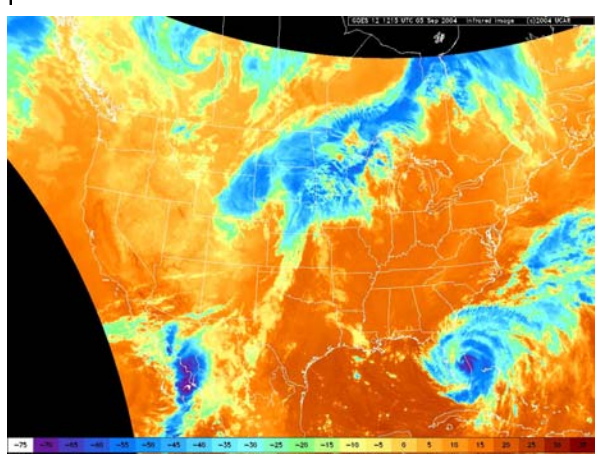

Fig. 4: *GOES 12 IR satellite image from 1215 UTC 5 September 2004.*

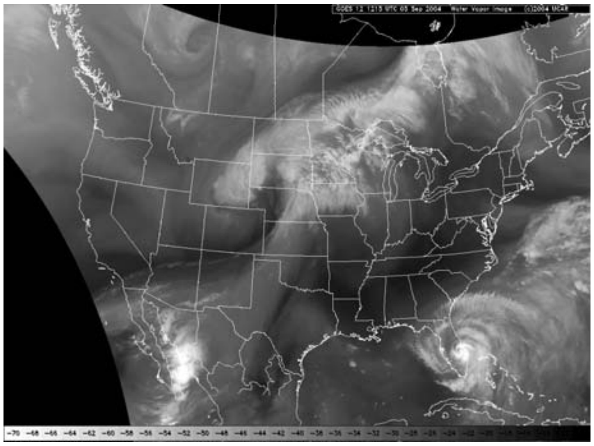

Fig. 5: *GOES 12 water vapor satellite image from 1215 UTC 5 September 2004.*

3.3 Radar Analysis

Several radars are in the area of interest for this case study. A composite of these radars is shown for a range of 0 - 240 km (Fig. 6) as well as 45 - 120 km (Fig. 7), based on maximum echo top in each 4 x 4 km box. The highest confidence is placed on the 45 – 120 km range where the height uncertainty related to the volume coverage pattern is reduced (Brown et al. 2000). In general, the highest echo tops in north-central Florida, over Miami, and south along the coast toward Key West are consistent with the highest CTOP product values. The area of lower observed heights from the radar echo tops in the central portion of the Panhandle, as well as the area off the southern tip and to the west of the Panhandle, also matches well with the CTOP diagnostic. Another thing to note is that the edge of the cloudy region over the Panhandle is also nicely matched between the two products.

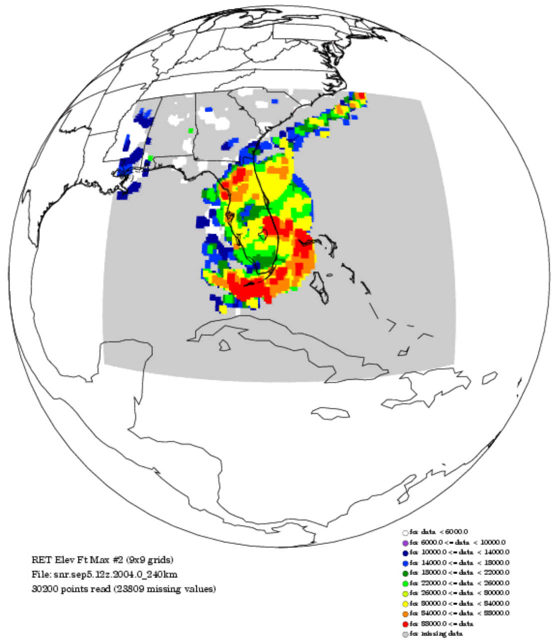

Fig. 6: *Radar echo top in feet for 0-240 km from radar locations, for 12 UTC 5 September 2004.*

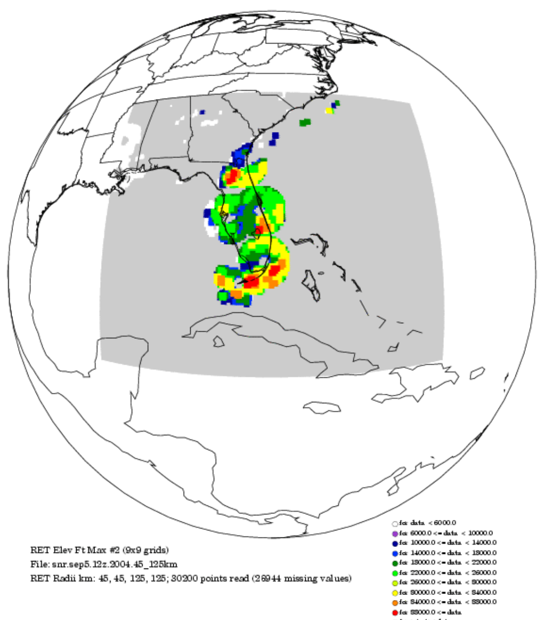

Fig. 7: *Radar echo top for 45-120 km from radar locations, for 12 UTC 5 September 2004.*

3.4 Rawinsonde Analysis

The final product used in the comparison is the RCTH. Soundings are generally only available every 12 hours at 00 UTC and 12 UTC but can be taken up to every 6 hours during special weather events. Figure 8 shows the cloud top height derived from the rawinsonde data at several launch sites around the southeastern U.S. and Figure 9 shows sample soundings from a few of these sites for 12 UTC on 5 September 2004.

Qualitatively, the heights at Miami (KMFL) and Jacksonville (KJAX), Florida, as well as Charleston (KCHS), South Carolina compare fairly well in the general area with the CTOP product, whereas the observation at Key West is lower than the CTOP product. The CTOP product does not indicate any clouds over Tallahassee (KTLH), Florida, but the RCTH has a top of nearly 21,000 feet. This difference could result from thin cirrus or an anvil blowing off the convection that is being picked up by the rawinsonde but not the CTOP product because the cloud is not opaque. In Atlanta (KFFC), Georgia, a low cloud bank much below cruising altitude is indicated by the RCTH, but in Mobile (KBMX), Alabama, the rawinsonde indicates a higher cloud top that is not detected by the CTOP product. For the opaque clouds, which are of greatest interest for aviation hazards and the CTOP, there is good agreement between the RCTH and CTOP data.

The RCTP and other cloud top measures were compared at points and within 6-, 12- and 24-km radius areas, and the results of these comparisons are shown in Table 1. The baseline cloud top height used for this analysis is the height found using the rawinsonde data. For each of the different radii the median and peak values within each radius are shown, as well as the value within the radius that best matches the RCTH. The RCTH measurements at KMFL and KJAX are about 10,000 ft. lower than the CTOP point value and the difference is nearly twice that big for KEYW. The NCTP point values at KMFL and KJAX are even higher than the CTOP values and thus are even more different from the RCTH. The CTOP height at KCHS is zero, whereas the rawinsonde has a height of 20,000 ft and the NCTP has a height of 30,000 ft.

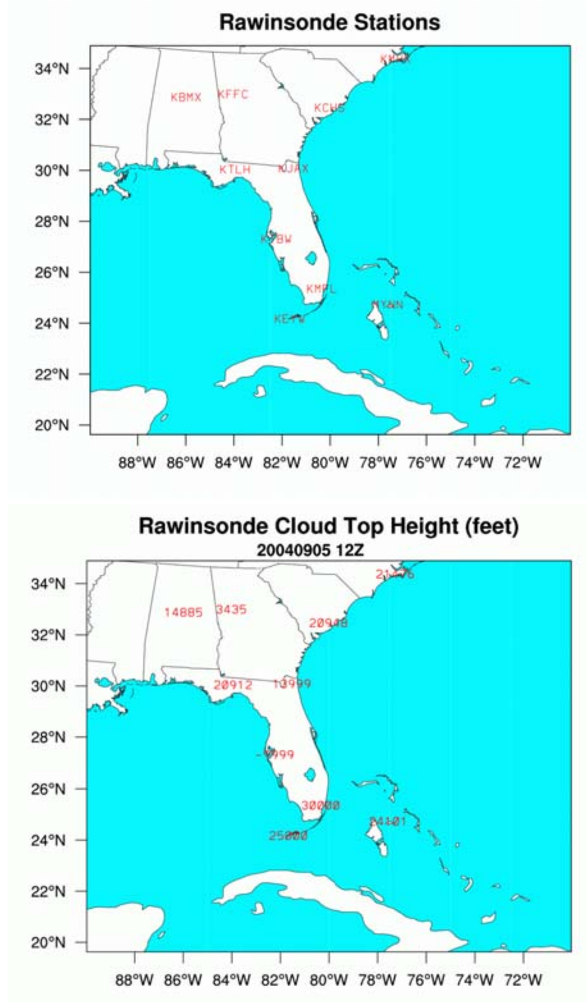

Fig. 8: *Top: Map of the rawinsonde launch locations across the southeastern U.S. Bottom: Rawinsonde cloud top heights (feet) from 12 UTC 5 September 2004. (-9999 indicates missing, or no cloud top was found).*

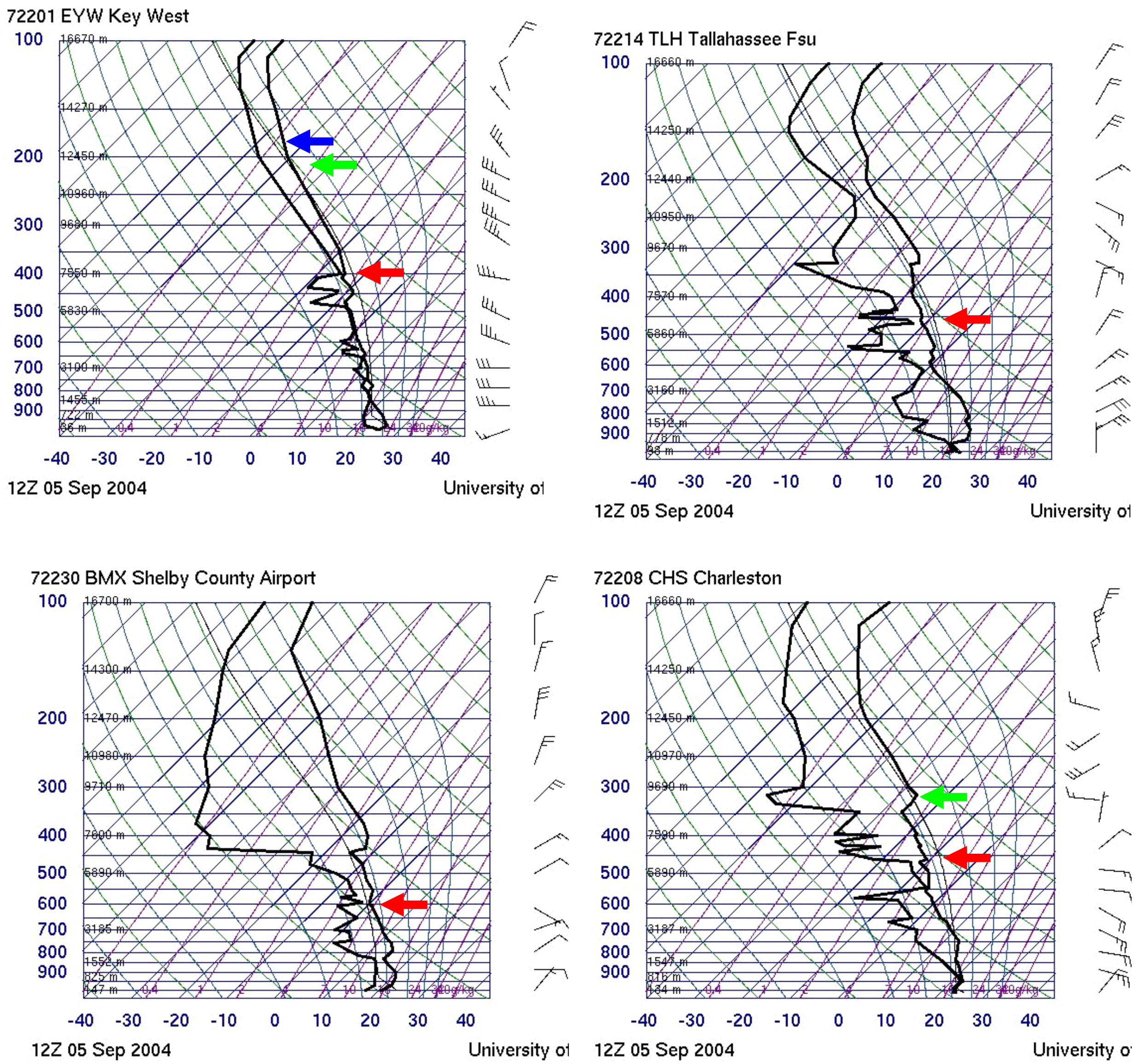

Fig. 9: *Sample rawinsonde plots in area of interest for 12 UTC 5 September 2004. The red arrows indicate the cloud top height based on the soundings, the green arrows indicate the NCTP cloud top height values, and the blue arrow indicates the CTOP height values. No clouds were indicated by the NCTP or CTOP products for TLH and BMX.*

As mentioned earlier, the cloud top height near KCHS from CTOP looked close to the RCTH. For larger radii, the CTOP best and peak values are quite close to the rawinsonde and NCTP values. Thus, the point difference may be due to slight displacements of the cloud top heights within CTOP.

Table 1 also indicates that the rawinsondes found a non-zero cloud top height for all locations where the CTOP and NCTP products agree with each other and are reporting clear skies (i.e. KTLH, KFFC, KBMX). In examining the raw sounding data (not shown), it was noted that KMHX, KBMX and KTLH all reported a single layer of relative humidity greater than 87%. This may be a thin cirrus cloud (or an anvil for KTLH as mentioned earlier) in these areas or just a layer of high RH with no clouds present. If it was a thin cirrus cloud the opacity of the cloud would not be great enough for the CTOP product to indicate clouds present in its diagnosis.

For three of the four sites (KMFL, KJAX, KCHS) NCTP reported cloud top heights that are greater than the CTOP heights, whereas the values for the fourth site (KEYW) matched quite closely. As the radius increases, the peak values of these two products become consistent with each other; however, the best NCTP match to the RCTH is still much higher for two of the cases (KJAX, KCHS). The ET and RCTP height values match relatively closely for the two sites where the radar ET product is reporting cloud top heights at the rawinsonde point. When increasing the ET radius to just 12-km, the KEYW, KMFL and KJAX ET and RCTP values match very well.

A quick look at the reported tropopause heights (also shown in Table 1) from the rawinsonde data shows that, for all the sites, the tropopause height is higher than any value from the CTOP, NCTP, and radar ET. This proves to be a good sanity check because the only scenario where clouds would be higher than the tropopause height would be within strong convection where overshooting tops are present, which is not the case here.

4. SUMMARY

For this case study, observations and diagnostics from 5 September 2004 were examined. This day was characterized by interesting and significant weather along the Florida Peninsula due to Hurricane Frances making landfall. All datasets (including the land based radar and rawinsondes) were also available along the coast line. Qualitative results show that the CTOP and NCTP products were similar. However, with a nominal resolution of 14 km in the region examined, the NCTP product did not capture the fine-scale details as well as the CTOP, which has 4 km resolution. The resolution also hindered the ET dataset, which displayed the maximum echo top in each 4x4 km box. For the rawinsonde data, balloons are launched twice a day at 00 UTC and 12 UTC, so the valid times can be difficult to match up with the CTOP. In general, the trends in both the ET and RCTH data provided analogous information regarding the minimum and maximum cloud top areas when compared to the CTOP.

Overall, the comparisons of all the different “observational” platforms with the CTOP product indicate good agreement much of the time for this case study. The higher resolution in the CTOP shows a greater detail with values that are consistent with the other types of observations.

		KEYW	KMFL	KJAX	KCHS	KTLH	KFFC	KBMX	KMHX
RCTP	**Point**	**25000**	**30000**	**13999**	**20948**	**20912**	**3435**	**14885**	**21476**
Trop Height	**Point**	**52710**	**NA**	**NA**	**51969**	**52310**	**52192**	**54790**	**53238**
CTOP	**Point**	**41908**	**37276**	**25365**	**0**	**0**	**0**	**0**	**6396**
CTOP 6km radius	Median	41467	37056	24924	0	0	0	0	0
	Peak	42790	37717	27351	6636	0	0	0	6396
	Best	41467	36835	24924	6636	0	0	0	6396
CTOP 12km radius	Median	41467	37276	26248	0	0	0	0	0
	Peak	42790	40364	31541	11663	0	0	0	6396
	Best	38820	36614	22057	11663	0	0	0	6396
CTOP 24km radius	Median	40805	37938	26468	0	0	0	0	0
	Peak	42790	42129	37497	32576	0	0	0	7940
	Best	35953	36614	18969	20309	0	0	0	7940
NCTP	**Point**	**40974**	**44321**	**36583**	**30066**	**0**	**0**	**0**	**0**
NCTP 6km radius	Median	40974	44321	36583	NA	0	NA	NA	NA
	Peak	40974	44321	36583	NA	0	NA	NA	NA
	Best	40974	44321	36583	NA	0	NA	NA	NA
NCTP 12km radius	Median	40096	44321	36583	6098	0	0	0	0
	Peak	44321	44321	38632	30066	0	0	0	0
	Best	39882	44321	33999	30066	0	0	0	0
NCTP 24km radius	Median	40096	44321	38632	6098	0	0	0	0
	Peak	44321	44321	38632	38632	0	0	0	0
	Best	33001	39353	32757	30066	0	0	0	0
ET	**Point**	**25000**	**20000**	**0**	**NA**	**0**	**0**	**0**	**0**
ET 6km radius	Median	25000	15000	0	NA	0	0	0	0
	Peak	30000	20000	15000	NA	0	0	0	0
	Best	25000	20000	15000	NA	0	0	0	0
ET 12km radius	Median	20000	15000	0	NA	0	0	0	0
	Peak	30000	25000	15000	NA	0	0	0	0
	Best	25000	25000	15000	NA	0	0	0	0
ET 24km radius	Median	25000	15000	0	NA	0	0	0	0
	Peak	35000	25000	15000	NA	0	0	0	0
	Best	25000	25000	15000	NA	0	0	0	0

Table 1: *Cloud top height comparisons for point to point and for the median, peak and best values within areas defined by 6-, 12- and 24-km radius around the RCTP height.*

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6. ACKNOWLEDGEMENTS

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