Transcript of talk presented for:
MS Thesis Presentation, 25th April 2005

SLIDE 1: Title

Today I am going to present some of the work from my thesis, in which I investigated the thermodynamic structure of tropical cyclones using aircraft reconnaissance data.

This work was done under the advisement of Prof. John Molinari.

SLIDE 2: Thesis Outline

So, what did I do for my thesis?

Well, I started out using a large amount of Air Force flight level data and created composite radial and vertical profiles of θ_e, which I categorised by storm intensity.

I then looked at Hurricane Bret from 1999. In this case study I looked at the θ_e evolution of a storm which intensified from a Tropical Depression to a Category Four Hurricane.

I next looked at Hurricane Claudette from 2003. For this I did a detailed case study of a storm which suffered from high vertical wind shear throughout its life. This storm did manage to achieve hurricane status on two occasions, although only for around six hours each time.

SLIDE 3: Thesis Outline

It is the results from the case study of Claudette that I will be discussing today.

The two points that I have mentioned here inspire some questions:
Firstly, how did Claudette manage to intensify to a hurricane when the shear was high?
Secondly, given that I mentioned that Claudette only maintained hurricane intensity for six hours each time, why was the hurricane phase so short-lived?

SLIDE 4: TC Genesis and Intensification

Before I go on to discuss the work I have been doing, I first want to review some methods posed for tropical cyclone genesis and intensification. I will also go on to review how shear can affect a hurricane.

So, first we have the role played by mid-level moistening. This has been discussed by Emanuel and Bister & Emanuel. Recall that in the tropics a θ_e minimum exists at mid-levels, about 600hPa. This situation is unstable to both updrafts and downdrafts. If we can moisten the mid-levels, we can bring the profile closer to neutrality, eliminating the instability and preventing cold downdrafts from reaching the surface and weakening the storm. But, you may ask, if we have a neutral profile, how are updrafts and convection going to occur and how is the storm going to form? Well, recall that one of the conditions for tropical cyclone genesis is that the disturbance must be over a warm sea surface. In this case, any energy supplied to the lowest levels of the atmosphere, by the warm ocean, will result in an unstable profile. Thus, we can have convection occurring, allowing a storm to form.

The second role, is that played by vertical wind shear. This is generally viewed as having a negative influence on both tropical cyclone genesis and intensification. This fact has been discussed by Bill Gray on many occasions and also Mark DeMaria has done some work investigating the effect shear can have on tropical cyclone intensification. Shear is also listed as a negative factor in both the SHIPS and CHIPS hurricane intensity prediction schemes, I believe. However, in the early stages of tropical cyclone genesis, shear can actually play a positive role. In case studies of Hurricane Danny from 1997 and Hurricane Gabrielle from 2001, Molinari et al found that the shear acted to form a new downshear vortex under the enhanced downshear convection. This new vortex can interact with or merge with the existing vortex, and may even become the dominant vortex. These vortex interactions increase the vorticity at low levels on a scale larger than the individual vortex, acting to intensify the storm.

<u>SLIDE 5:</u> WISHE Hypothesis

The only formal theory regarding tropical cyclone genesis is that posed by Emanuel in 1986 – the WISHE hypothesis, or wind-induced surface heat exchange.

The WISHE hypothesis is built on two key assumptions:
That there is a pre-existing axisymmetric, surface concentrated disturbance, and that this disturbance be symmetrically neutral. By symmetric neutrality, I mean that θ_e and angular momentum are conserved during vertical motions occurring close to the storm centre.

WISHE is basically a feedback mechanism between surface winds and surface fluxes. Where the wind blows over the warm ocean, there is a flux of energy to the lowest levels of the atmosphere. This energy is then distributed through the depth of the troposphere by deep convection, under the symmetric neutrality assumption. This acts to warm the column and decrease the surface pressure, which in turn causes higher winds, more fluxes... and we have the feedback.

In 2003, Roger Smith modelled the boundary layer for an axisymmetric hurricane, Importantly, he did not include cold downdrafts in his model. Smith calculated radial profiles of θ_e and latent and sensible heat fluxes, and he found his results generally supported the WISHE hypothesis.

However, in the early stages of tropical cyclone formation, the two WISHE assumptions are rarely met. So, how do we manage to get tropical cyclones that spin-up to hurricanes?

<u>SLIDE 6:</u> Pre-WISHE Hypothesis

Well, Molinari et al in 2004 proposed the pre-WISHE hypothesis to try to explain that.

In this phase of development, we can have wind shear acting to create strong asymmetries and we <u>can</u> have strong buoyant convection and cold downdrafts occurring. The pre-WISHE phase works through a two-fold method, including:
Firstly, vortex merger processes, where individual vorticity maxima at low-levels interact with each other, resulting in merger and axisymmetrisation of the individual vorticity maxima. This gives an increase in the low-level vorticity on a scale larger than the individual vorticity anomalies.

Secondly, through convective mixing, the profile can become more nearly neutral and prevent cold downdrafts from reaching the surface.

Through these processes, the system can approach a state where WISHE is valid and a hurricane can form.

SLIDE 7: Background – Shear

So, as I mentioned earlier, I am going to be presenting a storm that was subject to strong shear, so I thought I should review the effects shear can have on a hurricane vortex.

The most fundamental effect shear has on a hurricane is to tilt the vortex down shear. In numerical modelling studies, such as Frank and Ritchie and observational studies, such as Corbosiero and Molinari, it has been shown that enhanced convection and the maximum upward motion is expected downshear and downshear-left of the storm centre. Also, dynamically induced downdrafts cover a large area upshear.

I show here a schematic diagram of the mature hurricane eyewall under the influence of shear. The large grey arrow represents the low-level storm-relative flow, and the smaller, blue arrows represent the upper-level storm-relative flow, so we have westerly shear in this example. The swirling black arrows represent the storm's own circulation.

Looking first downshear of the storm centre, updrafts are initiated and rise helically through the eyewall, advected by the storm's own circulation. As the air rises in these updrafts, condensation occurs and precipitation forms, resulting in a reflectivity maximum downshear-left. As the updrafts continue to rise, the precipitation changes over to the ice phase, so we have a continuation of the reflectivity maximum to upshear. By this time, the majority of the precipitation has fallen out of the updrafts, and the updrafts have reached the upper troposphere. So we now have mainly downdrafts occurring upshear.

OK, having summarised the effects shear has on a mature hurricane vortex, I want to mention one other influence shear can have on a hurricane.

In the numerical modelling studies of Sarah Jones and Paul Reasor et al, it was found that although the vortex is initially tilted downshear, the upper and lower circulations or PV maxima can precess cyclonically around each other in an effort to offset the effect the shear is having. In this instance, the upper-level circulation can find itself upshear of the lower-level circulation.
Now, I will be coming back to these ideas later, but first let me show you what I have been working on.

SLIDE 8: Claudette (2003) – Case Study

As I mentioned earlier, my main source of data in this study is from US Air Force reconnaissance flights, which includes flight level observations and dropsondes.

I also used infra-red, visible and microwave imagery to investigate the convective structure of Claudette, although I won't be showing any visible imagery today.

I used ECMWF analyses on a $1^{1}/_{8}{}^{th}$ by $1^{1}/_{8}{}^{th}$ degree grid-scale to calculate the shear

Claudette experienced.

The centre positions of Claudette were obtained from the NHC Best Track, although I modified this for one flight so the centre positions agreed better with the flight level circulation centre fixes.

<u>SLIDE 9:</u> Track, Pressure and Windspeed

A quick overview of Claudette. In the top, right panel I show the track of Claudette, which passed through the Lesser Antilles as a tropical or easterly wave late on the 7th July 2003. The system continued west-north-westwards and was upgraded to a tropical storm at 18 UTC on the 8th July. Early on the 10th, the storm started to move more north-westwards and was upgraded to a hurricane at 12 UTC on the 10th. However, this intensity was only maintained for six hours. The storm continued north-westwards across the Yucatan and into the Gulf of Mexico. It eventually turned westwards and made landfall in Texas as a hurricane. The period of study I have focussed on is shown by the red line and begins at 00 UTC on the 9th July and ends at 00 UTC on the 11th.

In the lower left panel I show the pressure and windspeed trace for the time period shown for the track. Pressure is in burgundy and windspeed in blue. I have also outlined the case study period by the vertical red lines and the time at which Claudette is upgraded to a hurricane is indicated by the H1, which was at 12 UTC on the 10th July. As you can see, the intensification to a hurricane was accompanied by a sharp decrease in pressure, an equally sharp increase in pressure accompanied the subsequent weakening.

<u>SLIDE 10:</u> 850-200hPa Shear

I calculated the vertical wind shear Claudette experienced for the layer 850-200hPa. Here I show the shear magnitude and direction for the entire period of Claudette's existence. Again, the case study period is bordered by the two vertical red lines and the time at which Claudette was upgraded to a hurricane is indicated by the H1 symbol.

During the case study period, the shear was mostly south-westerly and fluctuated between about 9 to 17ms^{-1}. Interestingly, Claudette became a hurricane when the shear was 16ms^{-1} and still increasing to a maximum of 16.7ms^{-1} at 18 UTC on the 10th.
Another interesting point is that a large portion of Claudette's life occurred when the shear was greater than 12.5ms^{-1}. This value is considered a cut-off, above which storm's can no longer sustain themselves. However, we have Claudette actually intensifying to a hurricane with shear much greater than this value.

So, what was going on in this storm that enabled it to resist the strong shear and intensify?

Before I go on to try to answer this question, I am first going to show a satellite animation of Claudette.

<u>SLIDE 11:</u> IR Animation

<u>http://www.atmos.albany.edu/student/kay/03cir.html</u>

➔ *Advance one, then back one to Frame No. 0.*

Let me first of all orientate you to this image. The small, white dot is the storm centre. The cloud top temperatures of the red and dark red colours range from approximately -70°C to -80°C and the bright yellow colour that forms inside the dark red colours represents temperatures less than -80°C.

OK, so I will run the animation through a couple of times.

➔ *Press the animate frames forward button, then adjust speed to slow a few times.*

As this runs through, you will see deep convection continually occurring downshear of the storm centre. Also repeated pulses of convection develop over the storm centre.

➔ *Stop at Frame No. 26.*

OK, so we are now looking at Claudette at 0215 UTC on the 10th, some ten hours before the storm is upgraded to a hurricane. What we see is a strong convective burst occurring just to the north-north-east of the storm centre.

➔ *Step forward one. (27)*

As we step forward in time, we see the cirrus shield associated with this convective burst expand to cover the storm centre.

➔ *Step forward one. (28)*

The deep convection then remains fairly close to the storm centre as time goes on.

➔ *Step forward to Frame No. 36.*

We are now at 1215 UTC on the 10th. This is the time at which Claudette was upgraded to a hurricane. At this time, the deepest convection, indicated by the darkest reds seems to make a swirling pattern within the deep convection, and actually, the storm centre is located within this spiral of deepest convection.

➔ *Step forward 2. (38)*

As we continue to step forward in time, the cloud tops over the storm centre warm.

➔ *Step forward 3. (41)*

And the convective bursts start to develop further downshear of the storm centre.

➔ *Step forward 3. (44)*

The storm centre is now located on the very edge of the cirrus shield.

➔ *Keep stepping forward to the end. (48)*

Convection is now occurring far away from the storm centre.

SLIDE 12: Flight 6 – Composite Observations

Right, now I am going to show some of the flight level data. Here I show observations from the entirety of Flight 6, which was flown at 850hPa. The observations shown here represent a time period of approximately three hours, centred on the time of the IR image, 0715 UTC on the 10th July. This is about five hours prior to the time Claudette was named a hurricane.

Each of the observations shown here has been relocated relative to the moving storm centre to form the composite. So, each observation is located in the position it was in, relative to the storm centre, at the time the observation was made.

What these observations show is a small, closed circulation located under deep convection. The small circulation is embedded in a larger-scale wave, which is not surprising, since Claudette formed from an easterly wave.

SLIDE 13: Fl. 6 Pass 1 – Centre Cross-section

I am now going to show some observations from the flights into Claudette. I start here with the first pass of the storm centre in Flight 6. As I said earlier, this flight was at 850hPa, the pass began to the north-east of the storm centre or downshear and ended south-west of the centre or upshear. The aircraft passed the storm centre at 0601 UTC, about six hours before Claudette became a hurricane.

Let me quickly explain some of the details of these figures. The horizontal axis shows a 30 minute time period, which represents a horizontal distance of around 150 to 200km, depending on the actual flight track the pass takes. I am going to be mentioning D-value and D-value depression a lot in the following figures. You can think of the D-value as a height anomaly from the standard atmosphere value. When I talk about the D-value depression, I am simply referring to the difference in D-value between the start or end of the centre pass and that at the storm centre. I indicate the D-value depression by the red vertical arrow and give its magnitude.

OK, so in this pass of the centre, the D-value depression is 50m and the D-value minimum is collocated with the flight level circulation centre. This circulation is quite asymmetrical, with low windspeeds on the upshear side and much higher windspeeds, near 40-50kts, downshear. Looking at the θ_e profile for this pass, no sign of the asymmetry shows up. We have high θ_e values near the storm centre, decreasing by about 10K over approximately 80km either side of the centre. The temperature and dewpoint profiles show we have a warm core system with fairly moist air both downshear and upshear of the centre.

SLIDE 14: Fl. 7 Pass 1 – Centre Cross-section

We now look at observations from a later pass of the storm centre. Here I show the first pass of the centre from Flight 7, also flown at 850hPa. This pass reaches the storm centre at 1201 UTC, six hours after Pass 1 of Flight 6, which I just showed. This is the time when Claudette is upgraded to a hurricane. The flight track for this pass is a little odd, so let me first explain that. The aircraft starts off around 75km west-south-west of the storm centre, it then spirals inwards towards the centre, passing through south-west and south. The aircraft passes through the storm centre from south to north, and then exits towards the north-east then south-east.

So, at this time, we now have a D-value depression of 145m, a 95m increase in magnitude over the past six hours. The D-value minimum is collocated with the flight level circulation centre. In the windspeed profile, the circulation is much stronger, reaching close to 80kts. If we allow for storm motion, the windspeed profile is fairly symmetric about the storm centre. Looking at the θ_e profile for this pass, the same asymmetry is not present. We still have high θ_e values at the storm centre, now close to 360K. However, approximately 30km upshear we have <u>much</u> lower θ_e values, below 340K. So there is a very strong θ_e gradient between the storm centre and just upshear of the centre, over 20K decrease in θ_e in just over 25km.

In the temperature and dewpoint profile, we see we still have a warm core system, however we now have very dry air just upshear of the centre at 850hPa.

<u>SLIDE 15:</u> Surface Observation

Now, luckily, as the aircraft passed through the centre of Claudette in the first pass of Flight 7, the crew released a dropsonde. The IR image I show here is from 1215 UTC on the 10th, the time at which Claudette was named a hurricane. Also note that there is no discernible eye in the IR image at this time.

The surface wind observation from the dropsonde is indicated on the plot by the 65kt, cyan wind barb. The 850hPa wind observations from the centre pass I just showed are shown by the white wind barbs. I have also added some 700hPa observations as the the plane exited the system to the south-east, these are the black barbs. The storm centre at the time of the dropsonde is indicated by the white dot.

So, basically, what this figure shows is that from the surface to 850hPa there is virtually no tilt in the vortex, despite the high shear the system is experiencing at this time.

<u>SLIDE 17:</u> Flight 7 – Composite Observations

OK, so now I am going to go on and show the rest of the observations from Flight 7, these are all from the 700hPa flight level. Again, here I show a composite of observations, which span a time period of 4½ hours and is centred on the time of the IR image, 1415 UTC on the 10th, about 2 hours after Claudette is named a hurricane. Recall that in these composite plots, each observation is relocated relative to the moving storm centre.

This figure shows that the system consists of a small-scale vortex embedded within a larger-scale wave. Note that the embedded circulation is still under deep convection.

<u>SLIDE 17:</u> Fl. 7 Pass 2 – Centre Cross-section

So, lets now look at some of the actual 700hPa observations. Here we have the second pass through Claudette. The pass is made from north-east, downshear, to south-west, upshear, and traverses the centre at 1352 UTC, around two hours after Claudette is named a hurricane.

The D-value depression at this level is 100m and the D-value minimum is collocated with the the flight level circulation centre. The circulation is fairly symmetric, allowing for storm motion, with maximum winds near 70kts. The smaller D-value depression and slightly weaker winds at this level compared to those we have just seen at 850hPa are consistent with a warm core vortex, where the intensity of the vortex must decrease upwards.

The θ_e profile for this pass is also fairly symmetric and we have generally high θ_e values at the storm centre, with lower θ_e values either side of the centre. Notice that either side of the general θ_e maximum is a spike of much higher θ_e values. Now, each spike is located just radially inside the radius of maximum winds on either side of the storm. In the temperature and dewpoint plot, we see these high θ_e spikes are associated with saturated air, indicative of a eyewall, with the warm, dry air of the eye inside. However, literally just upshear of the eyewall to the south-west, is a large area of dry air. The air on the downshear side is still fairly moist.

SLIDE 18: 1330UTC/10th – SSM/I

Luckily, while Claudette was a hurricane, there were a couple of overpasses of the system by satellites carrying microwave instruments. Firstly there was the SSM/I overpass at 1330 UTC on the 10th. This is around 30 minutes before the observations I showed in the previous centre pass. Both images I show here come from the 85GHz channel. This channel is generally sensitive to scattering by ice phase precipitation.

On the left I show the horizontal polarisation of the 85GHz channel, with the W enhancement. This enhancement highlights higher brightness temperatures than the regular H enhancement. Thus warmer or lower level clouds in the blue shades show up against the green sea surface. Deep convection shows up in the reds and blacks, the lowest brightness temperatures. In this image, the deep convection makes a curved band, spiralling in around the flight level circulation centre. The small black arc makes the eyewall we just saw in the flight level observations.

The image on the right shows the PCT composite of the horizontal and vertical 85GHz polarisations. This isolates convection since it is sensitive to un-polarised scattering by large ice phase precipitation in deep convective cores. Basically this shows there is deep convection occurring in the eyewall.

SLIDE 19: 1456UTC/10th – TRMM

Around 90 minutes after the SSM/I overpass, there was an overpass by the TRMM satellite.

Again, here I show images from the 85GHz microwave channel. The left image is the pure horizontal polarisation, so colder brightness temperatures show up compared to the image I showed for the SSM/I overpass. Again, we see deep convection occurring in what appears to be a partial eyewall. Just inside this arc of deep convection is a small area with a much higher brightness temperature, i.e. an eye. The location of this corresponds exactly to the location of the flight level circulation centre at this time.

The right hand image is a colour composite, which combines information from the horizontal and vertical polarisations along with the PCT to give a qualitative view of the convective structure. Deep convection is shown by the reds, low level clouds are in the blue-green colours and cloud free or dry regions are indicated by the grey areas. This image shows the deep convective arc of the partial eyewall, and the eye with the lower level clouds inside.

SLIDE 20: Intensification Summary

To summarise what we have seen in the intensification phase of Claudette, in the IR animation we saw repeated convective pulsing over the storm centre. Initially, a small vortex formed, embedded within the larger-scale wave structure. From dropsonde and flight level observations we saw that the vortex remained aligned from the surface to 850hPa, despite the strong shear the system was feeling at the time. As the vortex deepened and intensified, an eyewall structure developed which was well defined by high θ_e values and strong winds in the flight level observations. This convective structure associated with the eyewall and the eye could also be seen in microwave imagery.

However, we saw dry air persistently upshear of the storm centre, with all of the moist air remaining downshear. Also, the storm attained hurricane intensity at a time when shear was high and still increasing. So, if the storm was experiencing strong shear, we would expect convection to develop downshear of the centre, but instead we have convection pulsing over the centre. How did this occur, and how was the storm able to resist the shear and intensify to a hurricane?

Well, I will come back to these issues, but first I am going to show the weakening phase of Claudette.

SLIDE 21: Fl. 7 Pass 3 – Centre Cross-section

Here I show the third pass through Claudette from Flight 7, again this is at 700hPa. The flight passed through the centre at 1526 UTC on the 10th, around 30 minutes after the TRMM overpass. The pass of the centre began in the south-east, or right of shear, and ended to the north-west, or left of shear.

Once again, the D-value depression is 100m and the D-value minimum is collocated with the flight level circulation centre. The winds are still fairly strong, near 80kts, and we still have a θ_e maximum at the storm centre, although slightly reduced from the previous pass. The system is still warm core, however we now have areas of dry air on either side of the storm, both right and left of shear.

SLIDE 22: Fl. 7 Pass 4 – Centre Cross-section

This pass of the centre of Claudette took place approximately an hour and 40 minutes after Pass 3. The Air Force had a lot of trouble trying to find a flight level circulation centre in this pass, but they did eventually manage. Hence, the flight track is slightly odd, the pass starts off to the south-west of the centre, then as the centre is approached, the track meanders north-west and north-east while generally in a northward direction.

There is only a small D-value depression for this pass. There is a D-value minimum, and it is collocated with a weak flight level circulation centre. There is no sign of a θ_e maximum at the centre and generally θ_e values are low at this time. In fact, the storm centre is characterised by cooler, near-saturated air, with a large area of very dry air just upshear.

<u>SLIDE 23:</u> Weakening Summary

To summarise the weakening phase of Claudette, we saw dry air persistently upshear and also to the left and right of the shear vector at 700hPa. We saw that the strong, small-scale vortex did exist at least until 1330 UTC, but just over 90 minutes later no sign of the strong circulation or large D-value depression could be found in Pass 4.

So, what could have been going on to bring about this rapid weakening?

Well, the dry air in the three quadrants of the storm could have allowed cold downdrafts to occur and weaken the storm. Advection of the dry air at mid-levels around the storm by its own circulation may also have brought about the weakening.

<u>SLIDE 24:</u> Comparison with Theories

Going back to the tropical cyclone intensification theories I mentioned at the beginning. How do these compare with what we have seen happened in Claudette?

Firstly, the role of mid-level moistening, or in the case of Claudette, the lack of mid-level moistening. I mentioned at the beginning that this was an important factor for allowing tropical cyclone genesis and intensification, but we have dry air present at mid-levels. Why then wasn't this a factor in the spin up and yet seems to have been very important in the weakening phase of Claudette?

I attempt to explain this using this schematic. Initially, we have shear acting on our tropical storm. This gives dry air upshear and moist air downshear. Although we have a circulation associated with our tropical storm, it is not so strong that the dry air is advected downshear. So, our storm remains as it is. But, as the storm spins up to a hurricane, the circulation strengthens. The circulation is now strong enough to advect the dry air located upshear, round the storm to downshear. This allows cold downdrafts to form downshear, which can eliminate the surface-based warm pool the convection had been feeding off, stabilise the profile, thus weaken the storm.

The second important factor in tropical cyclone intensification that I mentioned at the beginning was the role played by vertical wind shear. I explained that this acts to create dry and moist anomalies and forces convection downshear. I also mentioned that shear is generally considered a negative factor for intensification. However, since we have seen a tropical storm maintain itself and intensify to a hurricane while subject to strong and increasing shear, it would seem shear was not playing a exclusively negative role in this case. So, how did our storm manage to sustain itself and intensify with such high shear?

<u>SLIDE 25:</u> Comparison with Theories (cont.)

Carrying on with the various theories, I discussed at the beginning the WISHE and pre-WISHE hypotheses. These work through vortex interactions and convective mixing to create a symmetric, neutral system that can intensify, through the feedback mechanism, to a hurricane. However, in the reconnaissance data we can find no evidence of multiple vortices in Claudette, so presumably vortex interactions could not have occurred. Also, the θ_e profile in Claudette remains distinctly not WISHE-like, but a hurricane still manages to form!

So, how, when all conventional theories indicate a hurricane should not form, does one form?

Well, we pose the following theory......

SLIDE 26: Hypothesis

Imagine we are in situation A. We have a 700hPa circulation located upshear of a surface circulation. How could the system have got into this orientation? Well, recall the modelling results of Sarah Jones and Paul Reasor et al that I mentioned earlier. Although shear initially tilts the vortex downshear, the system can attempt to offset the effect of the shear by the upper and lower circulations or PV anomalies precessing cyclonically around each other. If this continues far enough, the upper PV maxima or circulation can find itself upshear of the surface circulation. In this situation we have dynamically induced motion occurring downshear of the 700hPa circulation, which excites convection over the surface circulation. The shear is then acting to advect the 700hPa circulation over the surface circulation, resulting in situation B.

At this time, the circulations are vertically aligned, strong convection breaks out, spinning up the low-level vorticity. All our conventional theories can now come into play and rapid intensification ensues.

However, the shear is still acting to advect the 700hPa circulation further downshear, situation C. At this point, the two circulations decouple and we now have dynamically forced descent occurring over the surface circulation. Altogether this brings about weakening.

SLIDE 27: Conclusions

So, that was the hypothesis for Claudette. To conclude, despite Claudette managing to overcome the strong shear and becoming a hurricane, it was never going to last for long. The shear was simply too large making conditions unfavourable for sustained intensification.

However, the fact that this system did manage to survive and intensify as it did arouses one particular question:

If this storm managed to do it, how many more of these embedded, mini-hurricanes have existed and have been missed?

There now exists a relative abundance of flight level and dropsonde data available from the US Air Force's missions into developing tropical cyclones. If more of this kind of system have existed, we should be able to find them. If they are fairly common, then the NHC forecasters will have to address the issue of being able to predict such small and short-lived hurricanes.

Thank you!