Determining the potential for Tornadoes in Northeast Caribbean Cyclones

Tornado in Antigua during Tropical Storm Chantal on 9 July 2013

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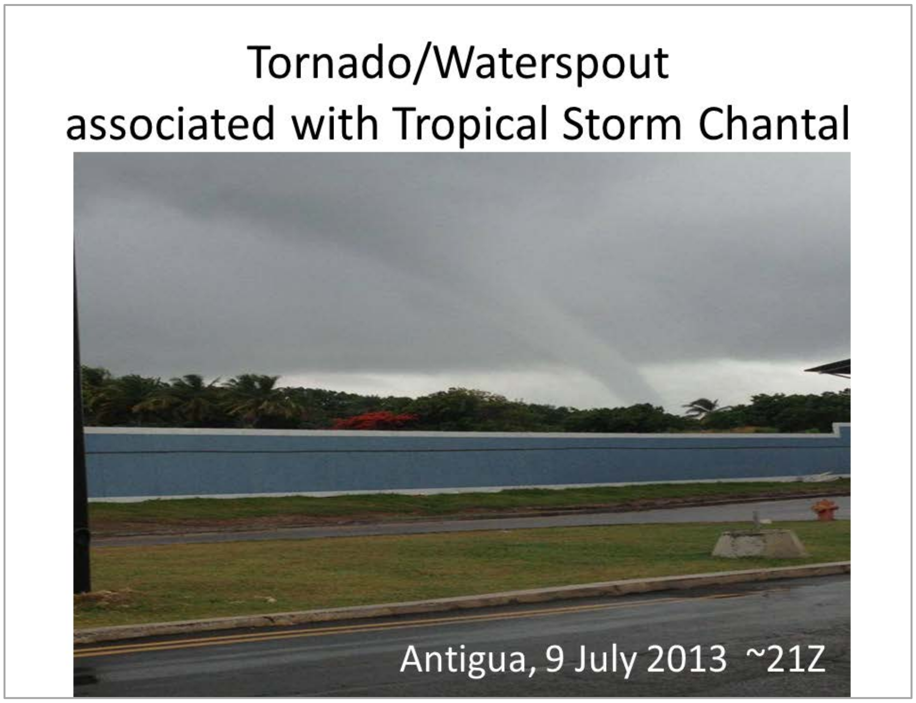
Location of Antigua

Latitude: 17.1 Degrees North
Longitude: 61.8 Degrees West

Climate of Antigua

-Average Temp: 26.5 degrees celsius
-Average Annual Rainfall: 44 inches
-Wet Season : Jul – Dec
-Dry Season : Jan - Jun



A tornado affected the northeastern Caribbean island of Antigua during 9 July 2013 in association with Tropical Storm Chantal. The tornado occurred around 21Z and formed over waters to the east/southeast of the island and moved inland affecting areas to the north of the airport. Pictures and videos of the tornados are available.

Possible reasons for not forecasting tornadoes

- Low confidence
- Tunnel focus (more concerned with the three major hazards oftentime associated with tropical cyclone).
    - Storm surge
    - Flooding
    - Wind

No Tornado watches/warnings are issued in Antigua. This is even true when a Tropical Cyclone approaches such as Chantal. When a cyclone is in the vicinity, forecasts focus on the three major hazards associated with Tropical Cyclones. These are storm surge, rain-induced flooding and wind damage. The potential for tornadoes is not evaluated, but it can matter. A goal of this study is to improve the detection of the potential for tornadoes in association with tropical cyclones with the ultimate goal of designing a watch/warning system for such risk.

Literature review:

Potential for Tropical Cyclone Tornadogenesis

- According to (Hales 1988; Grazulis 1993), the predominant convective storm type for tornadogenesis in Tropical Cyclones appears to be the supercell.
- (John and Doswell 1992) also used an ingredient – based approach and suggest that the forecasting environment favourable for supercell TCs involves four major ingredients. Moisture, instability, lift and wind shear.

Supercells are the most common sources of tornadoes associated with Tropical Cyclones. These types of supercells are often shallower than those that develop during continental severe weather events. The ingredients described in the literature as being the most relevant to the development of tornadoes are moisture, instability, lift and wind shear.

Correlation coefficients (derived from multiple linear regression) between the number of tornado reports in the same quadrant of TC in a 12h interval vs each of the indicated geographic and atmospheric parameters (Oderlinde, 2009)

Parameter	Correlation		Parameter	Correlation	
Hour of report	0.27		Temp 500	-0.01	
Hours after landfall	0.16		Temp 550	-0.03	
Hur. Wind Speed	0.17		Temp 600	0.00	
CAPE sfc	-0.21		Temp 650	0.03	
CAPE 1000-900	-0.14		Temp 700	0.00	
CAPE 1000-950	-0.16		Temp 750	0.01	
RH 500	0.32		Temp 800	0.02	
RH 550	0.30		Shear 0-1 km	0.47	
RH 600	0.25		Shear 0-3 km	0.51	Present
RH 650	0.15		Shear 0-6 km	0.48	
RH 700	0.16		SRH 0-1 km	0.49	
RH 750	0.11		SRH 0-3 km	0.50	
RH 800	0.04		Sin az angle wrt flow	0.47	Present
			Sine az angle wrt N	0.48	

Onderlinde (2009) developed a thesis on tornadoes in Tropical Cyclones that affected the southeastern USA. He tested different parameters and established simple correlations. The highest correlations were identified with low-level shear, storm relative helicity and the storm quadrant. From these parameters, the ones clearly present in the Antigua 9 July 2013 case study were low-level shear and the location within the storm quadrant favorable for tornadogenesis.

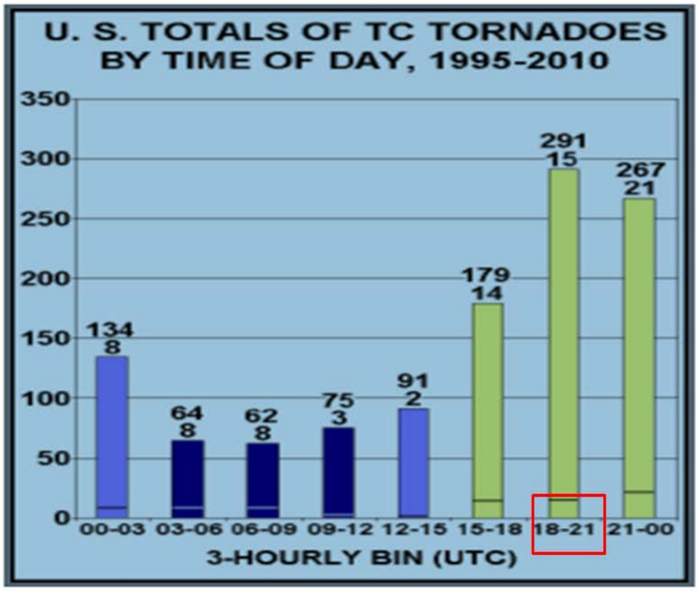
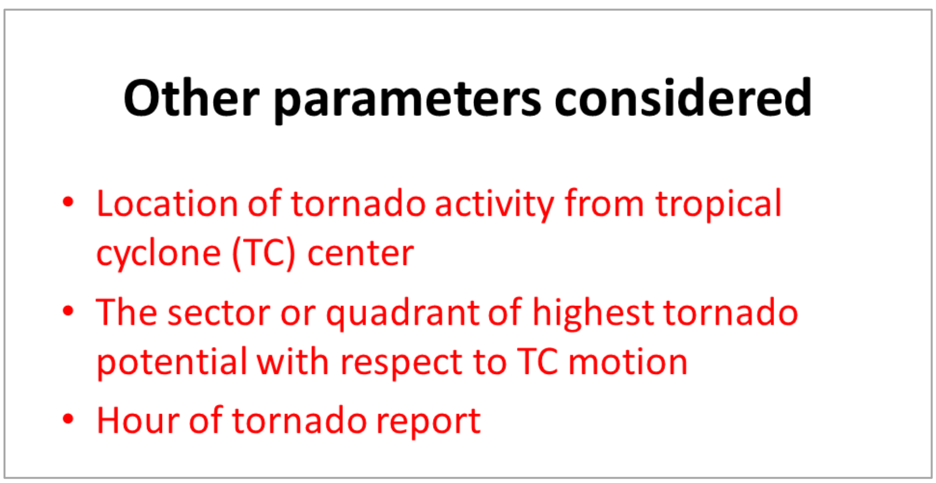
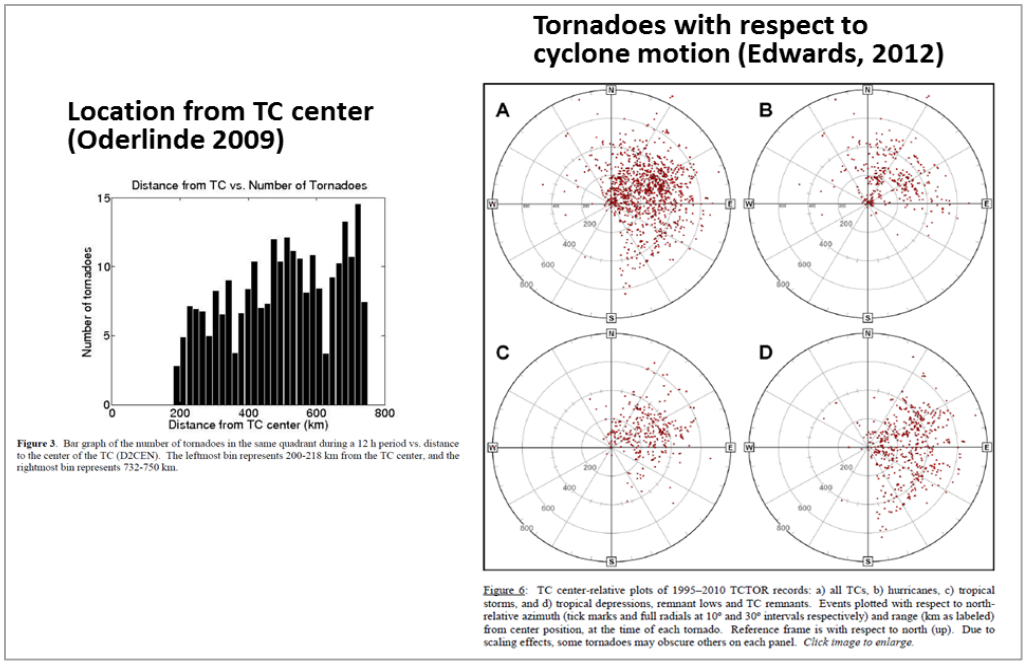


Figure 5: Time bins of 1995–2010 TCTOR events, starting with local evening period (0000–0300 UTC) on the Gulf and Atlantic coasts. Yellow bars denote peak periods and

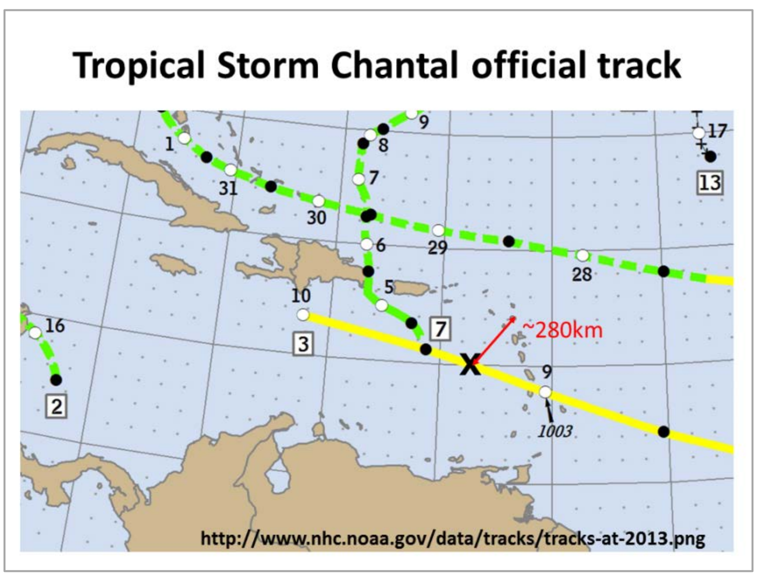
Onderlinde (2009) also showed that tornadoes associated with Tropical Cyclones follow a diurnal cycle. They peak near 18Z and 00Z, which is the end of the afternoon/early evening in the southeastern USA. The tornado in Antigua occurred within this period as well, consistent with the findings of Onderlinde (2009). It should be yet noted that the diurnal cycle in the Southeastern USA might be stronger than in the northeastern Caribbean due to the differences in land-water coverage.



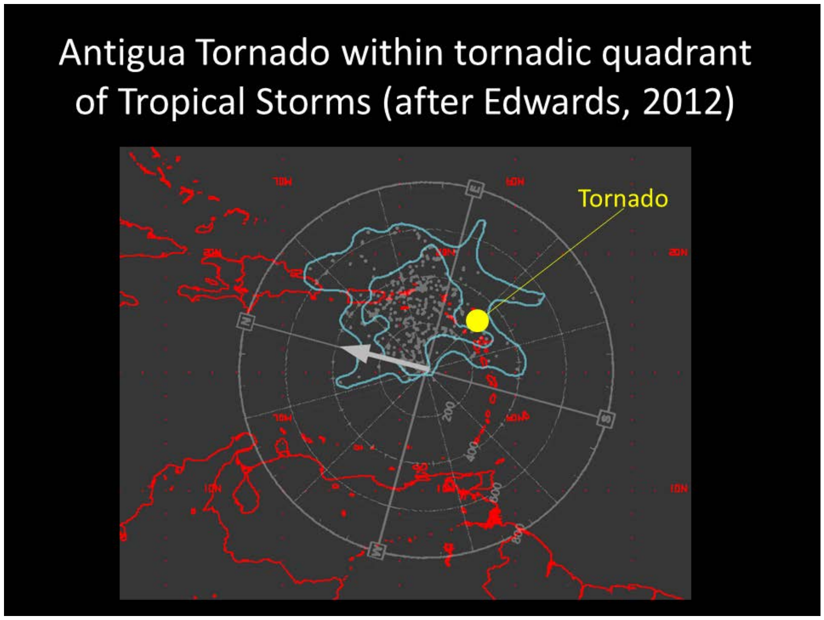
Thus, other parameters considered in the study were the location of the tornado with respect to the tropical cyclone center (quadrant/sector), the distance to the cyclone center and the time of the day when the tornado occurred.



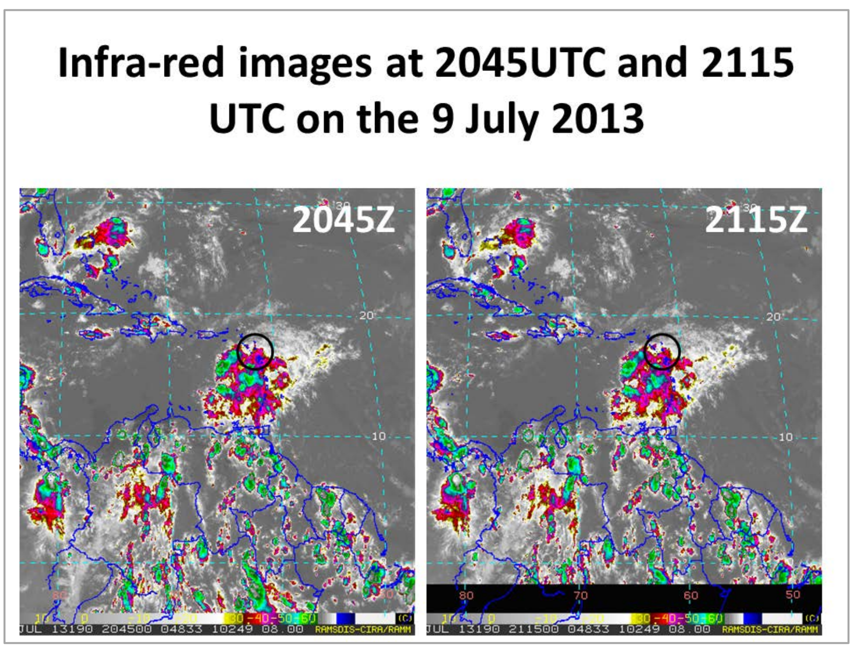
Onderlinde (2009) also showed the distribution of tornadoes with respect to distance from the center of the storm (left), and within the storm quadrant and intensity (right). It shows that most tornadoes occur between 200km and 750km from the storm center. It also shows that the distribution of tornadoes with respect to storm quadrant vary upon storm intensity. In stronger cyclones such as hurricanes most of the tornadoes occur in the right front quadrant of the storm. They relocate to the lower right front quadrant and right back quadrant as the cyclones become weaker (e.g. tropical depressions).



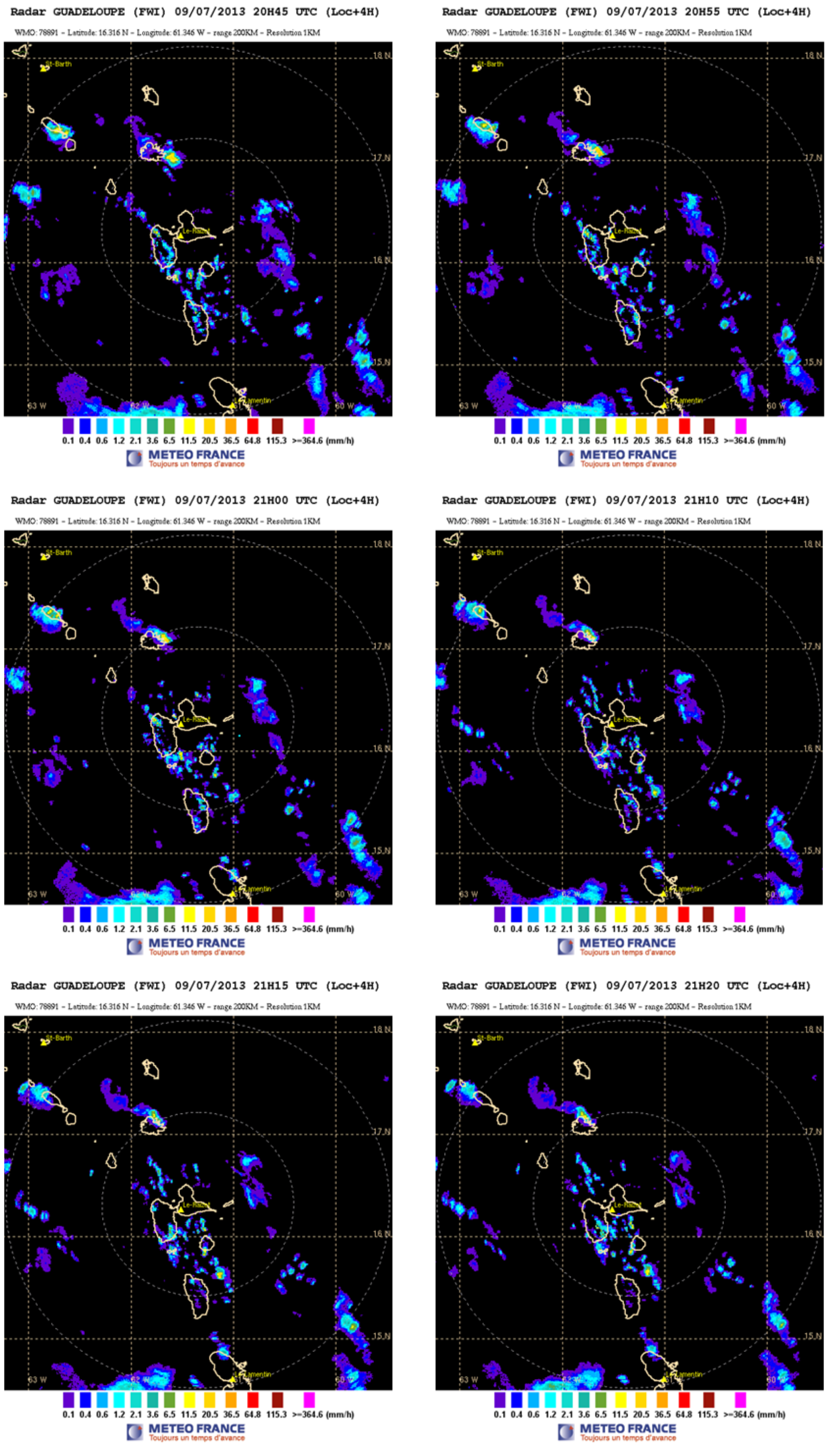
The National Hurricane Center Final Storm Track Analysis shows that weakening Tropical Storm Chantal was located at 280km to the west-southwest of Antigua during the time when the tornado occurred. This was consistent with the findings of Oderlinde (2002).



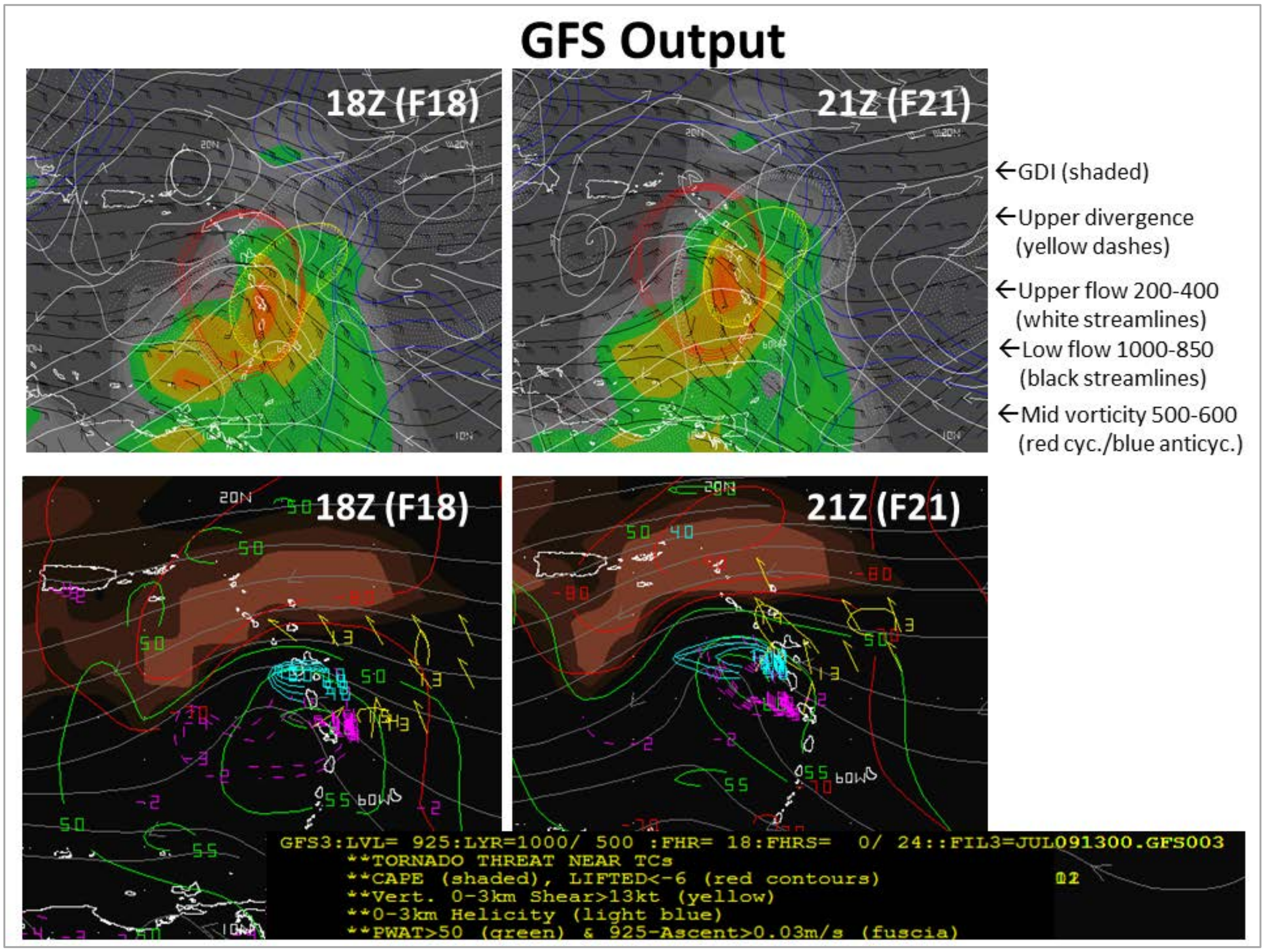
This slide shows the location of the tornado overlaid to Onderlinde (2002)' tornado-storm quadrant analysis for tropical storms. The tornado was located in the right back quadrant at a distance closed to that of the maximum density of tornado observations during this period.



The RAMSDIS IR4 satellite image shows the cluster of convection associated with the disorganized Tropical Storm Chantal affecting the Lesser Antilles during the time when the tornado was reported. No organized convection and clear banding features were visible, but scattered-to-widespread thunderstorms were occurring in the region.

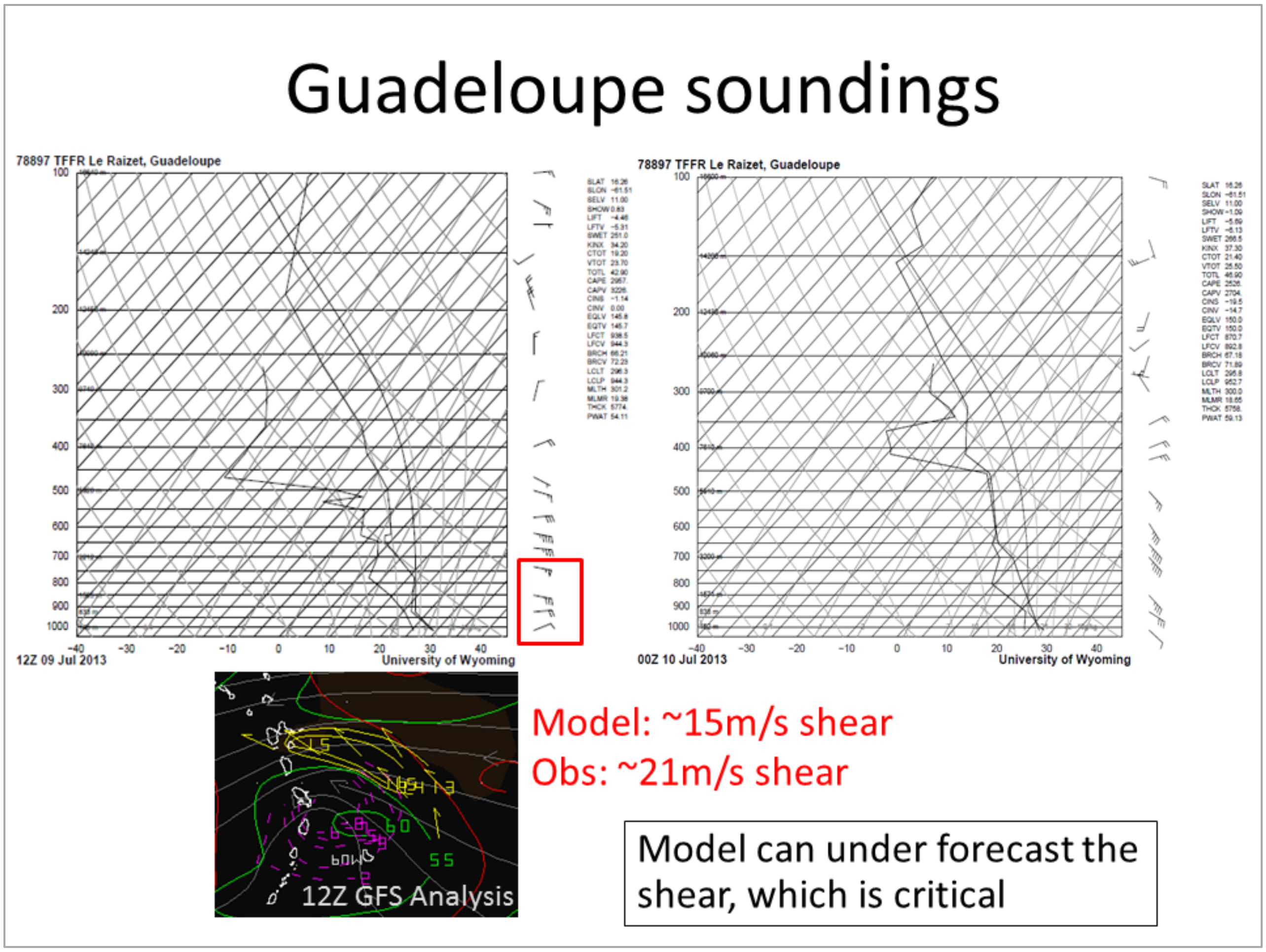


This six-panel composites shows data from the Guadeloupe radar during the period when the tornado occurred. The reflectivity data suggest the presence of a strong thunderstorm (potential supercell) moving from the east-southeast into northeastern Antigua. Convection in the periphery of Chantal was organized into discrete cells more than into banding.



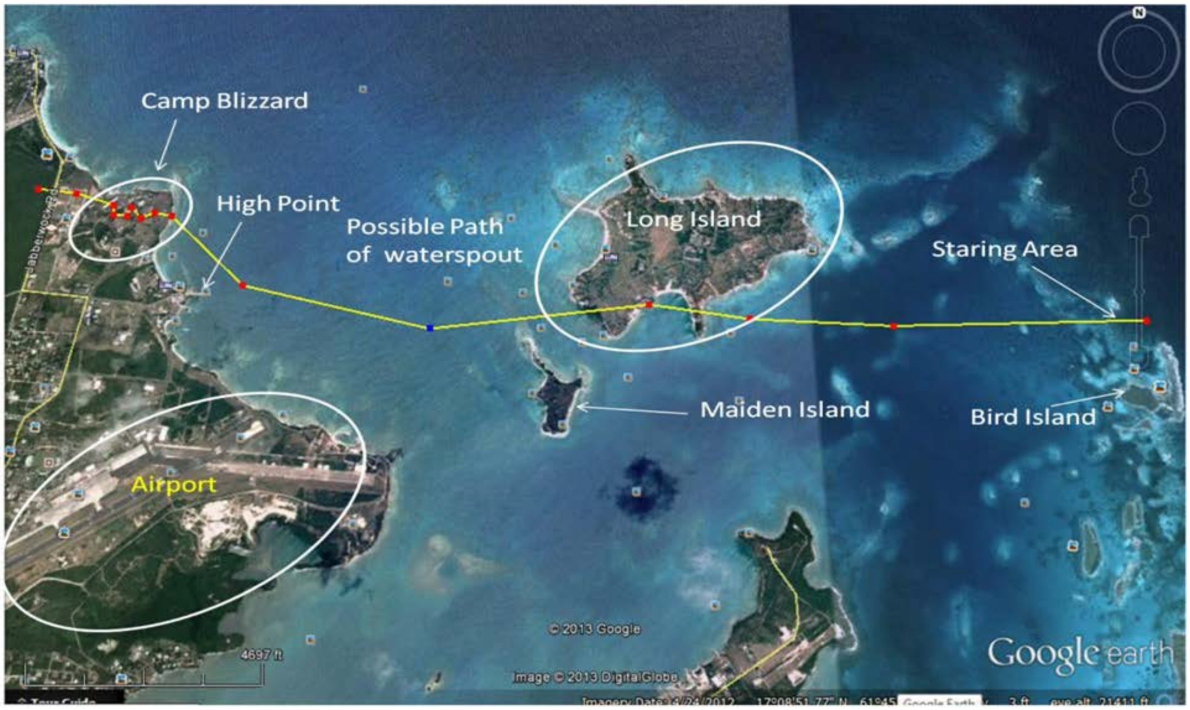
Several of the parameters that showed enhanced correlations in Onderlinde (2002) were calculated from GFS model data to estimate their role on the 9 July 2013 case and assess potential predictability. From all the parameters, the one that showed a clear signature was 0-3km bulk shear (yellow contours and arrows). A threshold used for severe weather forecasting in the plains of the USA is 15 ms^{-1} (Patrick Burke, personal communication, 2015). The values of this parameter according to GFS forecasts was in the order of 15 ms^{-1} . Helicity was marginal according to the GFS with higher values closer to the storm center and reaching only 50 m^{-2} s^{-2}. Precipitable water was plentiful with values exceeding 55mm. From the stability indices the most extreme were the CAPE and Lifted Index. The CAPE reached values close to 3200 J Kg^{-1} close to Antigua. The Lifted was also large aided by the presence of cool mid-levels to the north. These were present in association with a TUTT to the northeast of the cyclone.

A macro/script was developed based on the current analysis. The macro/script is an algorithm for the WINGRIDDS software designed to plot the discussed predictors and improve the detection/forecasting of future similar scenarios (see the Appendix).



The Guadeloupe soundings were used to verify that the GFS was capturing reasonably well the structure of the troposphere during the event. GFS-data shows that the band of highest 0-3km bulk shear extended into Guadeloupe by 12Z with shear values of 13-15ms^{-1}. The sounding, however, shows observed shear values approaching 21 ms^{-1}, which are 40% higher than those suggested by the model. This reinforces the concept that model data should be handled with care and – in some instances – can underestimate the severe weather parameters.

Path of Tornado from the Atlantic waters to the mainland



Damage done by Tornado

Damage done by TS Chantal

Summary and Conclusions

- The potential for tornadoes in the NE Caribbean can be evaluated
- From this case study we can conclude:
  - 0-3km>15 m/s bulk shear seems to be an important predictor
  - CAPE~3200 J/Kg and Lifted ~-8 were the indices that showed the strongest instability (cool mid-levels due to TUTT to the north)→did these matter in this case?
  - Helicity (often important) was marginal in this case
  - Tornado occurrence followed what is described in the literature:
    a) within the right sector of the storm (right quadrant)
    b) within the ~200-400km radius of the storm
    c) near 21Z, the diurnal cycle peak described in the literature.
  - TFFR sounding shows that in reality, the shear was larger than the model analysis and solution. Essential to verify obs when available.

- Thank you!!!

References

Edwards, R., 2012: Tropical cyclone tornadoes: A review of knowledge in research and prediction. *Electronic J. Severe Storms Meteor.*, **7** (6)**,** 1–61.

Onderlinde, Matthew John, "Developing a Parameter for Forecasting Tornadoes in Landfalling Tropical Cyclones" (2009). *Electronic Theses, Treatises and Dissertations.* Paper 2327.

APPENDIX

A WINGRIDDS (http://winweather.org/) macro/script was generated as a tool to improve the detection of the potential for tornadoes in the vicinity of tropical cyclones. The macro/script plots threshold values of the relevant predictors identified. The macro can be implemented in WINGRIDDS by generating the "TOR1.CMD" file inside the "C:/WINGRIDDS/MACROS/" directory. This executable must contain the following set of commands starting with "LOOP" and ending with "ENDL":

LOOP

PLAN
CTFC CFC1 CAPE
STRM WIND 1000 CLRE/
SMLC 10 PWAT GRTN 49 CIN5 CLR5/
SMTH SMLC 10 LIFT LSTN -69 CI10 CLR6/
HELI GRTN 30 CI10 CLR1/
VDIF WIND 700 WIND 1000 AROW GRTN 12 CLR2/
SCL0 STON MAGN LAST GRTN 12 CIN1 CLR2/
SMLC 1+3 VVEL 925 LSTN -1 CIN1 CLR3 dash/

*TXT2 **TORNADO THREAT NEAR TCs*
*TXT3 **CAPE (shaded), LIFTED<-6 (red contours)*
*TXT4 **Vert. 0-3km Shear>13kt (yellow)*
*TXT5 **0-3km Helicity (light blue)*
*TXT6 **PWAT>50 (green) & 925-Ascent>0.03m/s (fuscia)*

ENDL

For this macro/script to function, an additional set of commands needs to be added into the "C:\WINGRIDDS\USER\ALIAS.USR" file in order to configure the calculation of helicity (HELI). These command lines follow"

@@
@@STORM RELATIVE HELICITY 0-3km - START
@@
CVEC=VDVC 4 VSUM WIND 700 VSUM WIND 800 VSUM WIND 900 WIND 975

@@3KM (700)
UWL7=XCMP VDIF WIND 700 CVEC
VSH7=SDIF YCMP WIND 750 YCMP WIND 650
VWL7=YCMP VDIF WIND 700 CVEC
USH7=SDIF XCMP WIND 750 XCMP WIND 650
HEL7=SSUM SMLT VWL7 USH7 SNEG SMLT UWL7 VSH7

```
@@2KM (800)
UWL8=XCMP VDIF WIND  800 CVEC
VSH8=SDIF YCMP WIND  850 YCMP WIND  750
VWL8=YCMP VDIF WIND  800 CVEC
USH8=SDIF XCMP WIND  850 XCMP WIND  750
HEL8=SSUM SMLT VWL8 USH8 SNEG SMLT UWL8 VSH8
@@1.5KM (900)
UWL9=XCMP VDIF WIND  900 CVEC
VSH9=SDIF YCMP WIND  950 YCMP WIND  850
VWL9=YCMP VDIF WIND  900 CVEC
USH9=SDIF XCMP WIND  950 XCMP WIND  850
HEL9=SSUM SMLT VWL9 USH9 SNEG SMLT UWL9 VSH9
@@SFC
UWL1=XCMP VDIF WIND  975 CVEC
VSH1=SDIF YCMP WIND 1000 YCMP WIND  950
VWL1=YCMP VDIF WIND  975 CVEC
USH1=SDIF XCMP WIND 1000 XCMP WIND  950
HEL1=SSUM SMLT VWL1 USH1 SNEG SMLT UWL1 VSH1

HELI=SNEG SSUM HEL1 SSUM HEL9 SSUM HEL7 HEL8
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@STORM RELATIVE HELICITY - END OF CALC
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
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