1. Introduction

A large subtropical ridge dominated the weather over the eastern United States from 17-25 July 2010 (Fig. 1). A series of frontal systems in the strong flow over the ridge produced a series of severe weather events from 17-23 July 2010 (Fig. 2) and localized flooding. The flooding was more closely aligned with the surge of high precipitable water air about the subtropical ridge. Figure 3 shows the Storm Prediction Centers Plots of these events for particularly significant days when severe weather was observed. During this period there were two relatively big severe days in the eastern United States including 17 and 21 July when there were 50 and 201 reports of severe weather¹. On 17 and 21 July there were 31 and 88 severe reports in New York State.

Strong convective activity about subtropical ridges is quite common in the warm season. Galarneau and Bosart (2006) coined the term “ridge rollers” for convective systems which develop about the periphery of subtropical ridges. Often, mesoscale disturbances about the subtropical ridge and be traced to disturbances on the dynamic tropopause (DT). Sometimes these DT disturbances interact with frontal systems along the poleward edges of the subtropical ridge. They examine these features over North America during the summer of 1995 and Australia in the southern hemispheric summer of 1994. Thus the term poleward edges are used here.

Moisture and instability in the planetary boundary layer were found to be important in the production of sustained convective systems. The flow about subtropical ridges is an effective means to transport moist air along the western edges then poleward over the ridge. Thus subtropical ridges are important in terms of warm season heat waves and severe weather. Galarneau et al (2008) looked at closed subtropical anticyclones and examined their impacts and effects. Large anticyclones are important in terms of heat waves and severe weather.

It should be noted that during this heat event, heavy rainfall on 23-24 July 2010 produced flooding in Iowa. Over 15 inches of rain likely fell. This produced stress on the Lake Delhi dam, which failed on Saturday, 24 July². Flooding occurred along the Maquoketa river causing evacuations and destroying a small vacation community along the lake. This event in and of itself is worthy of further study.

The subtropical ridge also produced a prolonged period of warm weather. Comong

¹ Using MySQL to count severe reports east of 80W and north of 39N.
on the heels of the early July 2010 heat wave, many eastern cities experienced temperatures for the month about 5F above normal in cities such as New York City, New York. As bad as this heat wave may have or not have been, modern technology makes them more bearable. During the great 1896 heat wave, before the advent of air conditioning, over 1300 people perished in New York City alone (Kohn 2010). Europe also experienced a significant heat wave in July 1896.

The focus here is on the severe weather as the subtropical ridge pumped moisture into the central and eastern United States. The classic run-of-fire developed and produced some significant severe weather events, at times in places where large and widespread severe reports are often not very common. The focus is on the pattern and impacts mainly in the eastern United States.

2. Methods

The 500 hPa heights, 850 hPa temperatures and winds, other standard level fields were derived from the NCEP GFS and the NCEP/NCAR (Kalnay et al. 1996) reanalysis data. The means and standard deviations used to compute the standardized anomalies were from the NCEP/NCAR data as described by Hart and Grumm (2001). Anomalies were displayed in standard deviations from normal, as standardized anomalies. All data were displayed using GrADS (Doty and Kinter 1995).

The standardized anomalies computed as:

\[ SD = \frac{(F - M)}{\sigma} \]  

Where \( F \) is the value from the reanalysis data at each grid point, \( M \) is the mean for the specified date and time at each grid point and \( \sigma \) is the value of 1 standard deviation at each grid point.

Model and ensemble data shown here were primarily limited to the GFS and NAM. Displays will focus on the observed pattern and some forecast issues associated with the pattern.

For brevity, times will be displayed in day and hour format such at 21/0000 UTC signifies 21 July 2010 at 0000 UTC.

3. Results

i. Large scale pattern

The mean large scale pattern at 500 hPa was shown in Figure 1. These data show the large subtropical ridge over the southern United States. At least one closed 5940 m height contour was present most days (not shown). At times mid-latitude weather systems split the ridge leaving a western United States and western Atlantic closed 5940 m closed anticyclone.

The precipitable water (PW) field (Fig. 4) showed the surges of high PW about the subtropical ridge, often well timed with the convection about the ridge. Figure 4 shows a GOES-EAST water vapor image and the GFS 500 hPa heights at 22/1055 UTC. These data show the strong subtropical ridge and the MCS moving over and along the poleward edge of this feature. Note the surge of high PW are at 21/0000 and 22/0000 UTC over the plans were the MCS
developed (Figs 4h-i). These data show the relative importance of the subtropical ridge in transporting moisture, aiding in producing a warm moist unstable boundary layer, and favoring convective evolution.

Figure 5 shows the GOES imagery with 500 hPa heights on 22 and 23 July 2010. These data show MCS activity over the ridge emphasizing the impact of the moist flow about the ridge and the potential for severe weather and heavy rainfall. MCS’s were common from 17-24 July 2010.

**ii. Regional pattern**

Figure 6 shows the 500 hPa pattern over the eastern United States from 16/0000 UTC through 24/0000 UTC. These data show the trough moving over the ridge and splits in
the subtropical ridge. As the western Atlantic subtropical ridge retrograded and built over the eastern United States (Figs 6f-i), the ring-of-fire convection increased markedly over the central United States (Fig. 7).

This increase of precipitation was coincidental with a surge of high PW air (Fig. 8) into the region. The PW anomalies exceed 3SDs above normal at 23/0000 UTC (Fig. 8h) over a large portion of the Midwest. Comparable high PW air was in place at 24/0000 UTC (Fig. 8i).

The strong low-level jet about the subtropical ridge (Fig. 9) was enhanced and thus moisture flux (MFLUX) was much above normal. The MFLUX peaked over 6σ above normal over Wisconsin (Fig. 10h) at 23/0000 UTC and over Iowa (Fig. 10i) at 24/0000 UTC. High MFLUX is clearly linked to the flow about the subtropical ridge and the production of MCS activity in this instance.

In addition to the warm moist air along the edges of the subtropical (Fig. 8) there was abnormally warm air beneath the ridge. The 850 hPa temperatures increased and 850 hPa temperature anomalies of 2 to 3SD’s above normal developed over the eastern United States (Fig. 11) as the subtropical ridge moved over the southeastern United States. The warming was more pronounced at 700 hPa (Fig. 12).

iii. Composites
Composites from the 00-hour GFS were produced for select parameters. Figure 13 shows the composite 500 hPa heights, 850 temperatures, mean sea-level pressure and PWAT for the month of July. The persistent subtropical ridge (Fig. 13a) and surge of high PW air about the ridge are evident.

Figure 1 showed the same fields for the period of the active weather of 17-24 July. The ridge was stronger during this period and above normally warm air at 850 hPa was present over the eastern United States with a closed 20C contour evident in the mean. The flow of high PW air about the ridge is evident and maximized in the Midwest.

4. Conclusions
A large subtropical ridge developed over the southern United States. This ridge split at times as short-wave energy moved over the top to the feature (Fig. 1,Fig. 6 & Fig. 13). The interaction with flow over the ridge produced several significant severe weather events during the period. As the western Atlantic portion of the ridge retrograded over the southeastern United States, the low-level jet about the ridge strengthened. This produced a surge of moisture into the Midwest which in turn produced persistent organized convection and flooding from Iowa to Michigan (Fig. 7).

Short waves moving across the subtropical ridge produced a series of severe weather events in the eastern United States from 17-21 July 2010 (Fig. 3). The events of 17 and 21 July saw 31 and 88 reports of severe in New York State. Pennsylvania was on the
southern edge of these systems and had 13 severe weather reports on both days.

Figure 2 summarizes the impact of the subtropical ridge and its interaction with short-waves in the westerlies. A clear ring of severe weather was present over the ridge extending from Montana to New York State (Fig. 2). Most of the severe weather remained north of the 5940 m contour.

In addition to the severe weather produced on the poleward edges of the subtropical ridge heavy rainfall was also observed. As the subtropical ridge built westward (Fig. 6) over the southern United States heavy rain and flooding became an issue (Fig. 7) in the Midwest. The flow on the west side of the ridge increased with an enhanced low-level jet (Fig. 8) and increased PW (Fig. 9) which produced 5 to 6SD MFLUX anomalies (Fig. 10). The heavy rainfall in Iowa produced stress on the Lake Delhi dam, which failed on Saturday, 24 July with severe flooding along the Maquoketa river. Rainfall estimates and reports suggested over 15 inches of rainfall occurred during this event (Fig. 14 & 15) which will like be studied in detail in the near future. But this event and all the significant weather under score the potential impact of strong subtropical ridges which can produced heat, severe weather and flooding.

This brief overview shows the importance of subtropical ridges in terms of weather impacts (Fig. 2 & Fig. 14). These features can and do pump moisture northward. This moisture interacts with mid-latitude short-waves which then can lead to severe weather and heavy rainfall events. These events are likely the result of “ridge-rollers” interacting with the deep moisture flow, forming the ring-of-fire. The flow about the ridges can increase the low-level jet which can help build and sustain deep convection. This can lead to heavy rainfall (Fig. 14) and flooding. Finally, beneath the ridge itself it can be extremely hot. On the edges, the ring of fire provides convection and heavy rainfall while beneath the ridge there is often a heat episode. This event had it all.

5. Acknowledgements

A special thanks to Jason Krekeler for rainfall maps and data retrieval. To David Beachler and David Ondrejik for satellite images and plots, some were used herein, others helped tell the story. Thanks to Kevin Lipton for information on heat waves.

6. References


Figure 2. GFS 00-hour forecasts of mean 500 hPa heights for the period and all severe weather from the Storm Prediction Center storm reports page. Green square are wind, blue are hail, and red shows tornadoes. Return to text. This image will be replaced or supplemented with JRA25 in August. All 00-hour analysis in 6-hour intervals were used. Storm reports from 17-24 July 2010.
Figure 3. Severe weather reports from the Storm Prediction Center (SPC) showing severe weather by type from 17 to 22 July 2010. 22 July 23-25 are used in the composites. Return to text.
Figure 4. As in Figure 1 except for precipitable water (mm) and precipitable water anomalies. Return to text.
Figure 5. GOES IR image (upper) with GFS 500 hPa heights (m) and 700 hPa temperatures valid at 1055 UTC 22 July 2010 and lower panel shows 500 hPa heights, wind vectors and GOES IR Image valid at 0600 UTC 23 July 2010. Return to text.
Figure 6. As in Figure 1 except zoomed over the eastern United States and for the period of 1200 UTC 16-24 July 2010. Return to text.
Figure 7. Multi-sensor estimated rainfall for the period of 1300 UTC 21-24 July 2010. Return to text.
Figure 8. As in Figure 6 except for GFS PW and PW anomalies. Return to text.
Figure 9. As in Figure 6 except for 850 hPa total wind (kts) and total wind anomalies. Return to text.
Figure 10. As in Figure 6 except for 850 hPa moisture flux and moisture flux anomalies. Return to text.
Figure 11. As in Figure 6 except for 850 hPa temperatures and temperature anomalies.  

[Return to text]
Figure 12. As in Figure 11 except for 700 hPa temperatures.
Figure 13. As in Figure 1 except for the period of 0000 UTC 27 July 2010.
Figure 14. Accumulated precipitation (mm) from 00Z 17 JUL 2010 to 18Z 25 JUL 2010.

Figure 14. Accumulated precipitation (mm) from 0000 UTC 17 July through 1800 UTC 25 July 2010 from the 4km Stage-IV data.
Figure 15. KLOT radar rainfall estimates 22 to 24 July 2010.