Analysis of Flash Flooding Events in the Baltimore/Washington National Weather Service Forecast Region

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Introduction

The National Weather Service (NWS) defines a flash flood as *"…a rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event…"*[1] Flash flooding poses a danger to life and property; its accurate and timely forecasting is crucial.

For this study, data on flash flood events for the NWS Baltimore/Washington Weather Forecast Office (LWX) in Sterling, VA, were obtained from a locally-maintained storm data archive. This archive contains data on flash flood events that occurred in the LWX local county warning area (CWA) for January 2001–May 2009, inclusive. In this study a flash flood ***event*** is defined as comprising one or more reports of flash flooding that occurred in a single county (or independent city in VA) on a single day, all due to a single causative atmospheric event. These data were analyzed to reveal spatial and temporal (viz., time of day, month and season) characteristics of flash floods in the LWX CWA. Atmospheric soundings from the NOAA/ESRL Radiosonde Database were analyzed for each flash flood event. Statistical analyses of the representative soundings were conducted to quantify any key meteorological parameters associated with past flash floods that occurred in the LWX CWA. In addition, NOAA/ESRL PSD's NCEP NARR composites were utilized to develop means and anomalies for the surface environment, vertical wind field, and other atmospheric parameters that existed on days of past flash floods in the LWX CWA.

The results of this study led to a better understanding of flash flood climatology in the LWX CWA. This knowledge will hopefully allow improved watch/warning accuracy and increase lead time when forecasting flash flood events.

[1]NWS Directive 10-950 (2008)

Surface Environment

- Figs 1a and 1b show the anomalies of surface temperatures and mean sea level pressure, respectively, for dates from 2001 to 2009 where flash flooding was observed in the LWX CWA that were not attributed to tropical systems or winter stratiform rain.
- Warmer than normal temperatures (Fig 1a) are observed throughout much of the eastern United States, particular from the mid Atlantic into the northeast United States.
- The strongest negative mean sea level pressure anomalies (Fig 1b) were focused over the Ohio and Tennessee River Valleys. This suggests the center of the surface low pressure on average is 200-400 km west of the LWX CWA during flash flood events.

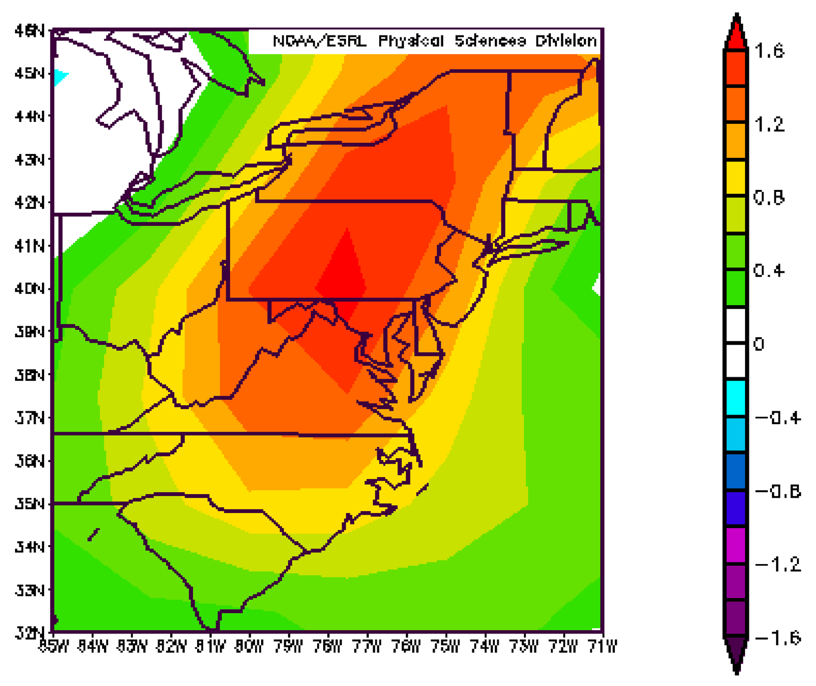

Fig 1a) Anomaly of surface temperature on flash flood days

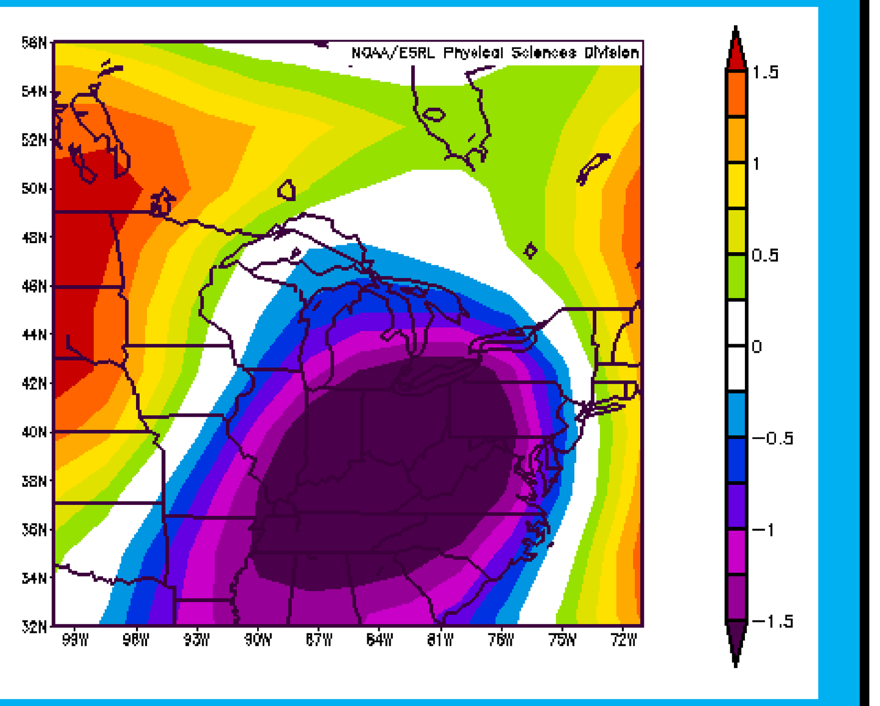

Fig 1b) Anomaly of mean sea level pressure on flash flood days

Atmospheric Parameters

- Fig 2a shows a strong positive anomaly of precipitable water, centered over the LWX CWA, throughout the mid Atlantic region and adjacent areas.
- Mean surface based CAPE during days of where flash flooding was reported in LWX CWA, as shown in Fig 2b, was moderate (greater than 500 J/kg) across much of the area, particular east of the Blue Ridge mountains. A narrow plume of 1000+ J/kg mean surface based CAPE stretches northward into lower southern Maryland and the Virginia Piedmont.
- Fig 2c depicts the negative anomaly associated with LI across the mid Atlantic.

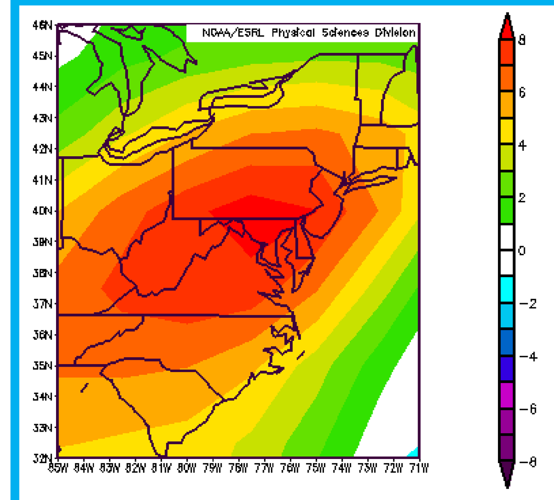

Fig 2a) Anomaly of precipitable water values on flash flood days

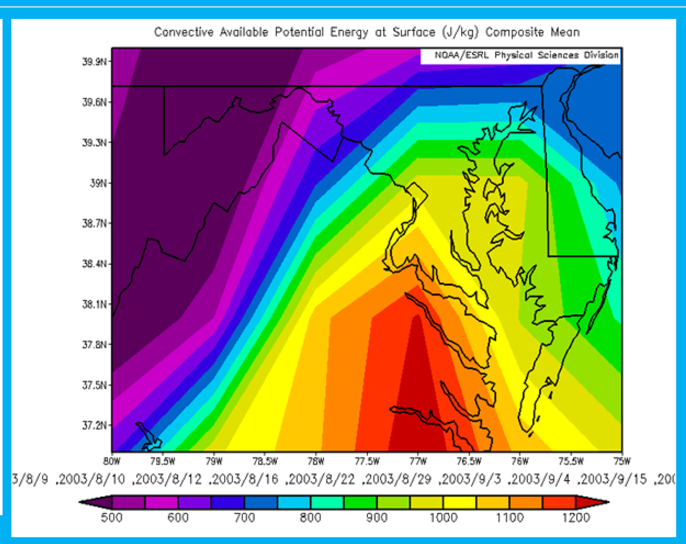

Fig 2b) Mean surface based convective available potential energy (J/kg) on flash flood days

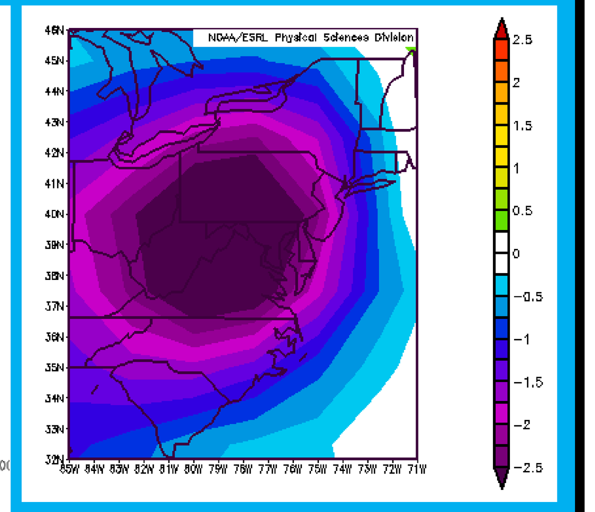

Fig 2c) Anomaly of lifted indices on flash flood days

Wind Field

- The figures below depict, clockwise from upper left, anomalies for meridional 500 mb wind (Fig 3a), zonal 500 mb wind (Fig 3b), zonal surface wind, (Fig 3d), and meridional surface wind (Fig 3c). As with all mean and anomaly maps in this study, dates from 2001-2009 where flash flooding occurred as a result of meteorological conditions other than a tropical system or winter stratiform precipitation were included.
- At the 500 mb level, positive meridional wind anomaly as shown in Fig 3a indicated stronger than average southerly flow, which is present throughout the domain of the map, with a maximum anomaly north of the LWX CWA.
- In terms of zonal wind at the 500 mb level (Fig 3b), negative anomalies are present from the Atlantic Ocean across the Atlantic into the Great Lakes. Negative anomalies in this case indicated stronger than normal easterly flow.
- Fig 3c shows the anomaly for meridional wind at the surface. As with the meridional winds at 500 mb, the map depicts positive anomalies along the east coast of the U.S., with a maxima off the mid Atlantic coast. The positive anomaly represents an area where the southerly component to the surface wind is greater than average.
- The anomaly of zonal wind at the surface is shown in Fig 3d. The negative anomaly, mainly north of the LWX CWA, represents areas where the easterly component of the surface wind is stronger than normal.

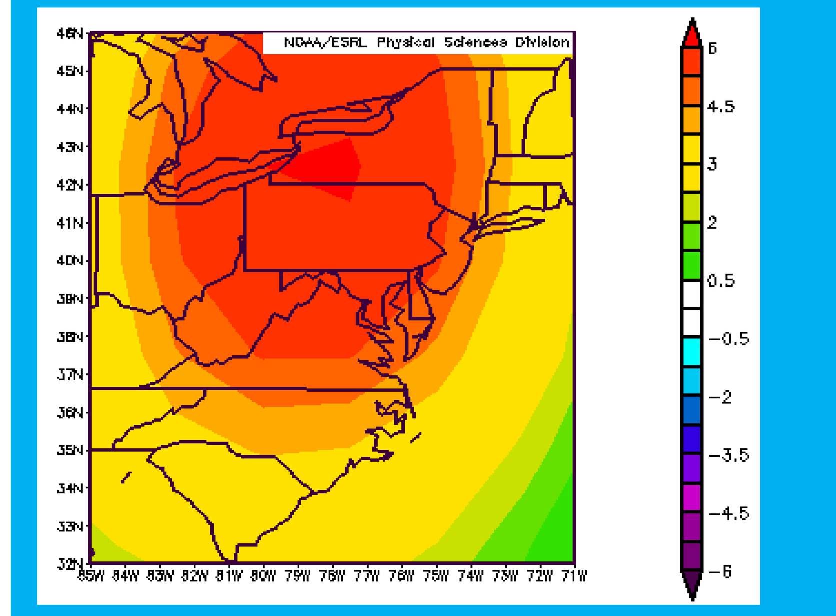

Fig 3a) Anomaly of 500 mb meridional wind on flash flood days

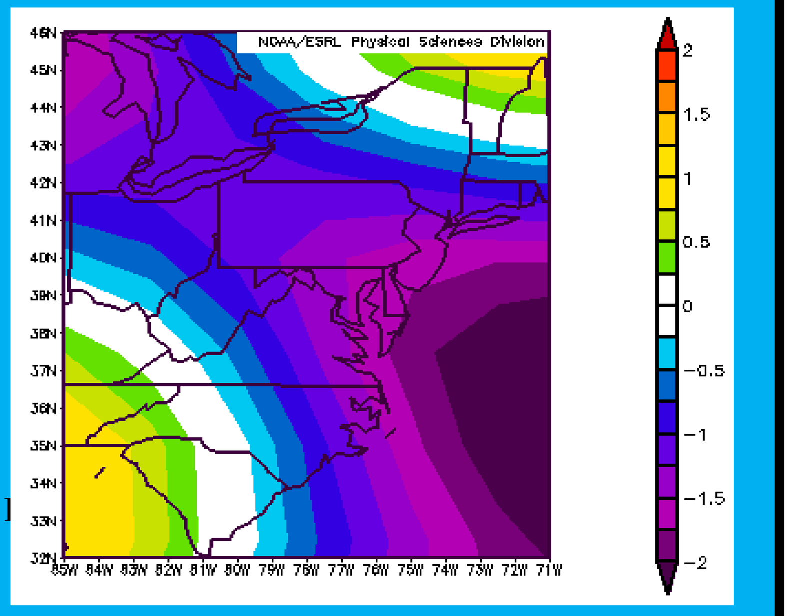

Fig 3b) Anomaly of 500 mb zonal wind on flash flood days

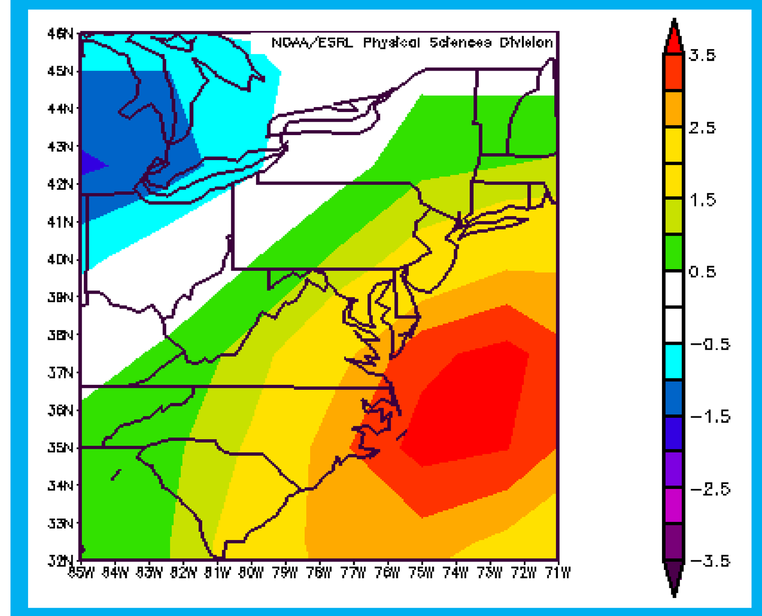

Fig 3c) Anomaly of surface meridional wind on flash flood days

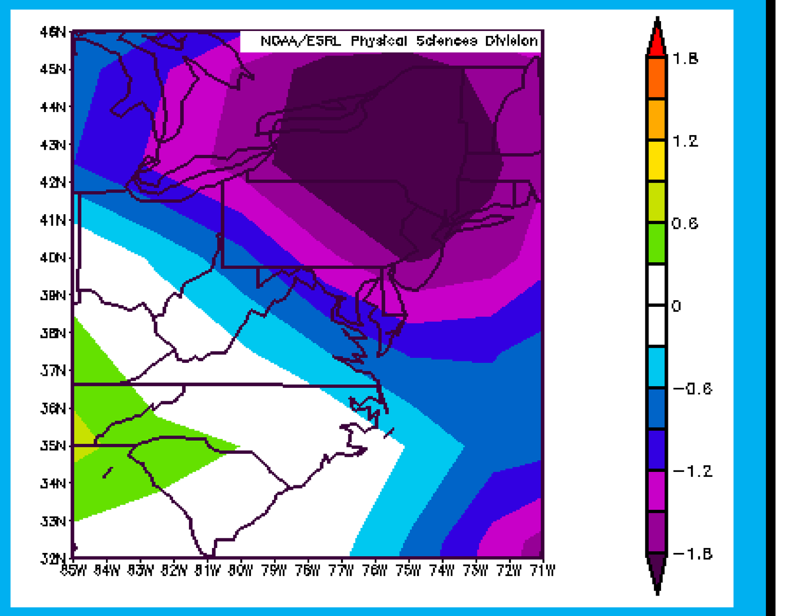

Fig 3d) Anomaly of surface zonal wind on flash flood days

Conclusions

A deep layer flow out of the south and east was most common during periods of flooding across the LWX CWA. The position of the surface low was over the Ohio Valley, with warmer than average temperatures and higher values of precipitable water than normal. Moderate CAPE tended to be present, with lower a lower than normal lifted index

The 25th, 50th, and 75th percentiles of FF-PWATs tended to be greater (less) than normal +2SD for October–March (May–September).

According to the sounding analysis, LWX flash flood events occurred with a deep warm cloud layer, moderate instability, weak wind shear, generally SW flow from 0-6 km, and efficient warm rain collision/coalescence processes. With meteorological parameters that were studied in both the NCEP/NARR composite data as well as atmospheric soundings, findings of each were in agreement.

Acknowledgements

- WFO Baltimore/Washington Weather Forecast Office (LWX): Steve Listemaa, Steve Zubrick, and Andrew Woodcock
- U.S. National Park Service, Rock Creek Office provided photos of 25-26 June 2006 flash flood.

References

- NOAA/NCDC Storm Data Archive
- NOAA/Earth System Research Laboratory (ESRL) Radiosonde Database
- PWAT graphic Fig 4a created from NOAA Upper Air Radiosonde database

Sounding Statistics

The following figures were created from the radiosonde data, mainly at Dulles VA (IAD); but other nearby sites were used if determined to be more representative of the FF environment. A single sounding was used from each flash flood event.

Fig 4a shows plots of monthly normal, the 25th, 50th (median) and 75th percentiles, max/min, and +2 standard deviation (+2SD) integrated precipitable water (PWAT) values. These values were derived from analysis of 45 years of radiosonde data from the co-located IAD soundings. This plot is useful when analyzing flash flood risk within the LWX CWA. PWAT percentile values corresponding to events examined in this study are also shown (brown solid lines) in the PWAT reference plot (Fig 4a). Compare the "FF 50th" percentile line with the normal +2SD green dashed line in Fig 4a. PWAT values of +2SD or more often signal an enhanced flash flood threat. This study showed that during the cool weather months (October – March), PWAT values associated with flash flood events in the LWX CWA tend to be greater than what the normal +2SD curve suggests. But during the warm season (defined as May – September), and especially in the summer (June - August) months, PWAT values less than the normal +2SD curve are observed during flash flood events in the LWX CWA.

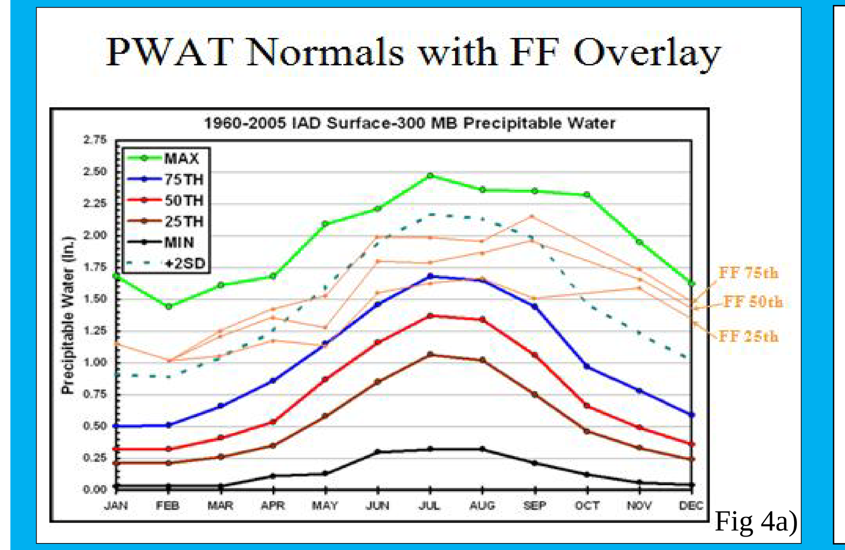

Fig 4a)

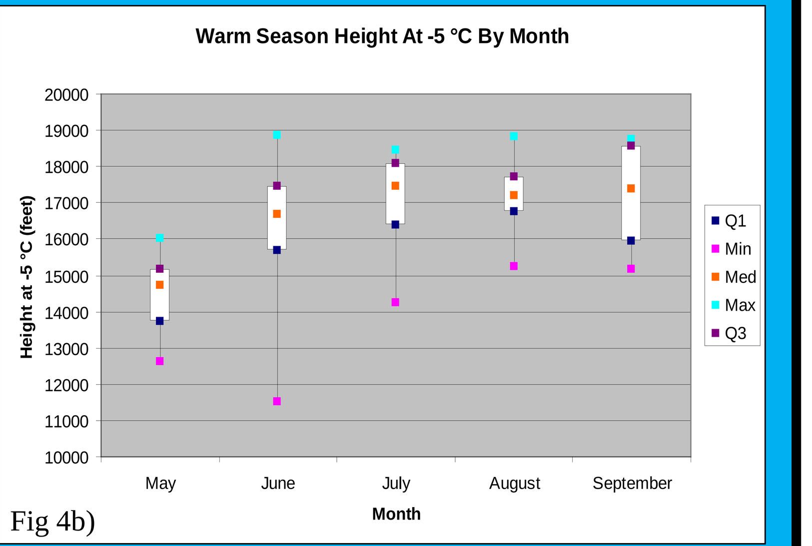

Fig 4b)

For the warm season events (cool season events not presented), analysis of other atmospheric sounding variables (Fig. 4b-f) revealed multiple trends. In general, events occurred with a deep warm cloud layer (Fig 4b) indicated by a high -5°C height and a low LCL height (Fig 4c), supporting efficient warm rain collision/coalescence processes especially below ~17 kft. The soundings revealed moderate (most unstable) convective instability (1000-2000J/kg MUCAPE – Fig 4e) and weak deep-layer wind shear (20-30kt 0-6km vertical shear – Fig 4f). Weak wind shear suggests minimal dry air entrainment in updrafts, thus allowing for efficient warm rain processes to occur in a high moisture environment.

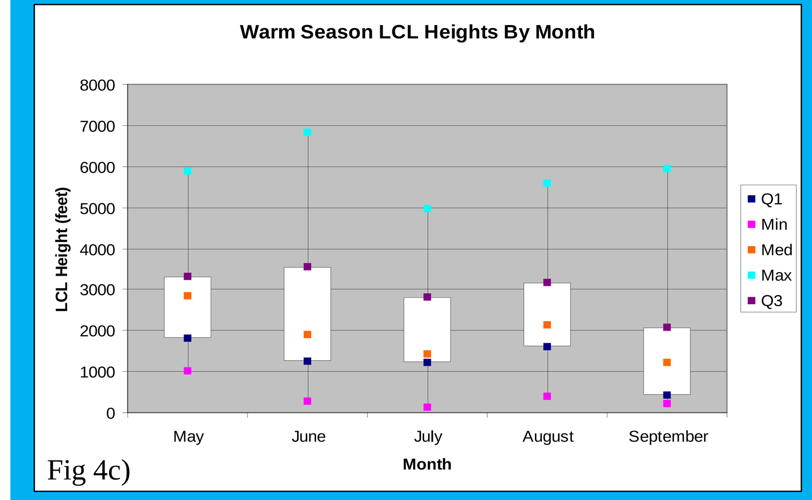

Fig 4c)

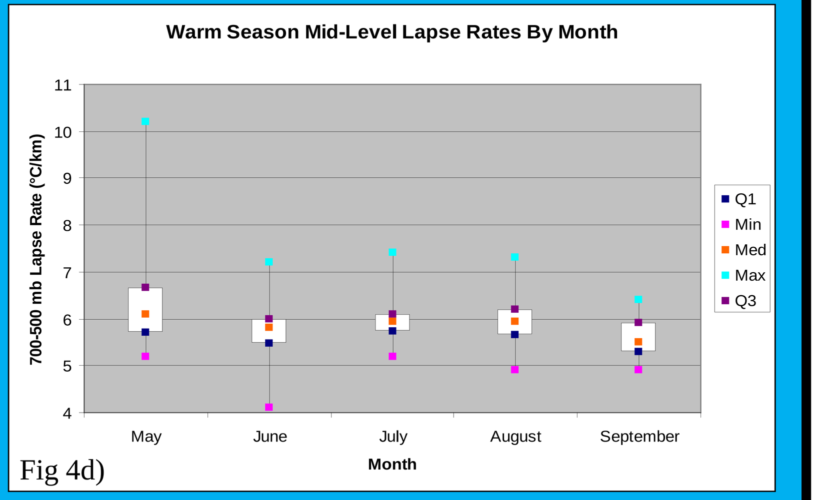

Fig 4d)

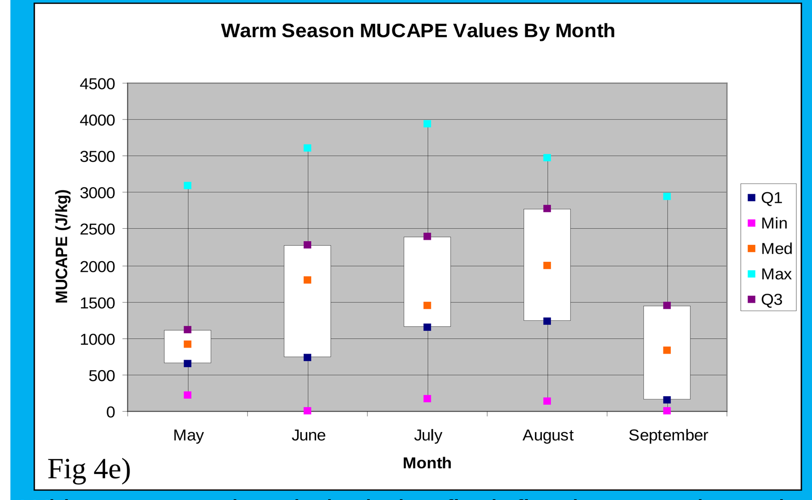

Fig 4e)

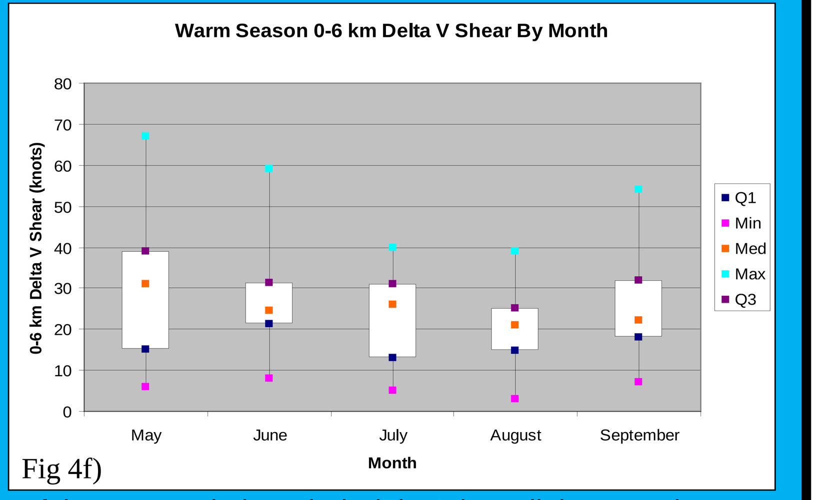

Fig 4f)

With respect to the winds during flash flood events, the majority of the storm relative winds (Fig 4g) are light to moderate west-southwesterly winds. Figs 4g and 4h show the percentage of storm relative winds (SRM) measured from each cardinal wind direction. The majority of the 0-6 km mean winds (Fig 4h) are moderate southwesterly winds. Most of the winds greater than 40 knots were measured during tropical systems and cool season low pressure systems. The calm to moderate winds can be attributed to warm season convective storms.

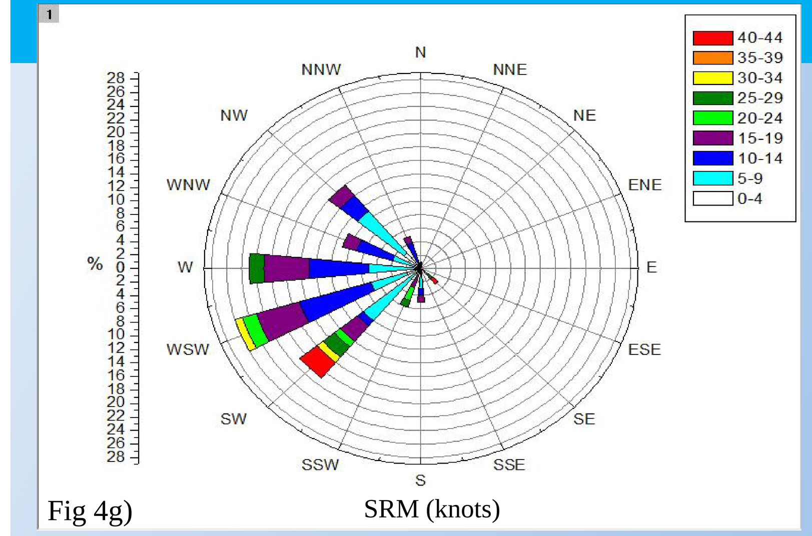

Fig 4g) SRM (knots)

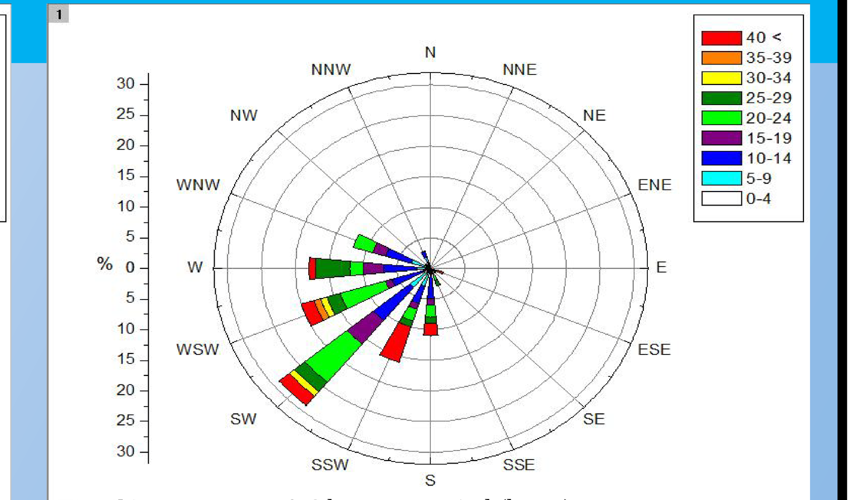

Fig 4h) 0-6 km Mean Wind (knots)