J3.13 AN UPDATED WARM-SEASON CONVECTIVE WIND CLIMATOLOGY FOR THE FLORIDA SPACE COAST

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1. Introduction

Convective wind warnings at Kennedy Space Center/Cape Canaveral Air Force Station (KSC/CCAFS) are the second most frequent type of weather advisory issued by the 45 Weather Squadron (45WS) (Wheeler and Roeder, 1996). The 45WS provides comprehensive weather services to America's space program at KSC/CCAFS (Harms et al., 1999). The requirements for the 45WS convective wind warnings are listed in Table 1. Due to the challenges presented by these convective wind warnings, improved methods for forecasting strong convective wind events around the Florida Space Coast were investigated.

An updated, warm-season convective wind climatology was developed using KSC/CCAFS wind tower data from May through September of 1995-2005. The climatology was expanded from a previous study (Loconto et al., 2005) to include two additional years of data, identification of all convective periods, and all peak winds, rather than just those exceeding 34 kt. The Loconto study was an expansion of an earlier study (Sanger, 1999). The 11-years of warm-season convective wind observations were further stratified into year, month, time of day, elevation, tower and wind direction.

The updated convective wind climatology was also used to determine if and how other atmospheric variables relate to convective winds. Low-level synoptic wind flow was used to characterize convective periods and determine if there was a connection between convective periods and flow regimes. Integrated precipitable water (IPW) values prior to and during convective periods for 2000-2004 were averaged to see if a relationship existed between IPW values and wind speed categories. The number of cloud-to-ground lightning strikes available for most convective periods was calculated to examine if there was a correlation between the strength of a convective period and the number of lightning strikes associated with it.

LOCATION	CRITERIA	DESIRED LEAD-TIME
KSC (surface-300 Ft)	≥ 35 Kt	30 min
	≥ 50 Kt	60 min
	≥ 60 Kt	60 min
CCAFS (surface-200 Ft)	≥ 35 Kt	30 min
	≥ 50 Kt	60 min
PATRICK AFB (surface)	> 25 Kt	30 min
	≥ 35 Kt	30 min
	≥ 50 Kt	60 min
	Gust Spread ≥ 20 Kt	Observed
	LLWS < 2,000 Ft	Observed
MELBOURNE (surface)	≥ 50 Kt	60 min

Table 1. Convective wind warning and advisory requirements at 45 WS.

2. Data and Methodology

2.1 Data

Five-minute peak wind speeds were gathered from 11-years (1995-2005) of warm-season (May-September) convective winds in a 30 X 40 km area of KSC/CCAFS. Wind data from 1995-2003 was previously quality controlled by the Applied Meteorology Unit (AMU). Raw 5-minute peak wind speed data were obtained from Computer Science Raytheon (CSR) for 2004-2005.

Forty-two tower sites, gathering wind data at nine possible elevations ranging from 12 to 295 ft, were included in the study. The tower locations are shown in Figure 1. Wind data from a tower site

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Corresponding author address: Dr James P. Koermer, MSC #48, Dept. of Chemical, Earth, Atmospheric and Physical Sciences, Plymouth State University, Plymouth, NH, 03264; e-mail: koermer@plymouth.edu was only included in the study if the tower reported at least 70% of all possible 5-minute observations for a given month. Additional manual quality control of the wind data was performed to remove outliers that lacked meteorological support, such as wind observations where there was no evidence of convection or where wind speeds were too high in comparison to previously reported winds or observed winds at nearby locations. Winds under relatively high pressure gradients were also excluded to ensure that only purely convective winds were analyzed. These were identified subjectively by a tight gradient of isobars on a surface analysis map. Most of the excluded cases were due to nearby tropical cyclones.

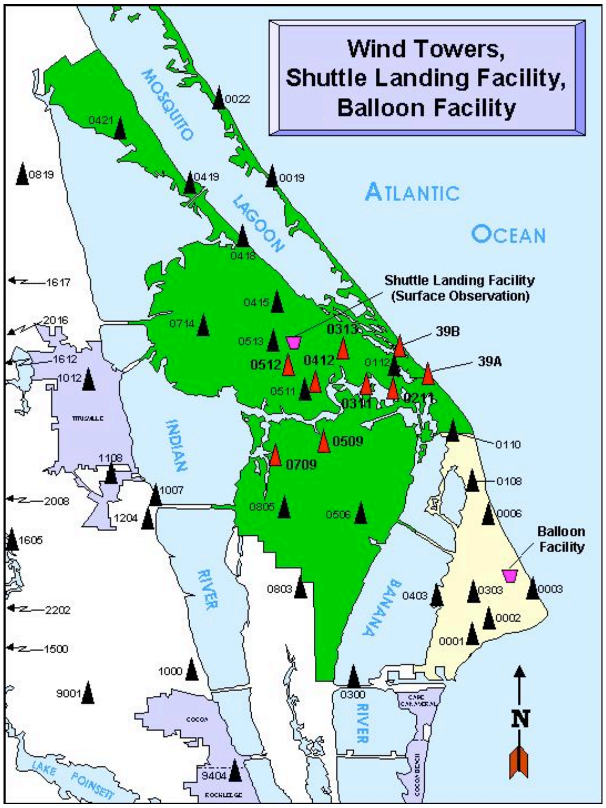

Figure 1. Weather towers at CCAFS/KSC.

2.2 Tabulation of Convective Wind Periods

A convective period was defined as a period of convective activity with at least a 6-hour break of no convection before and after the period. Start time was noted as the top of the hour when convection first occurred and end time was noted at the top of the hour after the last evidence of convection. Surface METAR observations, radar data and infrared satellite imagery were used to identify and verify convection. Convective periods were eliminated if they were associated with strong synoptic pressure gradients, such as those associated with tropical systems. Convective periods were also categorized according to their maximum wind speed (< 20 kt, 20-34 kt, 35-49-kt, and ≥ 50 kt), and then further stratified by year, month, time of day, tower, tower elevation, maximum wind speed direction and synoptic flow regime. The frequency of peak winds from convective events was modeled using a best-fit Gumbel curve. The area under this Gumbel curve was integrated to match the 45WS convective wind warnings, providing the probability that a warning threshold would be met if convective winds occurred. These probabilities became climatological guidance to the 45WS forecasters.

2.3 Other Atmospheric Variables

Five randomly selected convective periods representing each maximum wind speed category were chosen for each warm-season month of 2000-2004. GPS-based Precipitable Water data obtained from the U.S. Coast Guard Station at nearby Port Canaveral were used to examine possible correlations between the average integrated precipitable water 3-hours before a convective period and the strength of the maximum convective wind.

Lightning data from the 45WS Cloud to Ground Lightning Surveillance System (Boyd et al., 2005), obtained from the AMU, were also used to examine possible correlations between lightning flash density and convective periods. Flash density was determined by tallying the number of times a lightning stroke was reported in the 30 X 40km area during a convective period. A linear regression analysis was created using Microsoft Excel.

3. Results

3.1 Climatology

The convective wind climatology showed that there were 837 convective periods within the 11-year (1995-2005) warm-season (May-September) study, with an average of 76 convective periods per season, or 3.8 events per week. The results (shown in Figure 2) also indicate that 2005 had the fewest convective events (57) with 2002 having the most (96).

The monthly climatology of convective periods was found to form a roughly bell-shape distribution of the average number of convective events per month (Figure 3). August, on average, had the greatest number of convective periods. The maximum number of convective periods in any month in any individual year was August (28), while the minimum number of convective periods in any month was May (4). June averaged more warning level events than the other warm-season months (not shown).

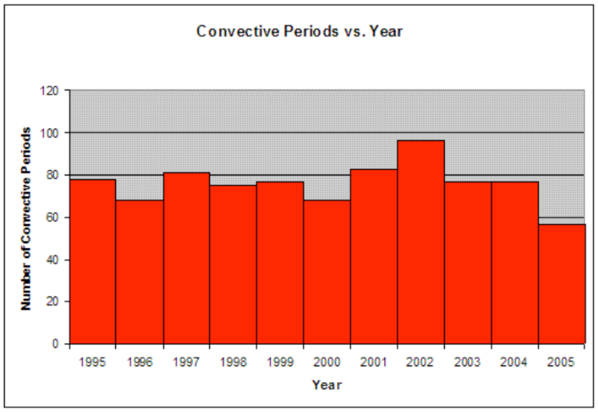

Figure 2. Annual number of convective periods.

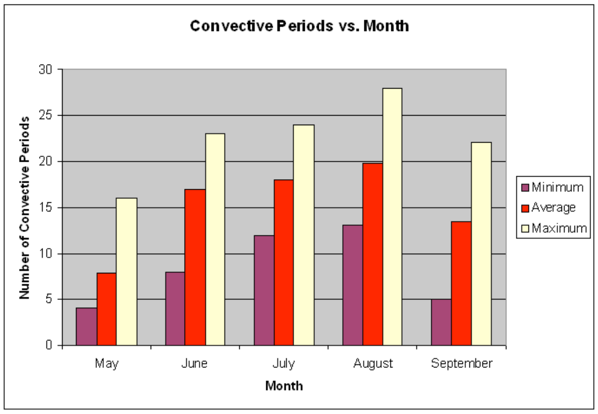

Figure 3. Monthly distribution of convective periods.

A distribution of the maximum wind speed for each convective period, with 5 kt increments, resulted in a skewed bell-shaped with a peak in the 20-24 kt range (Figure 4). A best-fit Gumbel curve was calculated. The Gumbel curve is often used to model extreme variables such as peak winds (Wilks, 2006). Integration under the curve found that 31%, 7% and 2% of the time maximum convective winds were ≥ 35 kt, ≥ 50 kt and ≥ 60 kt, respectively (corresponding to 45WS convective wind warning thresholds). The probability of meeting any speed threshold, given that convective winds occur, is provided by integrating the best-fit Gumbel curve from that speed threshold to infinity as in the following equation:

$$\text{Probability of speeds} \geq x = 1 - \exp[-\exp(-(x-25.4)/9)]$$

where x = inclusive speed threshold in knots

The diurnal distribution of convective wind observations showed one peak in the afternoon around 2000 UTC (Figure 5). The distribution of convective wind observations ≥ 35 kt (not shown) revealed a second smaller peak in the number of convective wind observations around 0100 UTC. The second smaller peak was most pronounced in September, with a maximum peak at 0100 UTC for winds ≥ 35 kt, unlike the other warm-season months, which had a maximum peak later in the afternoon. We speculate that this shift in the maximum peak from late afternoon to evening may be due to seasonal changes.

The data showed that the average maximum wind speed was 28.6 kt with little diurnal speed variation (_ = 3 kt). This suggests that while convective periods are less frequent in the morning, they are almost as strong as afternoon convective periods when they do occur.

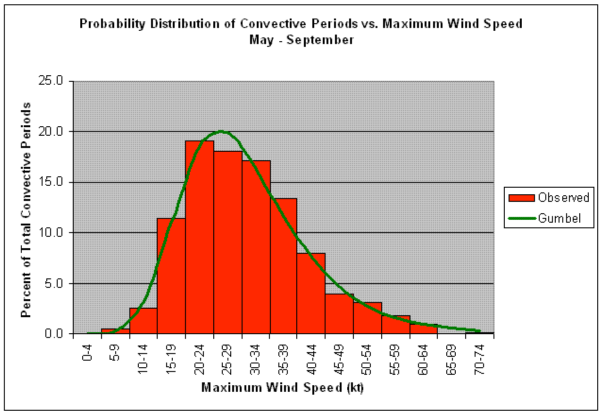

Figure 4. Distribution of convective periods by maximum wind speed with Gumbel curve.

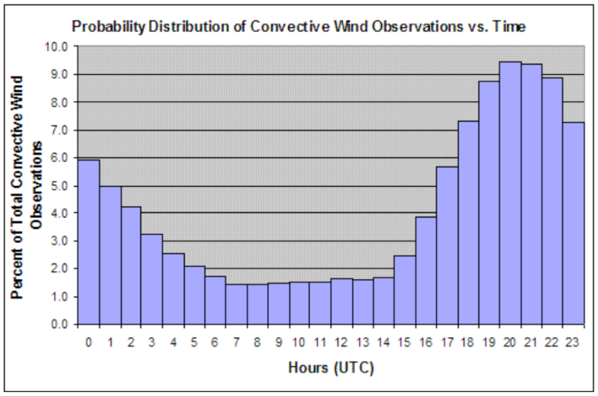

Figure 5. Hourly convective wind observations.

The direction of convective wind observations varied with wind speed. Convective wind observations ≥ 50 kt peaked in the southwest direction and 35-49 kt peaked in the west.

Convective wind observations 20-34 kt and < 20 kt peaked in the northeast and southeast, respectively. Figure 6 shows that convective periods with a maximum wind from the west were the strongest on average, while convective periods with a maximum wind from the east were the weakest on average.

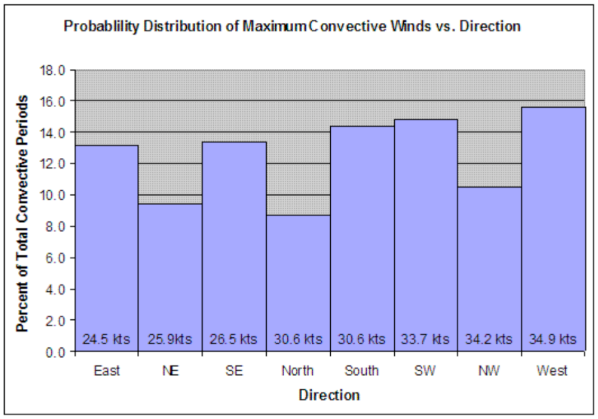

Figure 6. Distribution of the maximum wind direction for each convective period. The average maximum convective wind speed for each direction is noted on each column of the bar graph and these increase from left to right.

The number of convective wind observations by sensor height was analyzed and normalized by the number of sensors that report winds at each elevation. The normalization of the number of observations was required since the number of sensors varied widely by height with more observations at 54 ft than at any of the other elevations. The number of observations ≥ 20 kt increased with elevation, with the fewest observations at 12 ft and the most at 20 ft and 295 ft (Figure 7). The low number of observations at 12 ft is probably due to strong frictional effects and suppressed turbulence at the surface. As elevation increases there are increasingly stronger convective wind reports due to decreasing friction (Holton, 2004) and increasing kinetic energy with increasing size of the turbulent cells. When plotted in proportion to the height, these data suggest a turbulent mixed layer with an average depth of about 150 ft with a log-wind law beginning to apply above that depth.

A "lead time" between the first reported 20 kt wind and the first reported 35 kt wind was determined for all cases ≥ 35 kt. The lead time was calculated for the 35-49 kt cases and the ≥ 50 kt cases. The ≥ 50 kt cases ramped up slightly quicker than the 35-49 kt cases. The 35-49 kt and ≥ 50 kt cases had a 33% and 44% lead time of 30 min or less, respectively.

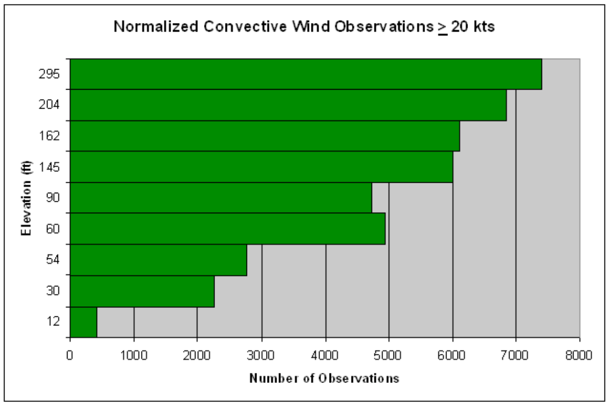

Figure 7. Convective wind observations ≥ 20 kt normalized by the number of instruments located at the respective elevation.

Flow regime types previously established by Lericos et al. (2000) were used in this study to classify convective periods. Flow regime types are based on the position of the subtropical ridge axis over Florida to predict where lightning is likely (Table-2). Convective periods with a SW-1 flow regime had the strongest average maximum convective wind, while the SW-2 flow regime contained the greatest number of convective periods (Figure 8). This agrees with earlier findings that the SW flow regimes lead to the most lightning along the east coast of Florida (Lericos et al., 2000). Flow regimes with higher averaged maximum convective wind speeds had a west wind component, while flow regimes with an east wind component had lower averaged maximum convective winds.

FLOW REGIME	SUBTROPICAL RIDGE POSITION
SW-1	Subtropical ridge south of Miami
SW-2	Subtropical ridge between Miami and Tampa
SE-1	Subtropical ridge between Tampa and Jacksonville
SE-2	Subtropical ridge north of Jacksonville
NW	Subtropical far to south and extending far in Gulf of Mexico and stronger than normal
NE	Subtropical far to north and extending into SE US and much stronger than normal
Other	Subtropical ridge position not defined

Table 2. Convective wind warning and advisory requirements at 45 WS.

The data suggested that the wind components of the synoptic scale flow regime were reflected in the typical direction of the maximum convective wind. For example, maximum convective winds observed in a SE-2 flow regime tended to have a southeast direction.

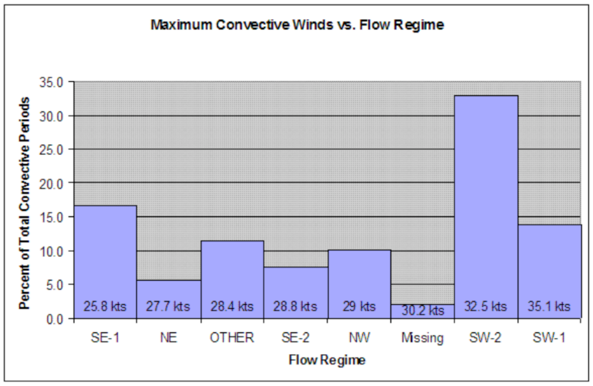

Figure 8. Distribution of convective periods by flow regime. The average maximum wind speed for convective periods in that flow regime are at bottom of bar and increase from left to right.

The towers were classified into three groups according to their location (Case and Bauman, 2004). The updated climatology (1995-2005) of convective winds ≥ 20 kt showed that the Coastal/Causeway, CCAFS/Merritt Island and Mainland towers reported 4549, 1915, and 604 observations, respectively. This suggests that towers close to the coast report more significant convective wind observations than towers further inland, which may be due to the sea breeze augmentation.

3.2 Integrated Precipitable Water

Integrated precipitable water (IPW) values during the three hours prior to convection were averaged for 95 convective periods. Convective periods with a maximum wind ≥ 35 kt had lower IPW values than convective periods with a maximum wind < 35 kt (Figure 9). The month of May had much lower IPW values compared to the other warm season months. Excluding May, the averaged IPW values for the < 20 kt cases, 20-34 kt cases, 35-49 kt cases and ≥ 50 kt cases were 1.97 inches, 2.01 inches, 1.88 inches, and 1.92 inches, respectively. This study suggested that IPW may have some use in forecasting convective winds at CCAFS/KSC, but further research is needed.

3.3 Lightning Flash Density

The number of lightning strikes per convective period was determined for 555 convective periods. The data showed that the stronger the convective period, the more lightning strikes (Figure 10). The < 20 kt cases, 20-34 kt cases, 35-49 kt cases and ≥ 50 kt cases had an average of 89, 233, 541 and 789 strikes, respectively.

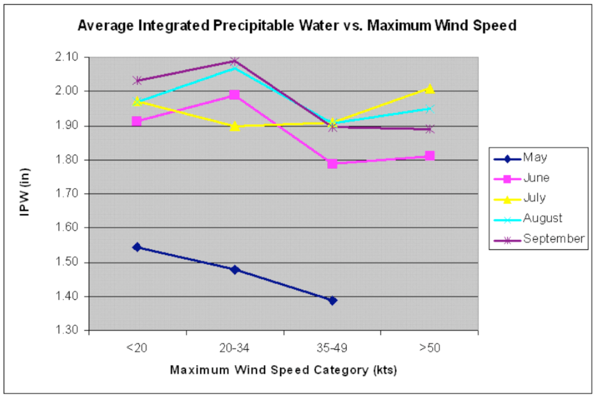

Figure 9. Average integrated precipitable water values by maximum wind speed categories.

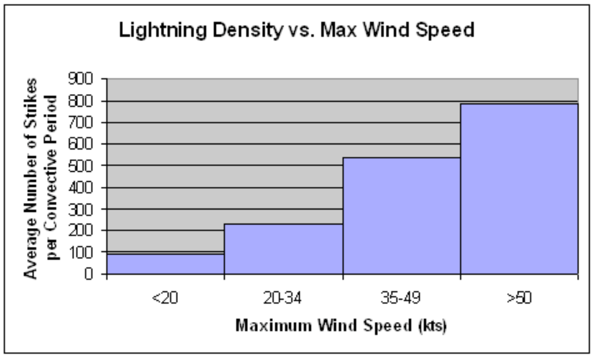

Figure 10. Average lightning flash density per convective period with maximum wind speed.

4. Future Work

Two case studies will be performed using the one-minute averaged convective wind tower data from the year 2005. These case studies will focus on two convective periods. The first study will investigate the 45 kt maximum wind event on 23 July 05, while the second study will investigate the 54 kt event on 31 August 05. These two cases were chosen because they each represent a different warning criteria for the 45WS, one being ≥ 35 kt and the other ≥ 50 kt. Both cases occurred in the densest part of the weather tower network and had significant numbers of peak wind observations meeting warning criteria. Both case studies will allow for a more in-depth study of the convective winds occurring in the KSC/CCAFS area.

Since the speed of convective winds is critical in issuing warnings and advisories, speed spread and decay will be investigated. By knowing how quickly the speed of the convective winds is spreading and decaying, forecasters will be better able to predict if convective winds approaching from outside the CCAFS/KSC area will or will not decay below warning criteria when they reach the area. This may also allow for the development of an automated radar tool for warning guidance. Radar tools exist that predict if a downburst is occurring and predict the peak speed, but the distance at which the peak speed will decay to the warning criteria is currently unknown.

Since the average maximum wind speed for convective periods (28.6 kt) is just below warning criteria (≥ 35 kt), forecasters at KSC/CCAFS frequently issue wind warnings even though only 31% of the time winds are above 35 kt. This leads to a high false alarm rate, since a missed warning is much worse than a false alarm. Future studies to develop tools or guidance on distinguishing between storms producing convective winds < 35 kt and ≥ 35 kt would most benefit 45WS operations.

Determining the probability of detection (POD) and false alarm rate (FAR) of different onset winds would help in finding the wind speed that provides the lowest false alarm rate for the operational requirements of a 30- and 60-minute lead time. This could help forecasters by potentially providing them with an onset wind speed at which to issue a warning, so that the desired lead times before the ≥ 35 kt and ≥ 50 kt would be met, thereby improving forecast accuracy.

To further analyze the correlation between IPW values and the maximum wind speed of convective periods, we plan on increasing the IPW sample size. All convective periods for 2000-2004 would be used, excluding May since its IPW values were much lower than the other months. A larger sample size may provide more reliable results.

Convective winds under relatively strong pressure gradients were excluded from this study. These cases should also be researched. Many of these cases were from nearby tropical cyclones. The study should consider cases with just strong pressure gradients and those where the tropical cyclone is directly affecting CCAFS/KSC, including rain bands and closer to the cyclone.

Convective winds during the winter season at CCAFS/KSC due to approaching fronts and squall lines should also be studied.

5. Summary

An updated climatology was developed for strong convective winds for the KSC/CCAFS range complex. The number of convective periods varies only slightly from year to year. On average, August has the most convective events during the warm season. There are two distinct diurnal maxima for wind observations ≥ 35 kt—one in the afternoon and the other before midnight. Convective wind observations ≥ 20 kt steadily increased with elevation. Stronger convective periods had more lightning than weaker convective periods.

Several atmospheric variables appeared to be helpful indicators in differentiating between the speeds of convective winds. The variation in IPW values with the maximum wind speed of convective periods appears helpful in distinguishing between convective cases < 35 kt and ≥ 35 kt, which have higher and lower IPW values, respectively.

Flow regime stratification did not help in discriminating between convective winds < 35 kt and ≥ 35 kt. However, it did indicate that winds with easterly components were overall weaker than those with westerly components. Knowing the flow regime would indicate to forecasters whether or not they would have convection and if a weaker or stronger event is likely to occur.

Diurnal stratification did not help in determining which warnings should be issued. While fewer convective winds occurred during the morning, they were usually only a few knots weaker when they did occur.

A well organized, quality-controlled database of the observations used in this study is available to the public online for future convective wind studies. (http://vortex.plymouth.edu/conv_winds/). Researchers are encouraged to contact 45WS (william.roeder@patrick.af.mil) to maximize the operational benefit from their studies.

6. Acknowledgements

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