Observed Relationship between Tornado Intensity and Pretornadic Mesocyclone Characteristics

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ABSTRACT

In a previous study, idealized model simulations of supercell thunderstorms were used to demonstrate support of the hypothesis that *wide, intense tornadoes should form more readily out of wide, rotating updrafts.* Observational data were used herein to test the generality of this hypothesis, especially to tornado-bearing convective morphologies such as quasi-linear convective systems (QLCSs), and within environments such as those found in the southeastern United States during boreal spring and autumn. A new radar dataset was assembled that focuses explicitly on the *pretornadic* characteristics of the mesocyclone, such as width and differential velocity: the pretornadic focus allows us to eliminate the effects of the tornado itself on the mesocyclone characteristics. GR2Analyst was used to manually analyze 102 tornadic events during the period 27 April 2011–1 May 2019. The corresponding tornadoes had damage (EF) ratings ranging from EF0 to EF5, and all were within 100 km of a WSR-88D. A key finding is that the linear regression between the mean, pretornadic mesocyclone width and the EF rating of the corresponding tornado yields a coefficient of determination (R^2) value of 0.75. This linear relationship is higher for discrete (supercell) cases ($R^2 = 0.82$), and lower for QLCS cases ($R^2 = 0.37$). Overall, we have found that pretornadic mesocyclone width tends to be a persistent, relatively time-invariant characteristic that is a good predictor of potential tornado intensity. In contrast, the pretornadic mesocyclone intensity (differential velocity) tends to exhibit considerable time variability, and thus would offer less reliability in anticipating tornado intensity.

To help illustrate this, we recall that the physical basis for the T17 hypothesis is conservation of angular momentum, or equivalently, Kelvin's circulation theorem, which can be represented by

$$2\pi u_T r_T = \Gamma = 2\pi u_M r_M, \tag{1}$$

where r_T and u_T (r_M and u_M) are, respectively, the radius and tangential wind speed of the tornado (pretornadic mesocyclone), and Γ is circulation. T17 used the meso-

In section 2, the creation of a diverse mesocyclone dataset is described, as is the method employed to analyze the mesocyclone characteristics. The results of the analyses are presented in section 3, which show that observed intense tornadoes tend to form more readily out of wide mesocyclones within different convective modes and environments. A discussion of how these results might be applied in an operational setting is provided in section 4, followed by a summary and conclusions in section 5.

2. Methodology

Archived, single-site, WSR-88D Level II data of 102 tornadic events (Table 1) during the period from 27 April 2011 to 1 May 2019 were manually analyzed using the Gibson Ridge radar software (GR2Analyst). The events were selected to provide: seasonal and geographical diversity; a reasonable sample of parent-storm morphologies; a range of EF ratings, from EF0 to EF5 (20 EF0, 27 EF1, 24 EF2, 21 EF3, 6 EF4, 4 EF5); and variations in environmental conditions, including those characterized as HSLC as well as high shear, high CAPE (HSHC). Because of the desire to have access to polarimetric radar data to help confirm tornado presence (see below), the events were required to have occurred during approximately the past six years, excluding the EF5 cases. They were also required to have radar ranges less than 100 km throughout their lifetime in order to lessen the impact of radar range and beamwidth limitations (Wood and Brown 1997). In addition, no more

The parent-storm convective mode was characterized simply as discrete supercells (DSC), quasi-linear convective systems (QLCSs), or multicells (MUL) using radar reflectivity data from the volume scan immediately prior to reported tornadogenesis. Following Trapp et al. (2005b) and Smith et al. (2012), a discrete storm was a relatively isolated entity with a single, high-reflectivity core (reflectivity $\geq$ 50 dBZ). A QLCS had contiguous reflectivity of at least 35 dBZ over a horizontal distance of at least 50 km, and a length-to-width aspect ratio of at least 3:1. If the parent storm did not meet the criteria of these two categories, it was typically a multicell storm or short line segment comprised of a more complex reflectivity structure including multiple reflectivity maxima in close proximity and thus was placed in the MUL category.

The primary analysis was of the pretornadic mesocyclone width, which was defined as the linear distance between velocity peaks in the vortex couplet. The latitude and longitude of the center of the gates of maximum velocity were used to calculate the linear distance. The presence of a mesocyclone itself was confirmed using a methodology similar to Smith et al. (2012). Specifically, we required a peak differential velocity (ΔV) $\geq 10\,\mathrm{m\,s^{-1}}$ over a horizontal distance of less than 7 km, over the depth of the three lowest radar elevation angles, during at least one volume scan. Each of the

tornadogenesis. The time of tornadogenesis was confirmed by a consideration and comparison of the NOAA Storm Events Database (NOAA/NCEI/NESDIS 2014) description of each tornado and the manual radar analysis (including evaluation of the possible presence of a tornado debris signature). The three elevation angles

3. Results

When all 102 cases were analyzed, higher EF-rated tornadoes tended to be associated with larger pretornadic mesocyclones (Fig. 3a), as quantified by a coefficient of determination (R^2) of 0.75 in the linear regression between these two variables. This linear relationship is based on the use of total average mesocyclone width, defined as the mean mesocyclone width over the lowest three elevation angles and all volume scans analyzed during the pretornadic period.

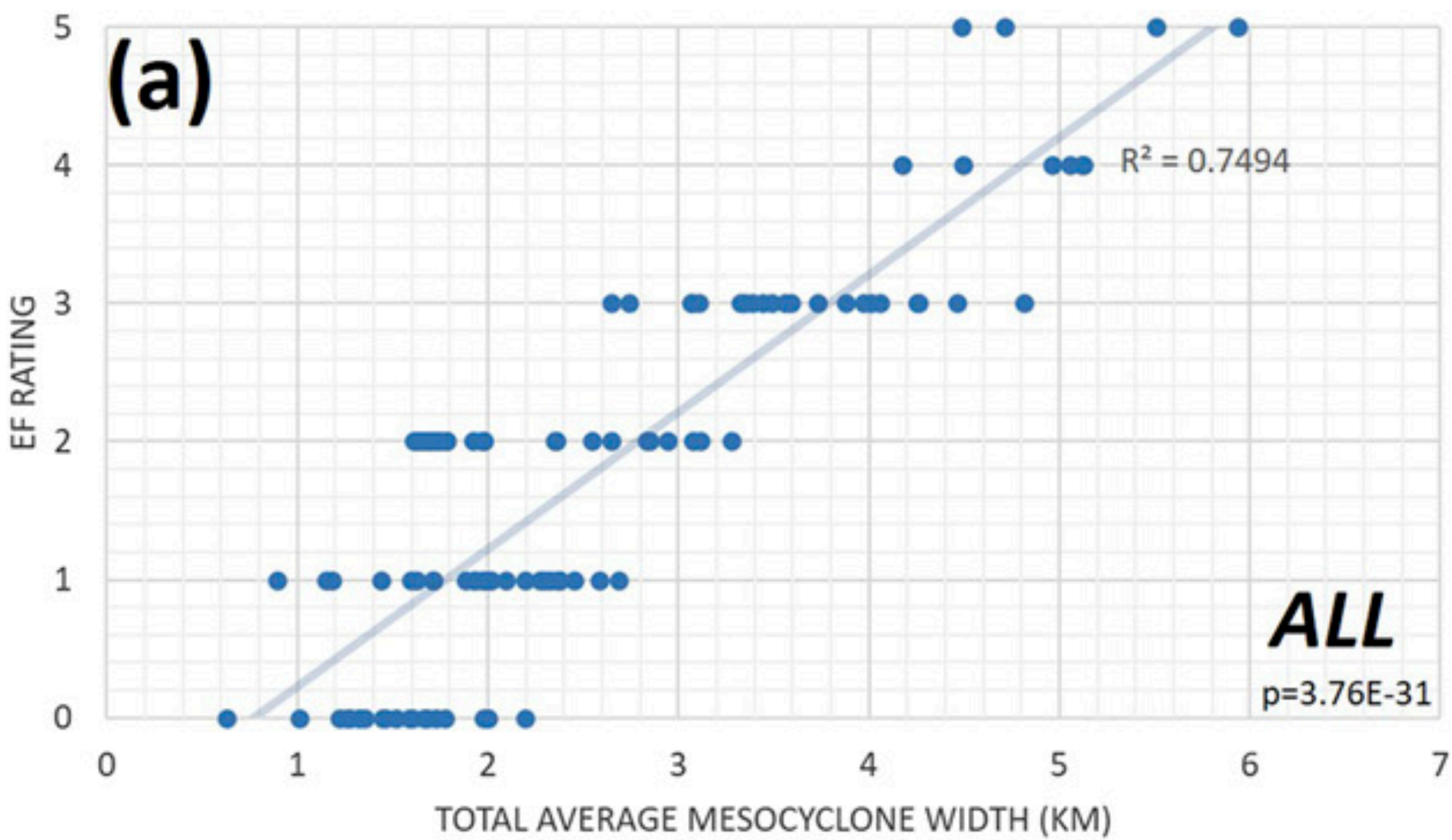
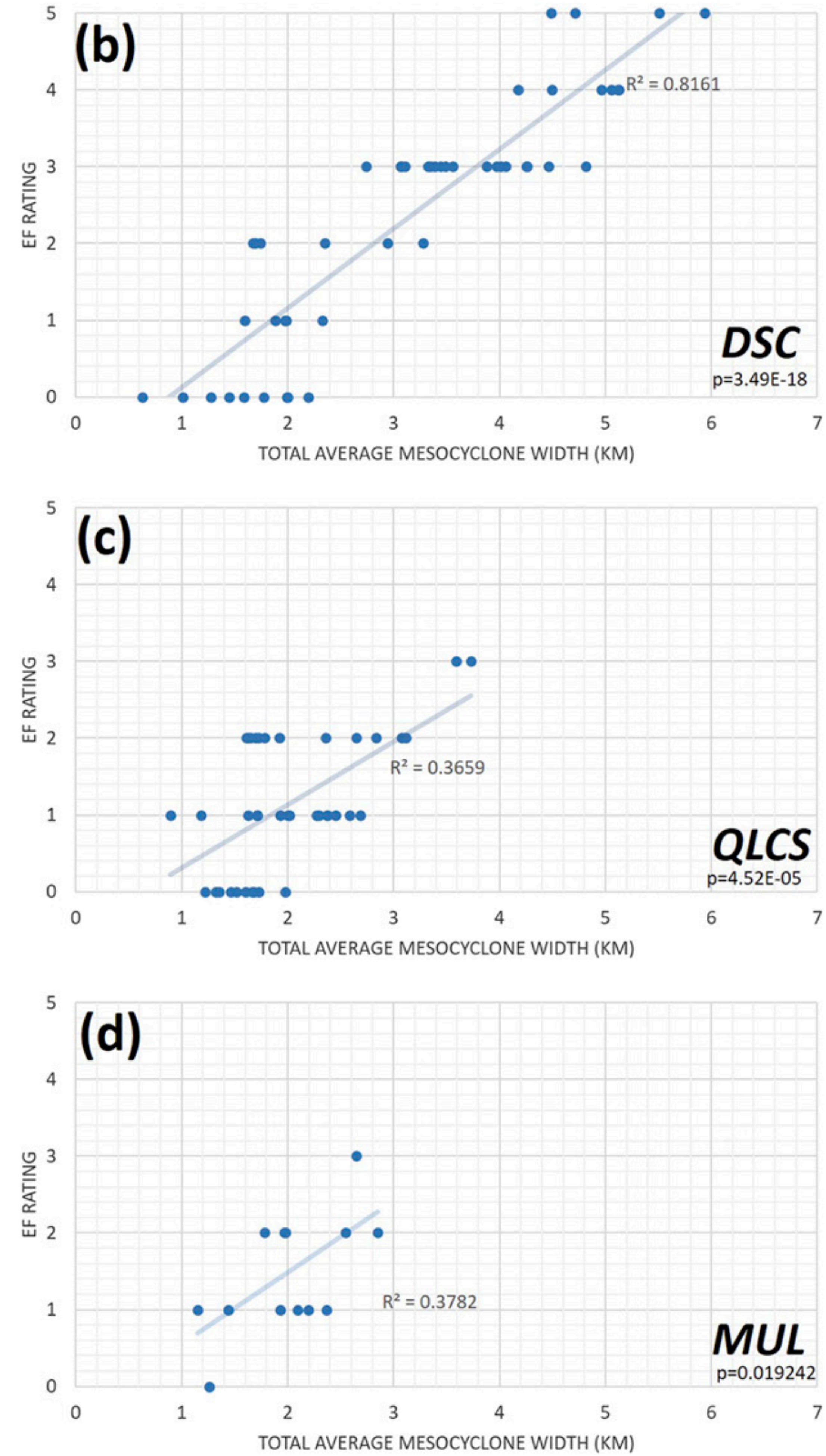

(a)
5
4
3
2
1
0
EF RATING
$R^2 = 0.7494$
ALL
p=3.76E-31
0
1
2
3
4
5
6
7
TOTAL AVERAGE MESOCYCLONE WIDTH (KM)

Fig. 3(a)

Fig. 3

rial). The linear relationship is slightly stronger when only the cases meeting the DSC mode classification (49 cases) were analyzed (Fig. 3b, $R^2 = 0.82$), and weaker when only the cases meeting the QLCS mode classification (39 cases) and MUL mode classification (14 cases) were analyzed (Fig. 3c, $R^2 = 0.37$ and Fig. 3d, $R^2 = 0.38$). This may be due to the fact that the



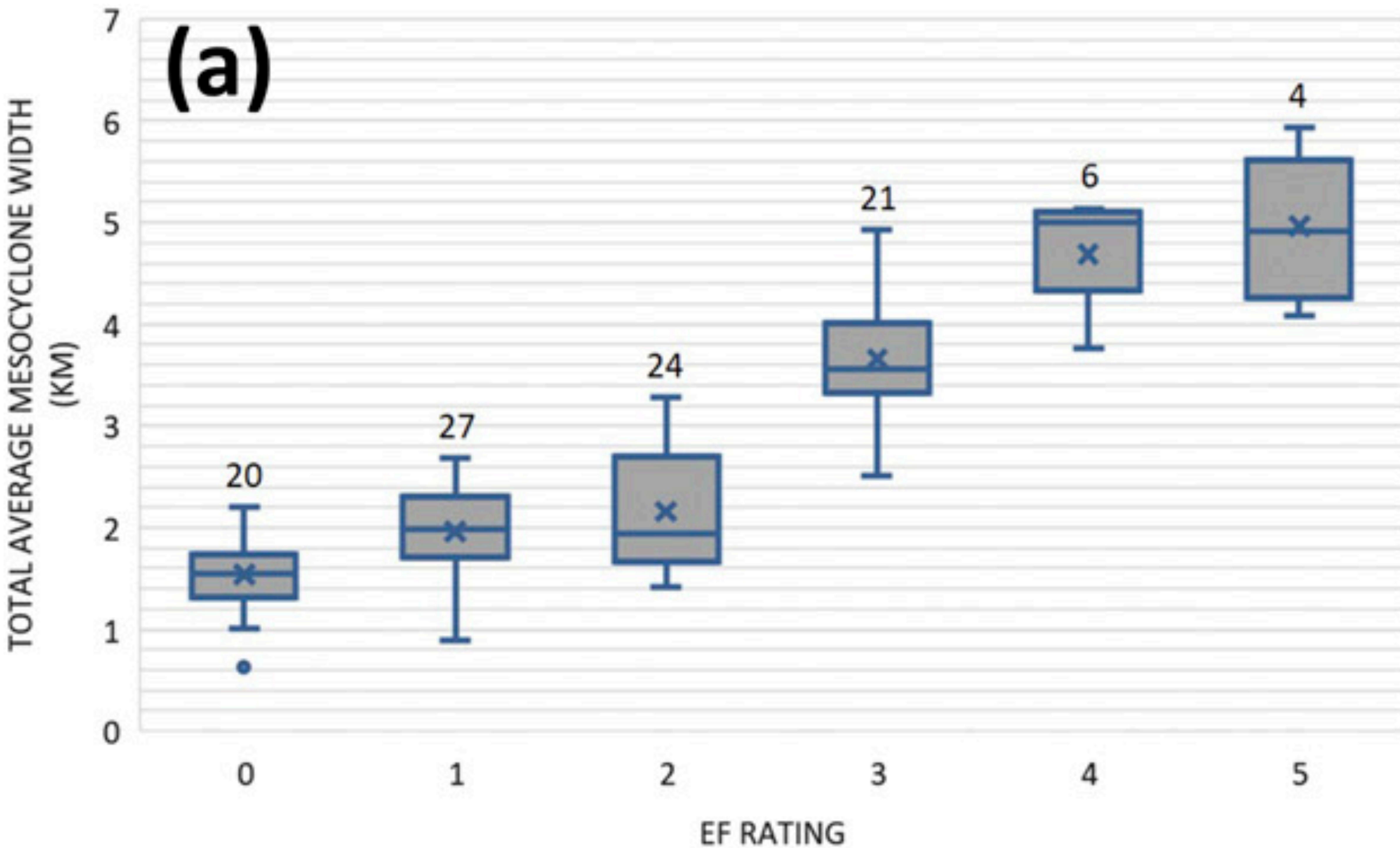
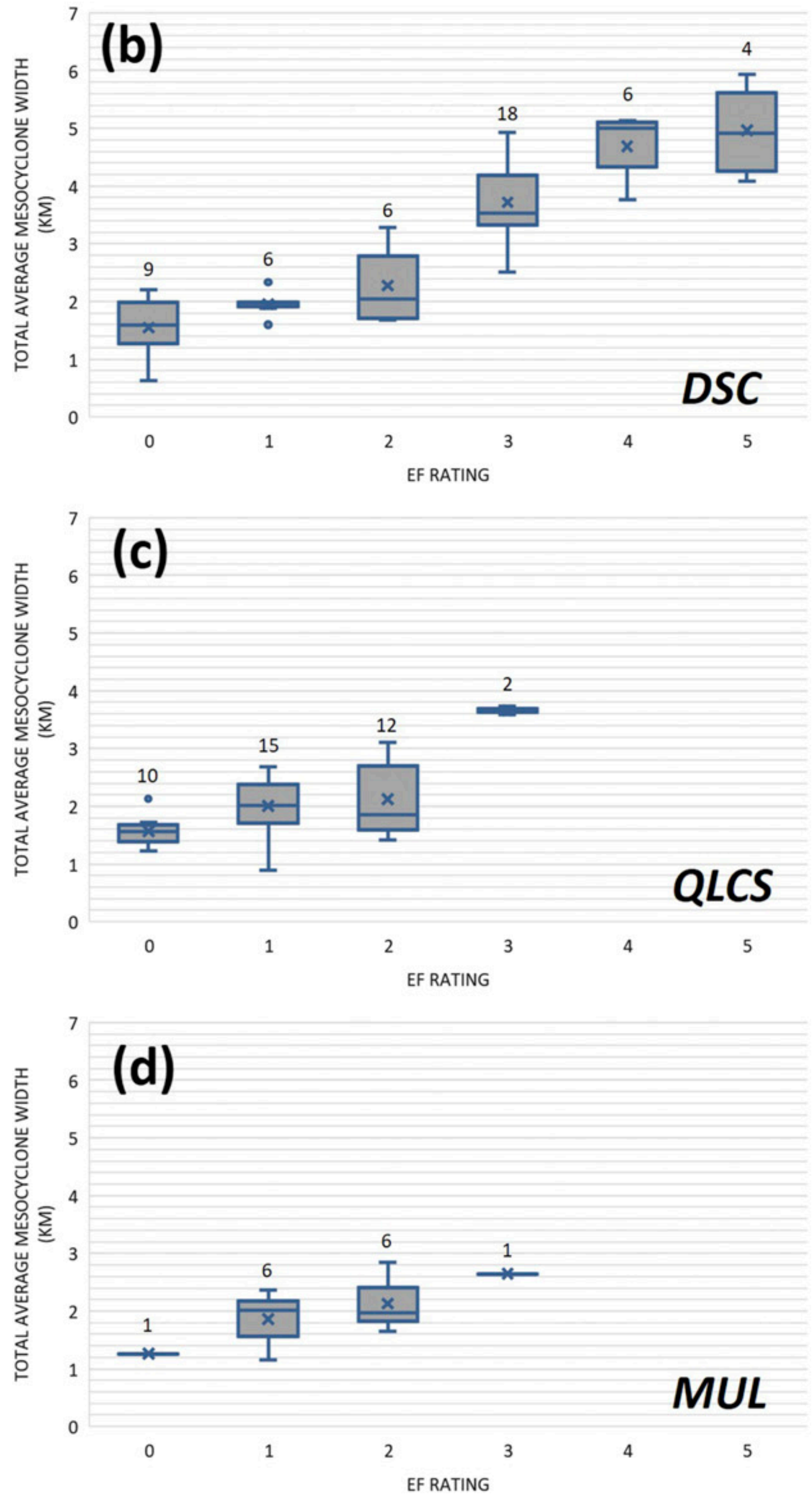


Fig. 4(a): like 3(a)

Fig. 4: like Fig. 3



Do conclusions change when

1. Data for *individual elevation angles* are examined?
2. *Maximum* pretornadic mesocyclone width is used?
3. Peak intensity of the tornadic vortex (differential velocity) is used? (next two slides)
4. When events are sorted by *radar range*?
5. When *peak pretornadic mesocyclone width* is used? (Fig. 16)
6. Using damage width instead of pretornadic mesocyclone width?

What about path length instead of tornado intensity?

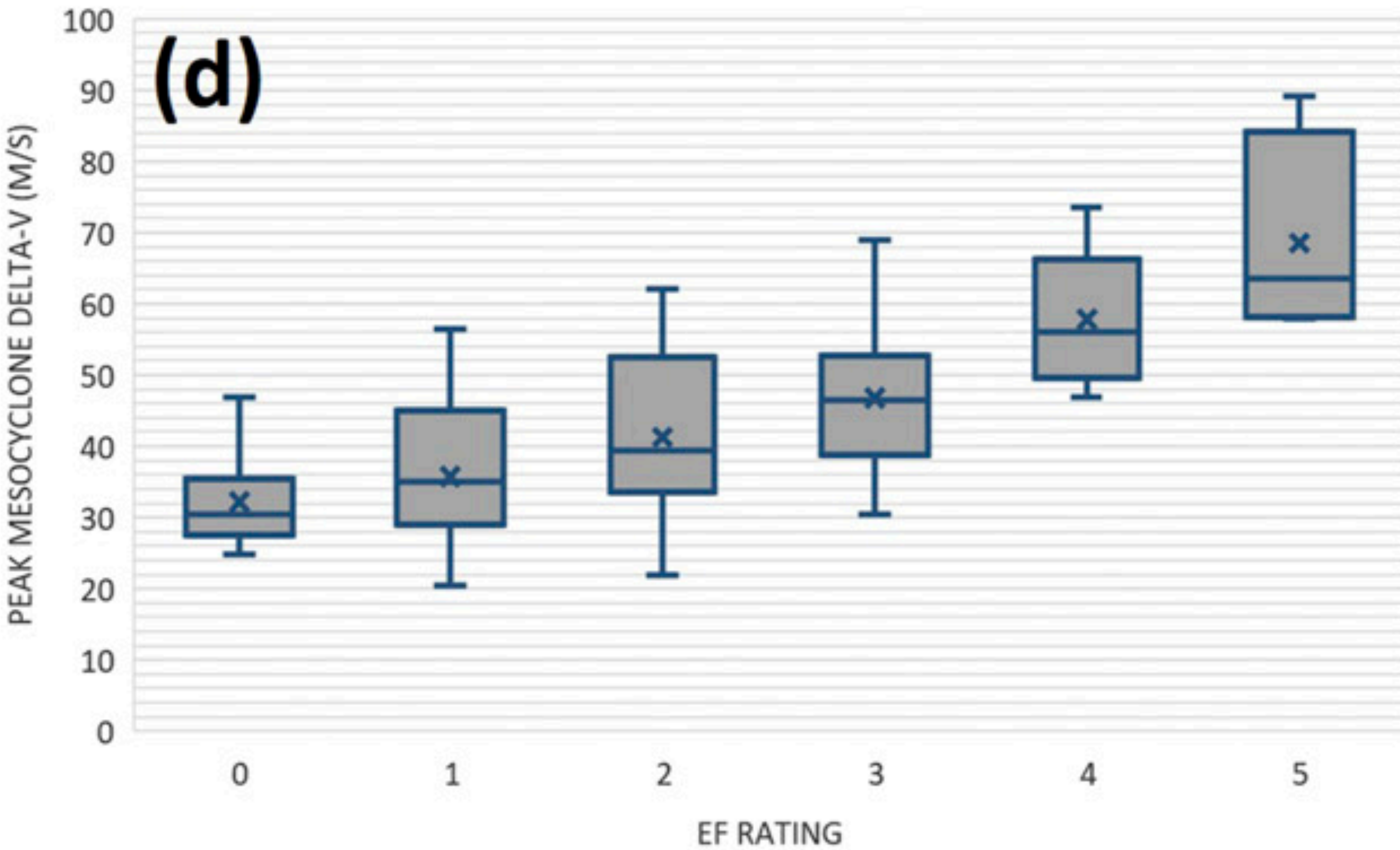


Fig. 14 (d): Like 4(d) except using peak pretornadic mesocyclone intensity (differential velocity)

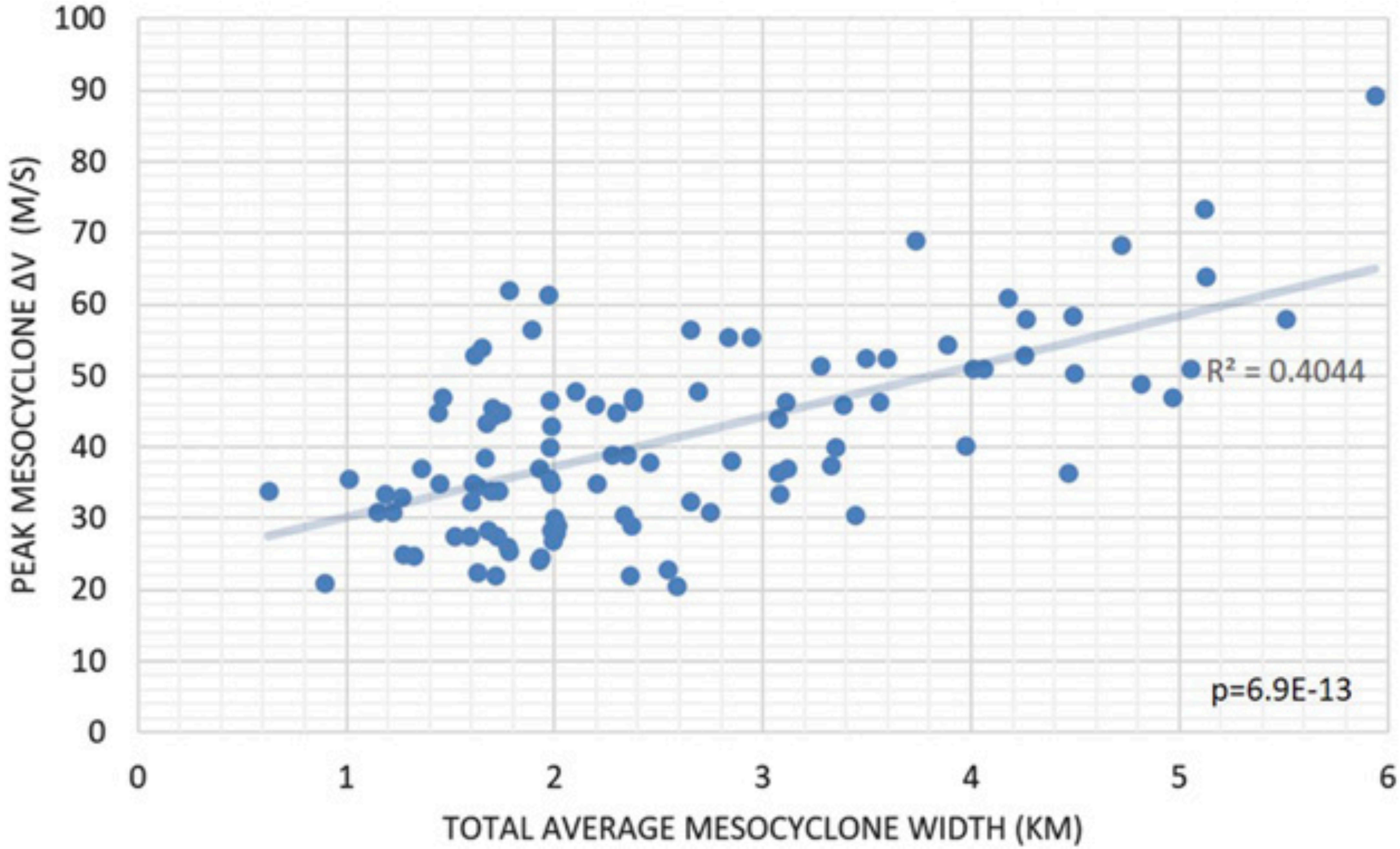


FIG. 15. Scatterplot showing the linear relationship between the peak pretornadic mesocyclone intensity (differential velocity; $\mathrm{m\,s^{-1}}$) and the average pretornadic mesocyclone width (km) for all cases.

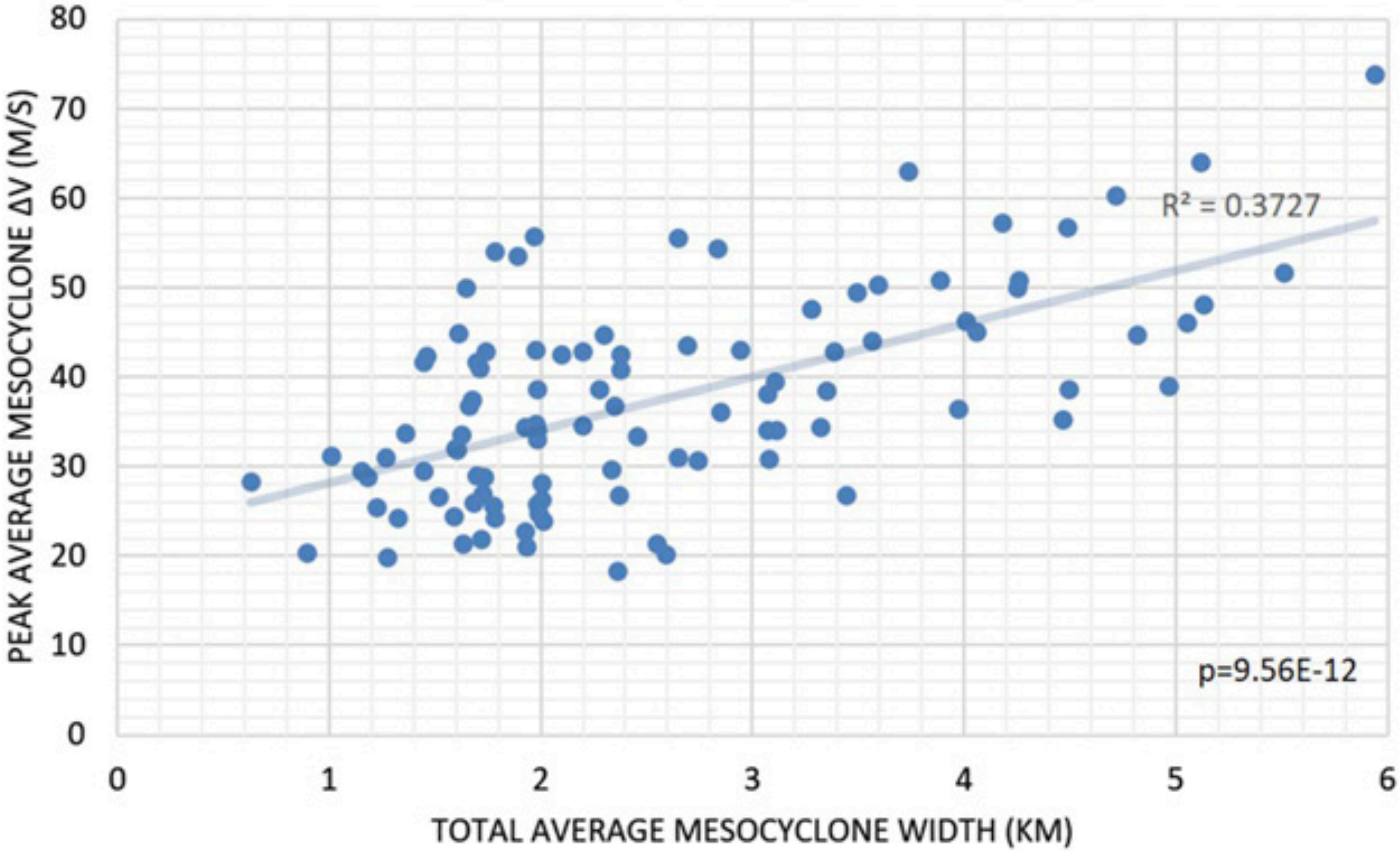


FIG. 16. Scatterplot showing the linear relationship between the peak average intensity of the pretornadic mesocyclone (differential velocity; $m\,s^{-1}$) and the total average width of the pretornadic mesocyclone (km) for all cases.