Comparison of in-situ Electric Field and Radar Derived Parameters for Stratiform Clouds in Central Florida

M.G. Bateman[1], D.M. Mach[2], S. Lewis[3], J.E. Dye[3], E. Defer[3], C.A. Grainger[4], P.T. Willis[5], H.J. Christian[6], and F.J. Merceret[7]

[1]Universities Space Research Association, Huntsville, AL
[2]The University of Alabama in Huntsville
[3]NCAR, Boulder, CO
[4]Atmospheric Sciences Dept, The University of North Dakota, Grand Forks, ND
[5]NOAA/Hurricane Research Division, Miami, FL
[6]NASA/MSFC, Huntsville, AL
[7]NASA/KSC, Kennedy Space Center, FL

ABSTRACT: Airborne measurements of electric fields and particle microphysics were made during a field program at NASA's Kennedy Space Center. The aircraft, a Cessna Citation II jet operated by the University of North Dakota, carried six rotating-vane style electric field mills, several microphysics instruments, and thermodynamic instruments. In addition to the aircraft measurements, we also have data from both the Eastern Test Range WSR-74C (Patrick AFB) and the U.S. National Weather Service WSR-88D radars (primarily Melbourne, FL). One specific goal of this program was to try to develop a radar-based rule for estimating the hazard that an in-cloud electric field would present to a vehicle launched into the cloud. Based on past experience, and our desire to quantify the mixed-phase region of the cloud in question, we have assessed several algorithms for integrating radar reflectivity data in and above the mixed-phase region as a proxy for electric field. A successful radar proxy is one that can accurately predict the presence or absence of significant electric fields. We have compared various proxies with the measured in-cloud electric field strength in an attempt to develop a radar rule for assessing launch hazard. Assessment of the best proxy is presented.

INTRODUCTION

The U.S. Space Program has a set of rules that operations personnel use to determine if weather conditions are safe for rocket launches. A recent field program focused on the launch rules that deal specifically with lightning and thunderstorm safety. For various reasons, when these rules were originally written, it was not possible to develop a radar-based proxy for cloud electrification. Developing a radar algorithm that can be used as a proxy for cloud electrification has been one of our priorities during the current field program and subsequent analyses.

One particular problem for launches in Florida is long-lived anvils. These anvils can persist for hours, and it was unknown whether they were safe for penetration any time prior to dissipation. Many passes were flown through anvils, repeatedly measuring the electric field in the same area until the field had decayed to near fair-weather magnitude. Using these decaying anvils as limiting cases, we crafted a radar algorithm that could be used as a proxy for electric field.

INSTRUMENTATION

The platform used during this field program was a Cessna Citation II jet operated by the University of North Dakota that carried six rotating-vane style electric field mills. The aircraft has been carefully calibrated so that we can retrieve the electric field vector components (in aircraft coordinates) from the field mill outputs. For details on the calibration technique, see the paper by *Mach et al.*, elsewhere in this issue.

GPS navigation data, along with aircraft heading and attitude were recorded onboard. The radar data presented here are from the National Weather Service WSR-88D radar at Melbourne, FL.

Algorithm

We tried several different algorithms for calculated radar parameters, and compared them with $|E|$ at the aircraft. We attempted to incorporate the mixed-phase and ice regions of the cloud without being biased by rain, which we believe does not contribute significantly to electrification. An approach that has worked well in the past is to vertically integrate the radar reflectivity from the 0°C isotherm up to cloud top. This turns out to be a noisy parameter, and averaging smoothed it out. Note that this is a conditional average; if part of the box contained no data, the total volume was reduced before dividing. Since E can be a fairly localized property ($1/r^2$ dependence), we attempted to limit the cloud that we consider as influential in creating E. To do this, we limited the calculation to a 10 km × 10 km box, centered on the aircraft, and extending vertically from 0°C to cloud top. The 0°C isotherm in Florida in June is typically 5 km altitude. Thus, the calculated radar parameter that we found to work best (so far) as a proxy for electric field is average reflectivity within the described box centered on the aircraft, and not extending lower than 5 km altitude. Algorithms that did not work as well include: (a) average over a 5 km box, (b) integrated reflectivity, (c) convert dBZ to Z, average Z, convert result back to dBZ (this was greatly biased by the largest particles), and (d) maximum reflectivity in the box.

Data

The data presented here are from a single Citation flight, 2020 UTC June 13 – 0020 UTC June 14, 2000. The plots shown in Figures 1 and 2 each have three panels. The top panel has a heavy line that indicates the aircraft track. The colored boxes represent gridded reflectivity in a vertical "swath" that contains the aircraft track. Note that this swath follows the aircraft track, and does not necessarily represent a straight flight path.

The second panel shows averaged reflectivity, for 5 km and 10 km boxes. The bottom panel shows the electric field; the heavy line is the z-component (E_z) and uses the left scale; the fine line shows the magnitude of the field ($|E|$) and uses the right scale.

Figure 3 shows a scatterplot of $|E|$ vs. averaged reflectivity for the entire flight. The threshold value that provides the best compromise between identification of potentially hazardous electric fields and safe field conditions is 5 dBZ (horizontal line). Electric field strong enough to be hazardous to a penetrating vehicle is 5–10 kV/m; the value 5 kV/m is indicated (vertical line). Two quadrants are identified: *Failure to Detect* (empty) and *False Alarm* (many).

In Figure 1a, the radar parameter crosses the 5 db$Z$ threshold at about 2114:30 (middle panel, heavy line). The $|E|$ remains near zero until 2115. The field remains hazardous until about 2120 (Figure 1b, bottom panel, thin line). The radar parameter does not come back down to threshold until 2120:45. Another example follows from 2123 to about 2129. The significant $|E|$ values occurred between 2125:50 and 2127:30. Figure 2 shows an example of a false alarm — high average reflectivity values with near zero $|E|$. This is not an uncommon situation.

Concluding Remarks

After looking at about 10 anvil cases, the averaged reflectivity above the 0°C isotherm seems to be a reliable proxy for cloud electrification. The threshold for danger also seems to hold at around 5 dBZ.

The *Failure to Detect* is already minimized, however, the *False Alarm* rate is high. Thus, this parameter is a one-way test, which errs in the conservative direction. Note that the imperative is to always detect the hazardous condition, with false alarms being unfortunate (a consequence of using a proxy), but operationally acceptable.

Implemented as a real-time available radar product, this 10 km-box averaged reflectivity will likely give guidance to which anvils may be hazardous for launched vehicles. Using this tool, launches may be permitted prior to the complete dissipation of the anvil in question, thus increasing launch availability without decreasing launch safety.
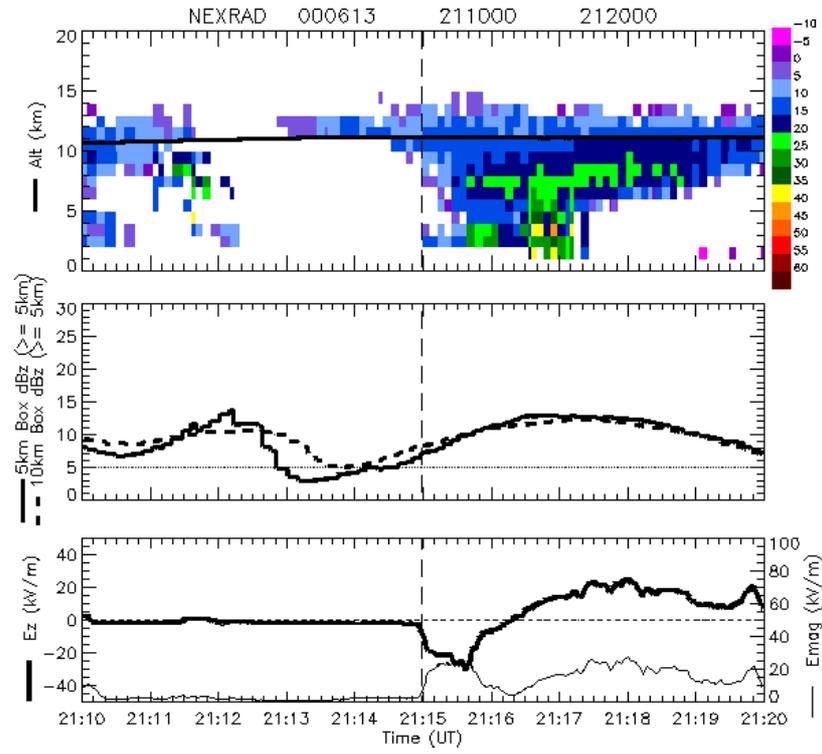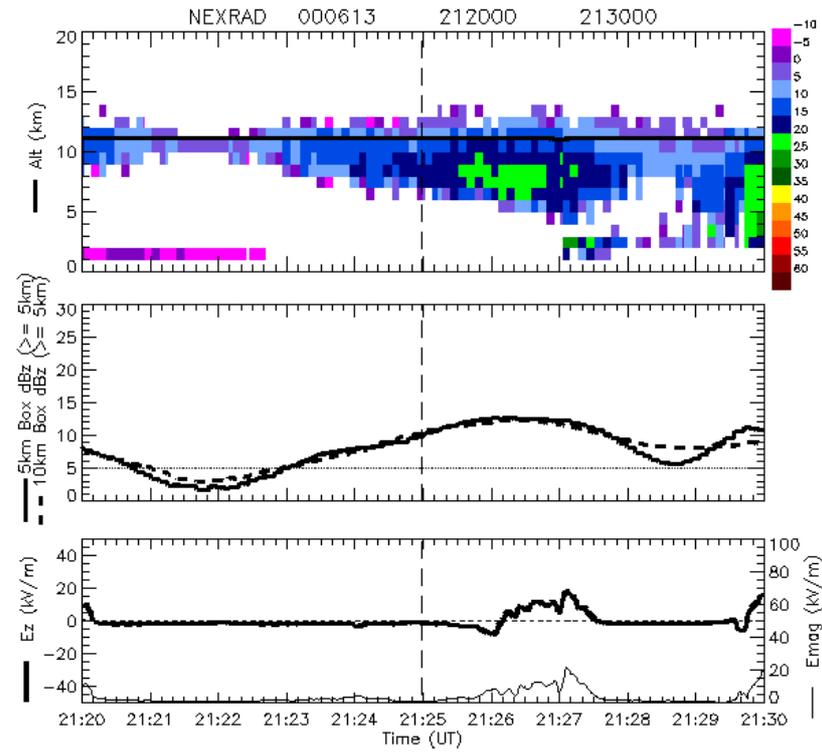
Figure 1: These figures show multiple passes through an anvil. In these 3-panel figures, the top panel is a vertical swath of reflectivity with aircraft track, the middle panel is the calculated radar parameter, and the bottom panel is E_z (thick line, left scale) and $|E|$ (thin line, right scale). Thes are examples of the radar parameter working well.
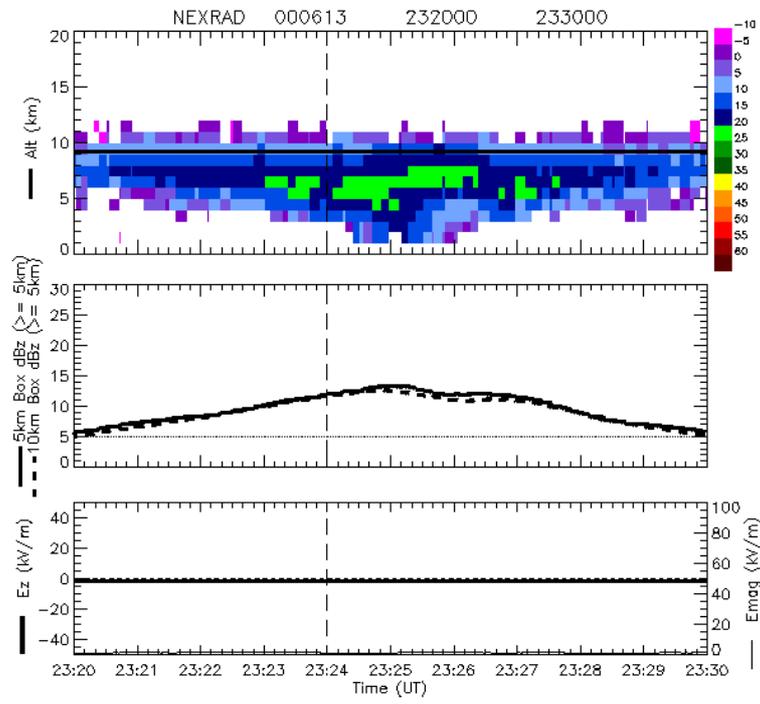
Figure 2: See previous description of plot format. This is an example of a false alarm.
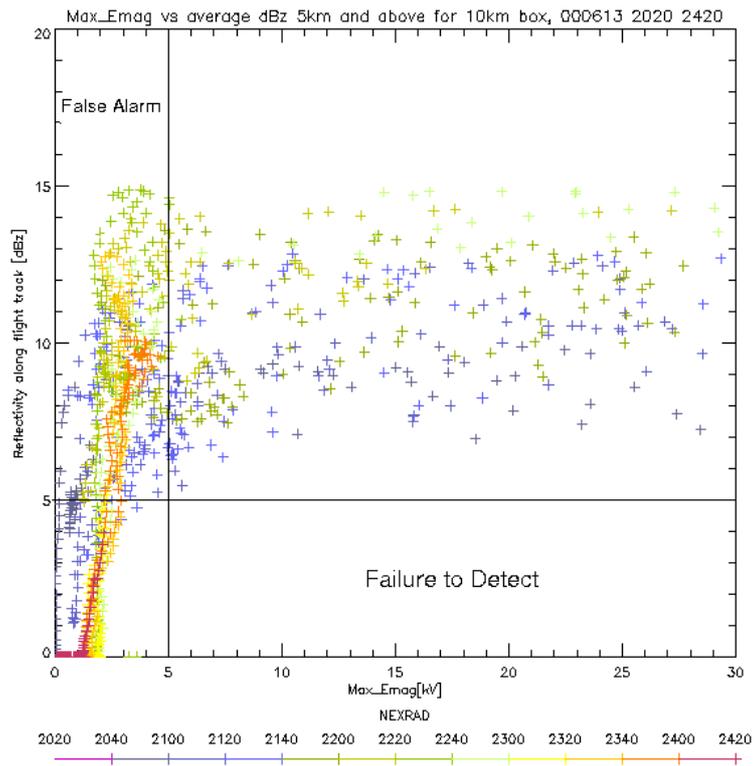
Figure 3: This is a scatterplot of $|E|$ and the 10 km box average reflectivity for the entire flight. Color indicates time.