Polarimetric Radar Characteristics of Weakly Electrified Clouds over the Eastern Range

Poster #44

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BACKGROUND AND MOTIVATION

- **Weakly electrified clouds** receive less attention than thunderstorms because they typically do not produce severe weather and are *not* associated with natural lightning
- Knowledge of electrification mechanisms and associated cloud processes in weakly electrified clouds is incomplete
- Methods to detect remotely the processes that lead to weakly electrified clouds are limited
- Weakly electrified clouds can be a **significant triggered lightning risk** for commercial aviation and space launch activities.

Lighting strike to lightning tower used to protect the Artemis 1 rocket preparing for launch at NASA KSC on August 27, 2022. Photo: NASA

- The **Eastern Range** is a Spaceport that supports rocket launches from Kennedy Space Center (KSC) and Cape Canaveral Space Force Station (CCSFS) in Florida.
- The 45th Weather Squadron utilizes a set of safety rules called the **Lightning Launch Commit Criteria (LLCC)** to help ensure safe launch operations at the Eastern Range.

OBJECTIVES

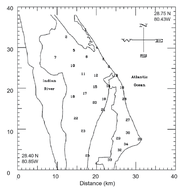
- To identify cloud conditions associated with the natural and **triggered lightning threat** (i.e., elevated electric fields not strong enough for natural lightning but sufficient to trigger breakdown when a conducting rocket + plume moves through cloud), the LLCC utilize
  - various observations (e.g., lightning, **surface electric field, radar reflectivity**) and **cloud types** (e.g., cumulus, attached and detached anvil, debris clouds, disturbed weather, **thick cloud layers**) relative to **temperature (T)** levels and cloud history thought to be associated with cloud electrification.
- Fill knowledge gaps with long-term goal of **increasing launch availability while maintaining launch safety**,
  - analyze **radar reflectivity (Z) characteristics** of weakly electrified clouds over Eastern Range
- **Thick cloud layers (TCL)** are one or more physically connected *layered clouds* with a total **vertical extent of ≥ 1.4 km** AND with *any part* at an altitude where $-\mathbf{20}$°C $\leq \boldsymbol{T} \leq \mathbf{0}$°C
  - focus on TCL since are weakly electrified with triggered lightning potential, can delay or scrub launches, *especially during cool season*, and their electrification mechanisms are poorly understood

DATA AND METHODS

- Verified no lightning was present as detected by the **Mesoscale Eastern Range Lightning Information Network (MERLIN)**, which uses VHF interferometry and LF magnetic direction finding/time-of-arrival techniques to detect and locate both intra-cloud and cloud-to-ground lightning
- Vertical component of the electrostatic field (E-field) at the surface as measured by **Launch Pad Lightning Warning System (LPLWS)**, which is network of 31 field mills over KSC-CCSFS
- Radar reflectivity (Z, dBZ) characteristics of thick cloud layers (TCLs) over LPLWS using **Melbourne (KMLB) Next Generation Weather Radar (NEXRAD)**, which is 48 km from KSC-CCSFS.
- Environmental temperature levels for TCL identification and cloud electrification inferences were obtained from the low-resolution **Automated Meteorological Profiling System (AMPS)** data available at the Eastern Range that was closest in time (usually within < 6 hours of the TCL event)
- KMLB reflectivity, LPLWS time series, AMPS and weather tower wind data were used to eliminate non-cloud sources of significant E-fields (e.g., noise, sunrise, surf effects)

KMLB NEXRAD

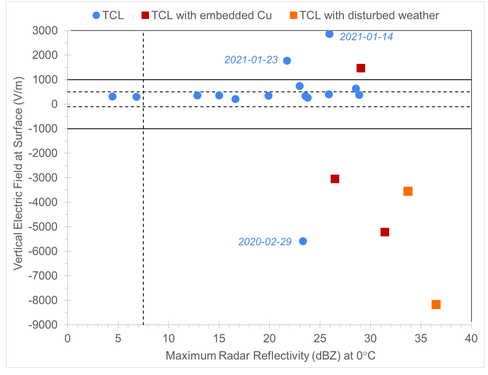
Field mill associated with the Launch Pad Lightning Warning System (LPLWS)



LPLWS field mill sensor site locations over KSC-CCSFS. Adapted from Handel et al. (2022)

THICK CLOUD LAYER (TCL): SUMMARY RESULTS

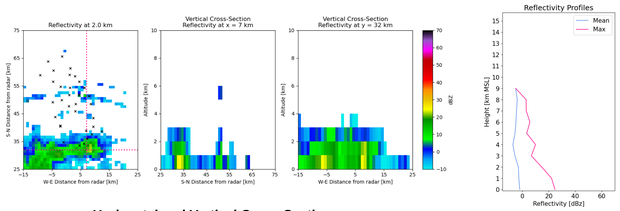
- Only 8 of 20 (40%) TCL associated with elevated |electric field| > 1000 V/m and hence triggered lightning potential
  - And they had higher maximum reflectivity (> 20 dBZ), were thicker, and were often (5 of 8) associated with embedded Cumulus (Cu) or disturbed weather (e.g., deep stratiform) clouds
  - 3 of 20 cases (15%) **TCL-only** with |electric field| > 1000 V/m
- > 20 dBZ (+/-) is necessary but not sufficient condition for elevated |electric field|, triggered lightning potential in TCL
  - LLCC TCL reflectivity exception allows launch for maximum radar reflectivity (MRR) < 7.5 dBZ but results suggest MRR < 20 dBZ +/- might allow for more launch availability.



Vertical E-field at maximum magnitude versus maximum reflectivity at freezing level. TCL cases between horizontal dashed lines showed no notable E-field response to cloud (i.e., indistinguishable from fair weather E-field). TCL red/orange cases with significant E-fields were embedded with other cloud types. Two-TCL cases had marginal fields (i.e., between horizontal dashed and solid lines) ***Only 3 TCL-only cases associated with significant E-fields (above or below solid horizontal lines)*** *while the rest were TCL + other cloud types (red/orange).*

REFLECTIVITY OF TCL-ONLY WITH TRIGGERED LIGHTNING THREAT

CASE 1: 2020-02-29, Max(Z)=23.3 dBZ, E-field = -5589 V/m, 0°C level = 1.798 km

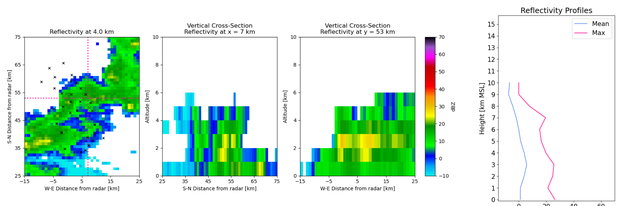


Horizontal and Vertical Cross-Sections

Mean and Maximum Vertical Profiles

2D Histogram and CFAD

CASE 2: 2021-01-14, Max(Z)=26.0 dBZ, E-field = +2857 V/m, 0°C level = 3.627 km

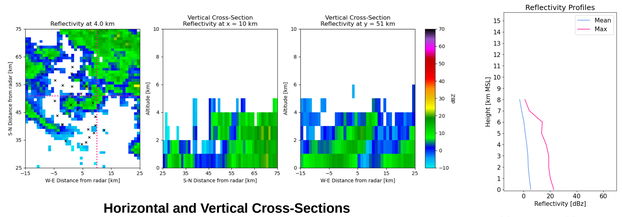


Horizontal and Vertical Cross-Sections

Mean and Maximum Vertical Profiles

2D Histogram and CFAD

CASE 3: 2021-01-23, Max(Z)=21.8 dBZ, E-field = +1767 V/m, 0°C level = 3.962 km



Horizontal and Vertical Cross-Sections

Mean and Maximum Vertical Profiles

2D Histogram and CFAD

SUMMARY AND FUTURE WORK

- Out of 20 TCL cases studied, only 8 (40%) events produced |electric field| > 1000 V/m and only 3 of them (15% of total sample) were TCL-only with no other combined cloud types
- All TCL cases with |electric field| > 1000 V/m were characterized by Max(Z) > 20 dBZ. The mixed cloud cases (TCL + Cu) and (TCL + disturbed weather) had some of the highest E-fields
  - Suggests MRR exception to the TCL LLCC rule could be raised from 7.5 dBZ to something higher (20 dBZ +/- ?), providing increased launch availability, but *need more TCL cases to assess safety of rule change*
  - Only one TCL-only case had very strong negative E-fields and it had a low 0°C height and was closer to the ground (i.e., charge closer to ground). Two other TCL-only with strong fields had positive E-fields.
- Future: *analyze MRR explicitly* and *dual-polarization (DP) fields*. QC of DP in TCL is big job!

ACKNOWLEDGEMENTS

- Research is supported by NASA KSC as part of 1st and 3rd authors' participation on NASA KSC Lightning Advisory Panel (LAP)
- The 1st and 2nd authors received research support from the UAH RCEU program
- We especially thank Dr. Sarah Stough (UAH ESSC) for Python code and programming support!