Analyzing the Vertical Electric Field Above Wintertime Mid-High Latitude Systems, and the Possible Implications to the Global Electric Circuit (GEC)

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Research Questions/Objectives:

- How significantly do large wintertime Mesoscale Convective Systems (MCSs) contribute to the upward vertical electric field, and thus the Global Electric Circuit (GEC) system?
- How do the vertical electric fields (Ez) measured above wintertime systems by the NASA ER-2 aircraft compare to those in the tropics and subtropics?
- What is the relationship between the Ez measured onboard the ER-2 aircraft and the nearby NASCOM IR brightness temperature (Tb) during wintertime MCS and tropical convective events?
- Can we determine a potential cause for such dramatically low magnitude electric fields measured above the large wintertime MSC events?

Datasets Used:

- Vertical electric field values are measured using the Lightning Instrument Package (LIP) onboard the high-altitude NASA ER-2 aircraft during various field campaigns between the years of 1993-2022.
  - Wintertime MCS system EZ data: Data used for the investigated of the wintertime events are from the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) field campaign project. These data come from the first year of flights in January-February 2020 in the Northeastern and Midwest USA. The aircraft was equipped with 7 electrical field mills, and thus is capable of determining the vector components of the electric field.
  - Other NASA ER-2 Ez data: Ez measured on other various field campaigns using the ER-2 over more tropical regions in Spring and Summer were used to study tropical convective Ez. These campaigns include: CAMEX-4, ACES, TEFLUN, TOGA COARE, and LBA.
- NASCOM IR brightness temperature data are used to describe the cloud properties and to approximate the Ez measured by the ER-2. This dataset is half-hourly and is used during the time period of 1998-2020.

Location of all LIP IMPACTS Flights:

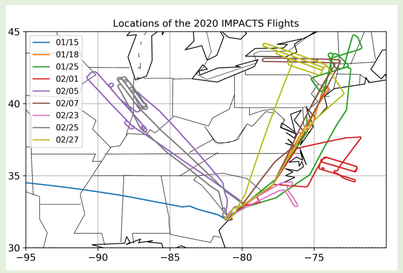

Figure 1: Location of all IMPACTS flights that took place during the 2020 year. Data was collected onboard the ER-2 Aircraft utilizing the LIP instrument package.

- The 2020 IMPACTS flights look place primarily in the Northeast and Midwest of the USA.
- The majority of the LIP overflights are concentrated in the southern USA and Gulf of Mexico. However, there are several measurements in South America, and the South Pacific.

Location of all Other ER-2 Flights:

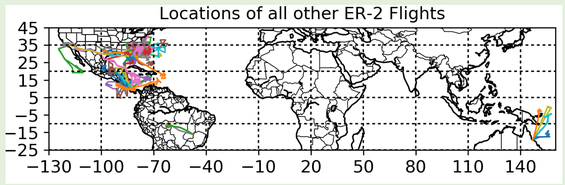

Figure 2: Location of all other flights that took place between the years of 1993-2014. Data was collected onboard the ER-2 Aircraft utilizing the LIP instrument package.

Background Ez and Histogram Counts:

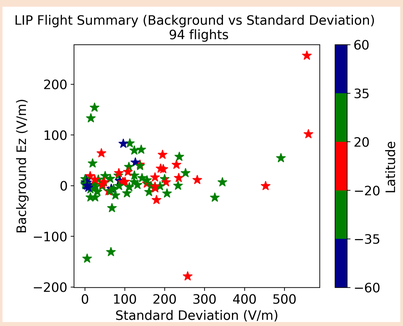

Figure 3: The standard deviation of the vertical electric field (V/m) verses the background Ez measured by the LIP package for all 94 ER-2 flights. Background was calculated as the most populated bin in a histogram of the measured Ez values.

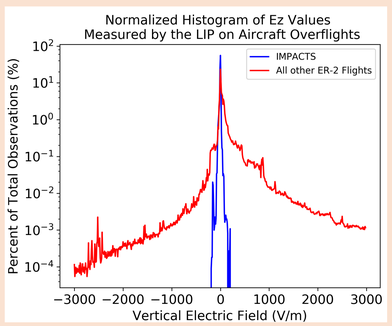

Figure 4: Histogram of the counts of measured Ez values for the IMPACTS (blue) and all other (red) ER-2 flights. Data was binned every 10 V/m.

Methodology and Case Study Examples:

IMPACTS

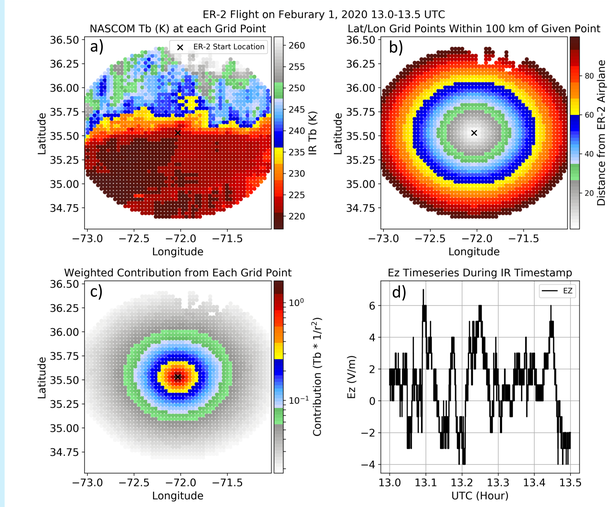

*Figure 5: a) Gridded NASCOM IR brightness temperatures, b) gridded latitude and longitude locations colored by distance from the ER-2 aircraft, c) the distance weighted brightness temperature (Tb) contribution, calculated as Tb*1/10+distance². d) 30-minute timeseries of the LIP measured Ez (V/m). Only grid boxes with colder than 225ºK were included in the analysis.*

- The ER-2 appears to be flying above cold clouds with IR brightness temperatures of 220-225K.
- Only clouds within 10-20km appear to contribute significantly to the Ez.
- A very low magnitude Ez is measured during this time-period, despite the proximity to cold clouds.

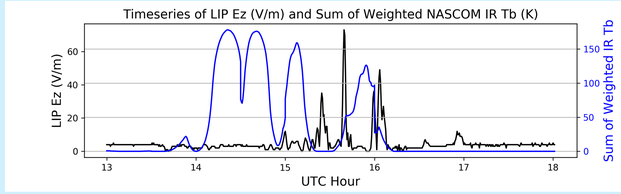

Figure 6: Timeseries of the measured Ez (black) and the sum of the weighted IR brightness temperature (blue) for the entire IMPACTS flight on 02/07/2020.

Integrated Precipitation and Hydrology Experiment (IPHEx)

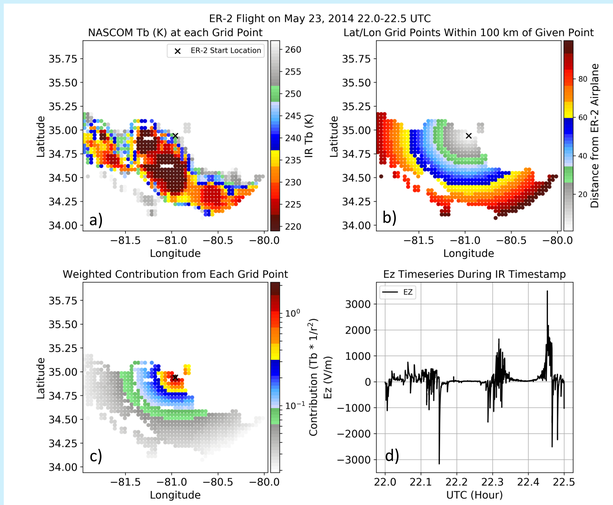

Figure 7: Same as Figure 5, but for an ER-2 flight that took place on May 22, 2014, as a part of the Integrated Precipitation and Hydrology Experiment (IPHEx) field campaign.

- Despite flying above clouds that contribute a smaller summation of distance weighted IR, the LIP aboard the ER-2 measured much larger magnitude vertical electric fields (+/-3,000 V/m).

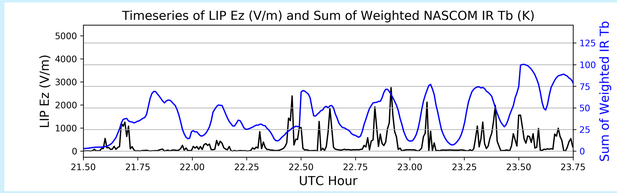

Figure 8: Same as Figure 6, but for an ER-2 flight that took place on May 22, 2014.

- A better relationship is observed between the measured Ez and the sum of the distance weighted IR in the IPHEx case in comparison to the IMPACTS case, with many of the peaks in phase with one another.

Composite Relationships Between IR brightness Temperature and the Ez:

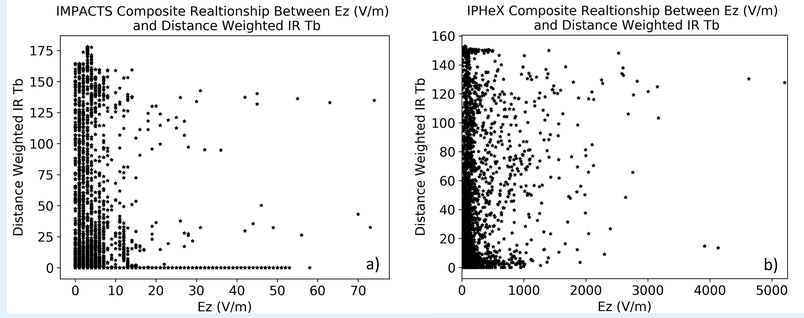

Figure 9: a) Scatter plot of the measured absolute value of the vertical electric field (Ez) and the sum of the distance weighted IR brightness temperature composited for all the IMPACTS flights. b) Scatter of the measured absolute value of the vertical electric field (Ez) and the sum of the distance weighted IR brightness temperature composited for all IPHeX flights.

IMPACTS Relationship to IR:
R-Value: -0.07
P-Value: 3.20 e-5

IPHeX Relationship to IR:
R-Value: 0.35
P-Value:1.17 e-167

- No relationship is present between the Ez measured above the clouds and the distance weighted IR during the IMPACTS campaigns.
- A slightly better relationship (r=0.35) is present during the other tropical convective cases.
- This possibly indicates differing regimes between these systems, and points to the possibility that not all systems contribute equally to the GEC, even with similar cold cloud properties.

Possible Screening Layer Theory:

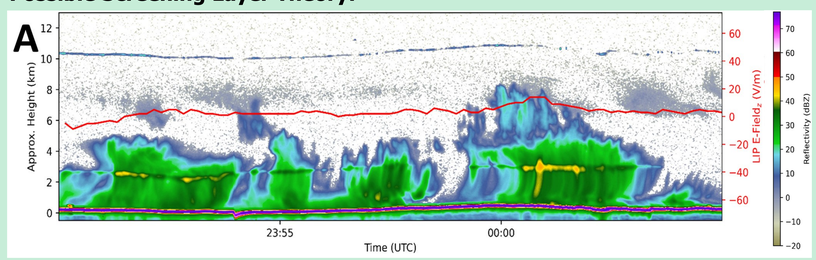

Figure 10: Radar reflectivity with overlayed LIP Ez during the February 5-6, 2020 IMPACTS flight. Figure 4a in Schultz et al., 2021.

One theory for the severely diminished electric field values above the IMPACTS cases is the presence of a thin cirrus clouds that could act as a screening layer, blocking the upward storm current.

Potential Implications to the GEC:

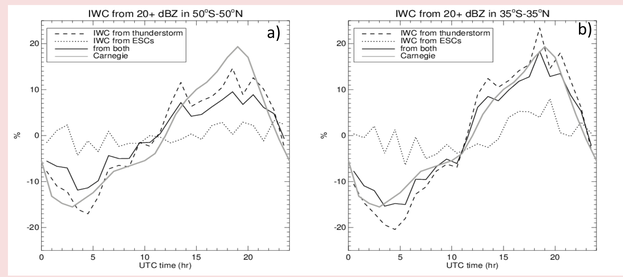

Figure 11:a) Diurnal variation of 20+ dBZ Ice Water Content (IWC) contributed from thunderstorms (dashed), Electrified Shower Clouds (dotted), and both (solid) in the latitude range of 50ºN-50ºS. The grey line indicates the Carnegie Curve. Panel b is the same as panel a, except for only include the range of 35ºN-35ºS.

When including IWC from thunderstorms and Electrified Shower Clouds (ESCs) occurring in the mid-high latitudes (35º-50º North and South), the diurnal relationship to the Carnegie Curve becomes less correlated than only including 35ºN-35ºS

Summary:

- The magnitude of the vertical electric field measured during the 2020 IMPACTS flights is significantly lower that that of other vertical electric field measurements measured around the globe also from the ER-2 aircraft.
- There is a slightly better correlation between the distance weighted IR and measured Ez during the ER-2 flights other than IMPACTS in comparison to the IMPACTS flights.
- When including properties from mid-high latitude systems, a worse relationship to the Carnegie Curve is present.
- IR brightness temperatures can be helpful in determining the contribution from clouds to the GEC, however, there are too many false alarms coming from thick anvils shallowing the global application.

Future Work:

In the future, we hope to utilize the passive microwave satellite constellation alongside CubeSats to better derive how thunderstorms and ESCs relate to the Ez. Currently, these platforms are mainly being used to measure precipitation. There are many further applications of these datasets, including deriving the IWC, lightning properties, and the contribution to the GEC from global precipitation systems.

Acknowledgement: This study was supported by NSF-2219639.

Reference:

Schultz, C. J., Harkema, S. S., Mach, D. M., Bateman, M., Lang, T. J., Heymsfield, G. M., ... & Sand, K. (2021). Remote Sensing of Electric Fields Observed Within Winter Precipitation During the 2020 Investigation of. Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) Field Campaign. *Journal of Geophysical Research: Atmospheres*, *126*(16), e2021JD034704.