

On the Variability of Wilson Currents by Storm Type and Phase

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ABSTRACT: Storm total conduction currents from electrified clouds are thought to play a major role in maintaining the potential difference between the earth's surface and the upper atmosphere within the Global Electric Circuit (GEC). However, it is not entirely known how the contributions of these currents vary by cloud type and phase of the clouds life cycle. Estimates of storm total conduction currents were obtained from data collected over two decades during multiple field campaigns involving the NASA ER-2 aircraft. In this study the variability of these currents by cloud type and lifecycle is investigated. We also compared radar derived microphysical storm properties with total storm currents to investigate whether these storm properties can be used to describe the current variability of different electrified clouds. The ultimate goal is to help improve modeling of the GEC via quantification and improved parameterization of the conduction current contribution of different cloud types.

INTRODUCTION

Electrical connections exist within the atmosphere that constitute the “global electric circuit” (GEC). As part of the GEC, these electrical connections are responsible for maintaining a quasi-static potential on the order of 240 kV between the Ionosphere and the Earth's surface. As first postulated by Wilson [1920], it is thought that thunderstorms and other electrified but non-lightning producing clouds play a major role in maintaining this potential difference by producing a globally integrated upward current – also called Wilson current - of about ~1000-2000 A. Dependent on various factors a downward current occurs in fair weather regions. Both upward and downward currents are dependent on variations in conductivity between the Ionosphere and the Earth's surface, and other factors imposed from geospace (variations in the solar wind, solar wind-magnetosphere-ionosphere coupling, and other effects [e.g., Roble 1991]). Figure 1 illustrates the various components in the GEC.

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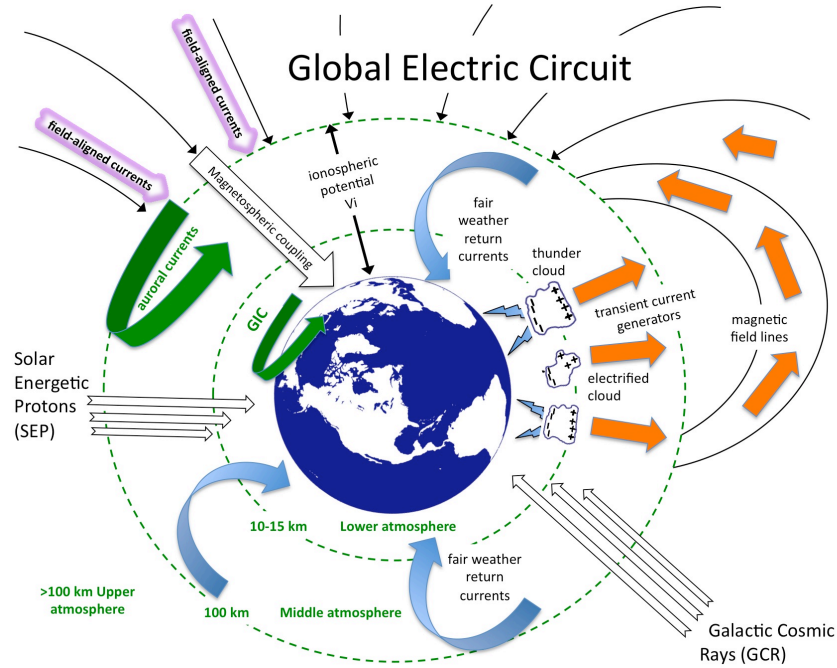


Figure 1: Schematic of processes relevant to the GEC, extending from Earth's surface to the upper atmosphere, geospace and beyond. Thunderclouds and other electrified clouds serve as generators of current (orange arrows) and maintain the Earth-ionosphere leaky "capacitor" at a potential with respect to the ground. Currents return in the fair weather regions (blue arrows). Magnetic field lines can serve to electrically connect the Northern and Southern Hemispheres. Modification of electrical resistivity by ionizing solar energetic protons and galactic cosmic rays are two ways in which the solar system modulates the GEC; a third is through coupling with the magnetosphere. Magnetic fluxes due to auroral currents (green arrows) produce "geomagnetically-induced currents (GIC)" in the ground. From: <http://sisko.colorado.edu/FESD/>

Electrified clouds, both lightning and non-lightning producing, of various types are thought to play an important role in supplying current to the GEC [e.g., Williams and Satori 2004; Williams et al. 2009; Liu et al. 2010; Mach et al. 2010; 2011]. However, the current contribution to the GEC of specific cloud types and possible current variability during their lifetime is still not well known [Mach et al. 2011]. Mach et al. [2010; 2011] determined total electric currents of clouds from overflights. They concluded that using a single global mean current for all clouds may not sufficiently describe the contribution of these clouds to the GEC. For lightning producing clouds, several studies have shown that a strong updraft within the mixed phase region plays a major role in storm electrification [Workman and Reynolds 1949; Williams and Lhermitte 1983; Dye et al. 1989; Deierling et al. 2008; Deierling and Petersen 2008]. Recent studies also suggest that storm updraft and mixed phase characteristics may represent storm conduction currents [Davydenko et al. 2009; Mach et al. 2010]. Additionally, Liu et al. [2010] used TRMM precipitation radar data to identify non-lightning and lightning producing clouds.

In this study we compare storm total conduction currents determined by Mach et al. [2010; 2011] with airborne and ground based radar data, lightning data and other observations in order to determine the

storm type, what stage in the lifecycle the storms is, and how storm microphysical parameters relate to the total storm currents. If relationships are found between storm microphysical and dynamical parameters, these relationships may be useful for parameterizations of storm currents in models (see accompanying paper from Kalb et al., this conference). This work ultimately seeks to improve the current quantification of different cloud types to the GEC within a new model framework of the GEC that is being developed under the collaboration within the “Electrical Connections And Consequences Within the Earth System (ECCWES)” project.

DATA

Estimates of storm total conduction currents were obtained from electric field mill and conductivity data collected by the NASA-ER2 aircraft throughout overflights above storms over two decades during multiple field campaigns [Mach et al. 2009; 2010]. The overflight data was matched with ground based and/or airborne radar data such as the S-band Next Generation Radars (NEXRAD's), the National Center for Atmospheric Research's (NCAR's) S-band dual polarimetric radar (SPOL), the Massachusetts Institute of Technology (MIT) C-band radar, and NASA's ER-2 Doppler Radar (EDOP) data. Lightning data were also used when available. Both radar and lightning data were used to characterize whether a storm was in its developing, mature or dissipation stage. Radar data were also used to classify storms by type as single and multicell storms, mesoscale convective systems (MCS's) and line storms. Further classification included oceanic, coastal, and continental categories as well as convective and stratiform categories. Figure 2 shows the geographical location of storm current data used in this analysis that are within ground based radar coverage. Storm locations include the Southern United States, Brazil and the south-west Pacific.

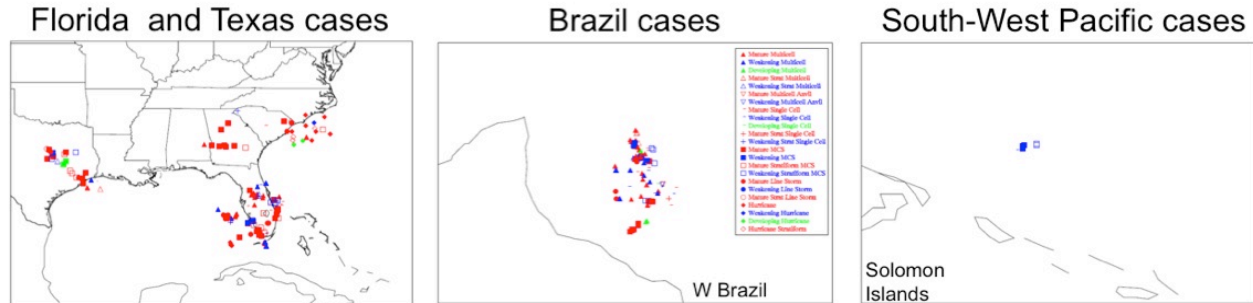


Figure 2: Locations of total storm currents obtained by Mach et al. [2009; 2010 & 2011] that are within ground based radar coverage.

RESULTS

Variations of Wilson Currents during Storm Lifecycle

For multiple cases, the ER-2 made several overpasses over the same storm covering most of its lifetime. This provides an excellent data set to study the variations of storm currents during the lifecycle of a storm. An example of the variability of Wilson currents during a storm's lifetime is shown in Figure 3. The figure illustrates the timeseries of Wilson currents and radar reflectivity from the EDOP radar on

board the ER-2 for a multicell case that occurred on 19 September 2001. The storm formed over the Florida Keys and lasted for approximately 4.5 hours. The ER-2 made multiple overpasses of this particular storm in its growing and mature phase and as the storm was dissipating. Wilson currents varied highly throughout the storm's lifetime exhibiting a strong peak in the storm's mature phase and small positive or negative values in the storm's dissipation phase after lightning activity ceased.

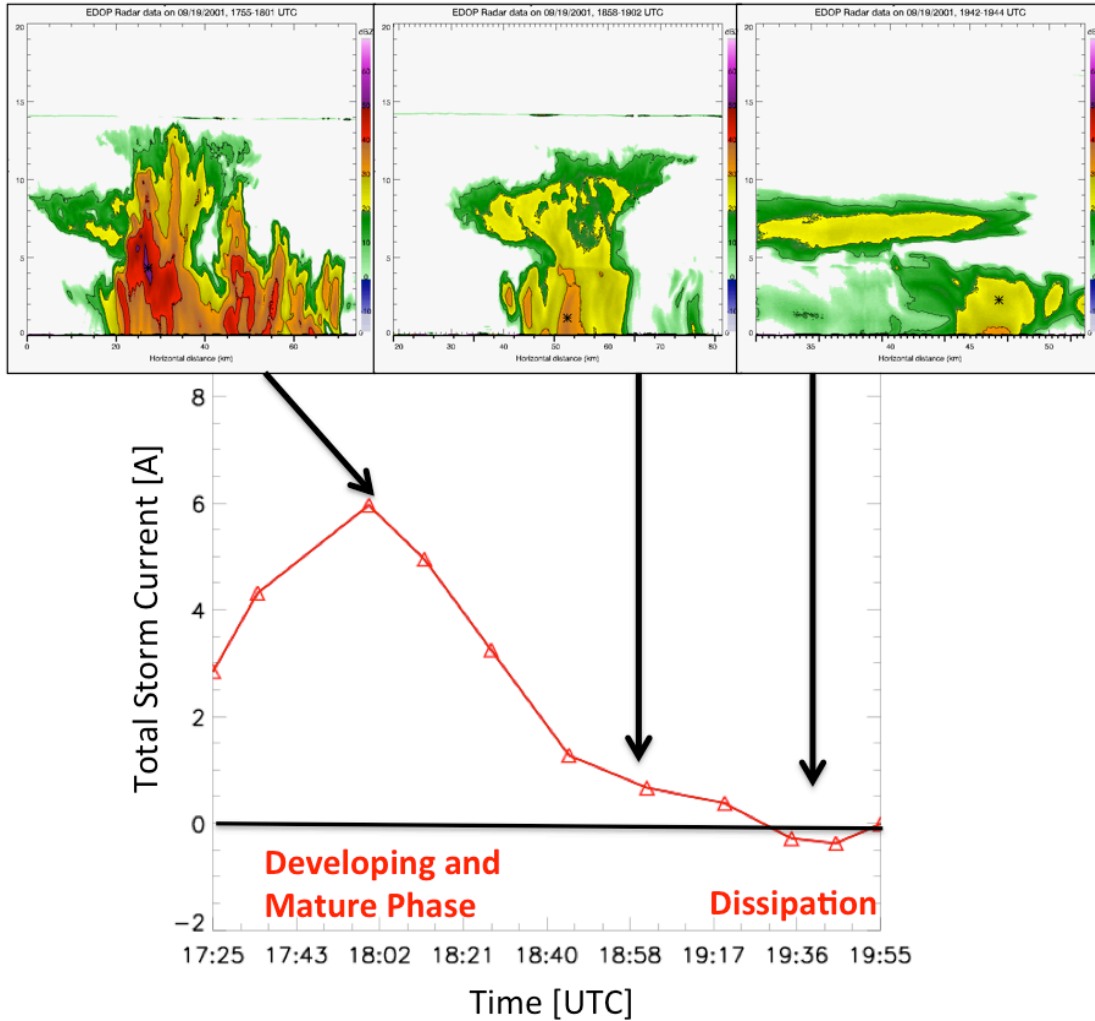


Figure 3: Time series of Wilson currents [A] of a multicell storm that occurred on 19 September 2001 over coastal Florida. The upper panels show vertical cross-sections of radar reflectivity from the EDOP radar on board the ER-2.

Figure 4 shows a histogram for Wilson currents dependent on the storm phase from all investigated cases in this study. Consistent with individual case studies such as shown in Figure 3, the highest Wilson currents occurred during the mature phase of the storm – though these can be highly variable. During the dissipation phase of storms, small positive or small negative currents can be observed. We further

categorized storm regions into stratiform and convective and also into oceanic, continental and coastal. Figure 5 shows histograms of Wilson currents for these categories. What can be seen from Figure 5 is that high currents coincide with convective cloud regions – though a lot of variation can also be noted. On the contrary, stratiform cloud regions are associated with low (positive) Wilson currents.

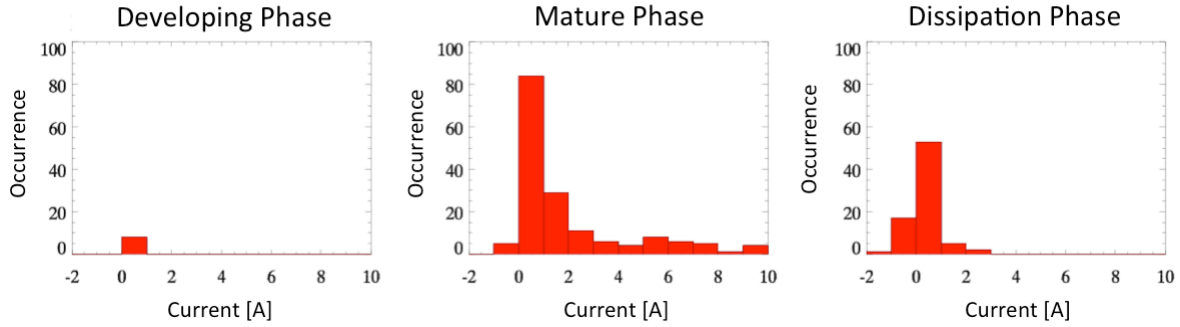


Figure 4: Histogram of storm total conduction currents for different storm phases.

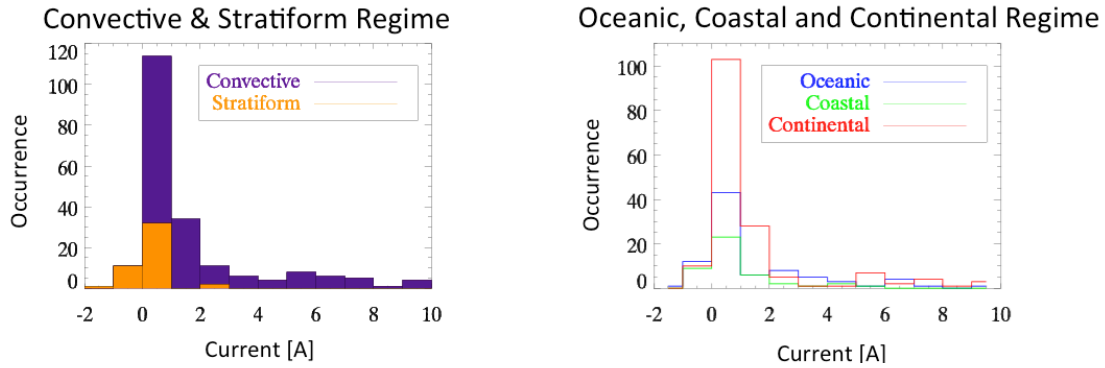


Figure 5: Histogram of Wilson currents for convective and stratiform storm regions (left) and oceanic, coastal and continental storms (right).

Wilson Currents and their Relationship to Microphysical Cloud Properties

To investigate the relationship between Wilson currents and cloud microphysical properties, radar data available from ground based radars were used to compute ice water path (IWP) for temperatures (T) colder than -10°C following Petersen et al. [2005], storm volume of radar reflectivities exceeding 35 dBZ for $T < -5^{\circ}\text{C}$, precipitation ice mass for $T < -5^{\circ}\text{C}$ following Deierling et al. [2008], maximum radar reflectivity for $T < -5^{\circ}\text{C}$ and echo top height of 18 dBZ.

For the same multicell case shown in Figure 3, Figure 6 shows the timeseries of IWP for $T < -10^{\circ}\text{C}$, maximum reflectivity for $T < -5^{\circ}\text{C}$ and storm volume of radar reflectivities exceeding 35 dBZ. The IWP and maximum radar reflectivity vary in phase with the total storm currents, although the amplitude change is not the same for both variables and maxima occur slightly later than the maximum Wilson currents. During the mature phase of the storm, precipitation ice represented by the 35dBZ reflectivity volume are also in phase with total storm currents but as could be expected it is absent in the storm's dissipation

stage.

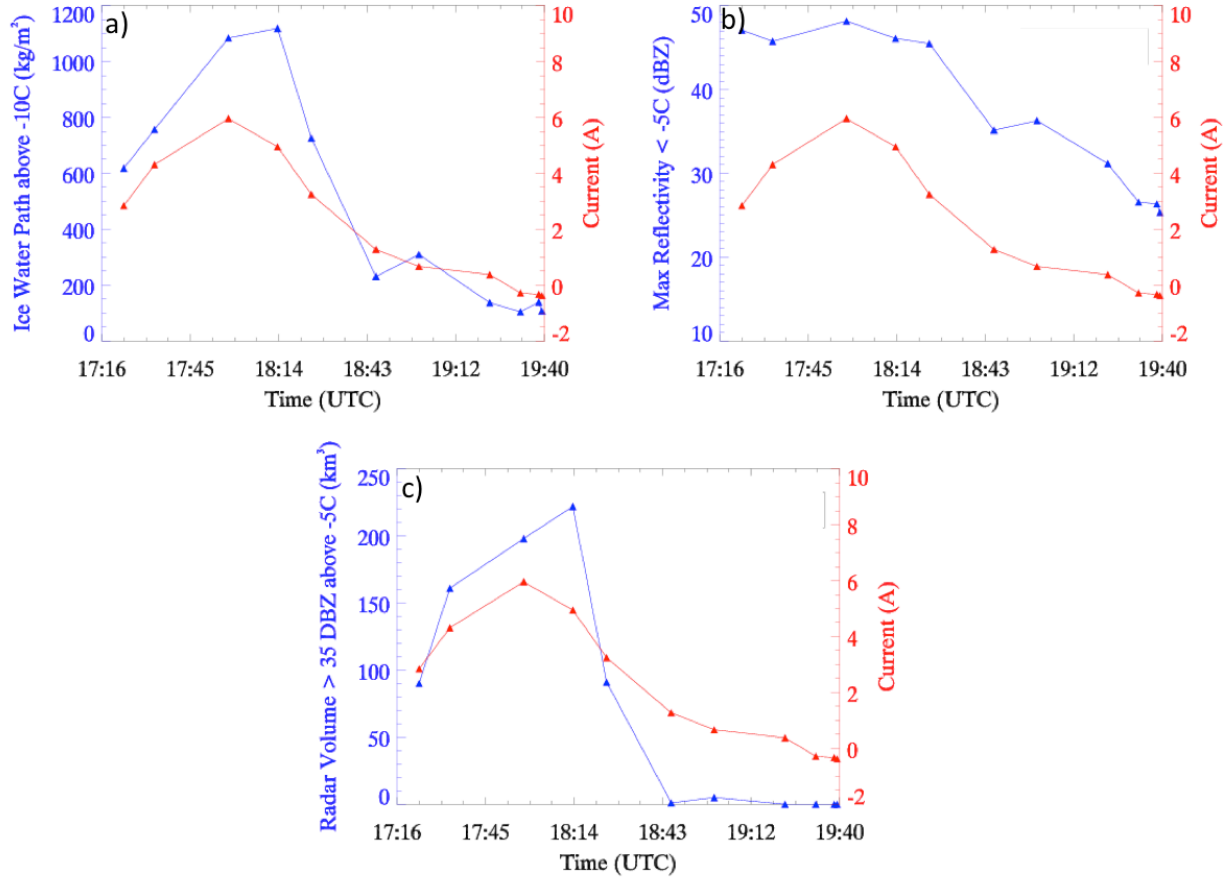


Figure 6: Time series of Wilson currents and IWP above -10°C (a), max. radar reflectivity above -5°C (b) and 35 dBZ radar reflectivity volume above -5°C for a multicell storm that occurred on 19 September 2001 in Florida.

Another case study that compares the timeseries of microphysical storm parameters with Wilson currents is shown in Figure 7. Depicted is an MCS in its developing and mature phase that occurred on 25 January 1999 in Brazil. Similar to the 19 September 2001 Florida case, the IWP varies roughly in phase. However the timeseries of the 35 dBZ radar reflectivity volume is slightly out of phase with that of the Wilson currents. For this case, the timeseries of maximum radar reflectivity varies also roughly in phase.

For both cases, in particular the IWP and 35 dBZ radar reflectivity volume show the best correlation with total storm currents over time.

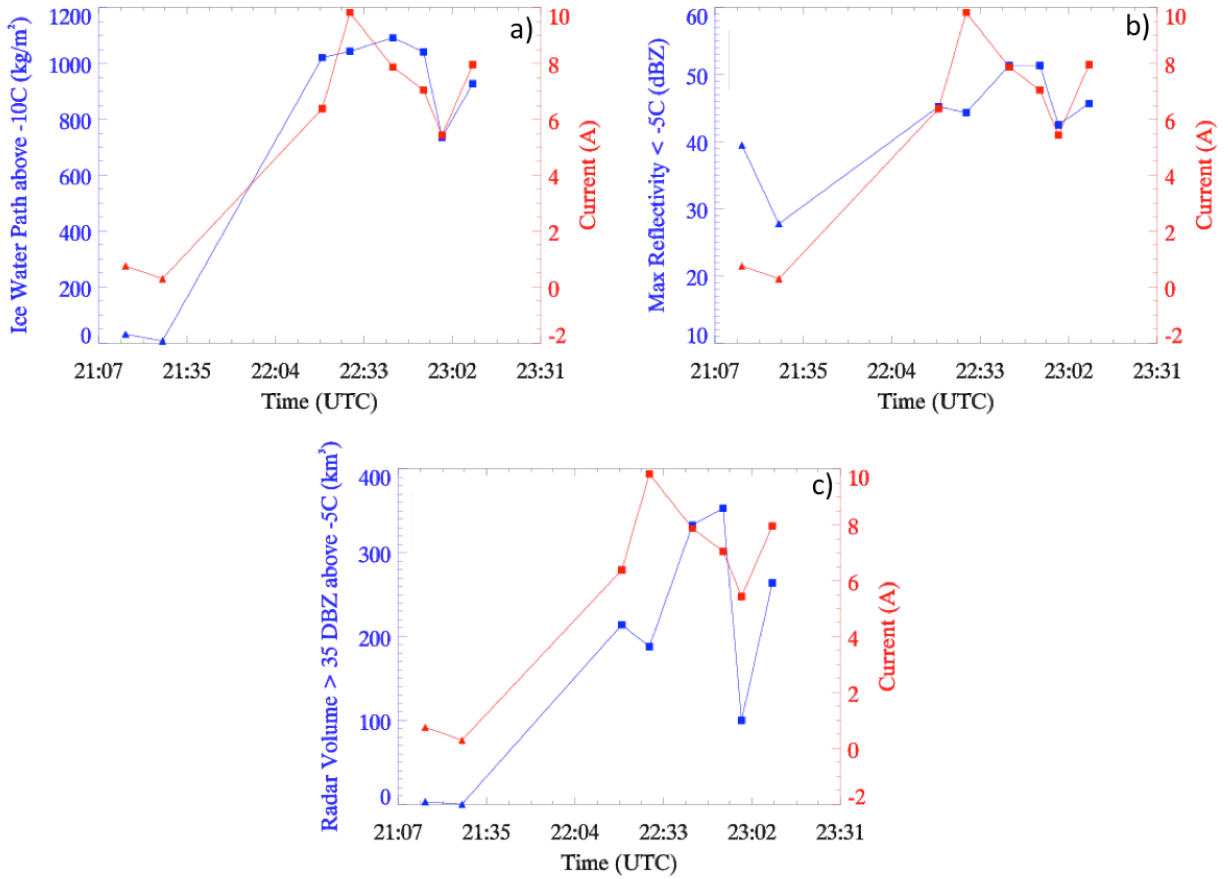


Figure 7: Time series of Wilson currents and IWP for temperatures colder than -10°C (a), maximum radar reflectivity above -5°C (b) and 35 dBZ radar volume above -5°C (c) for an MCS that occurred on 25 January 1999 in Brazil.

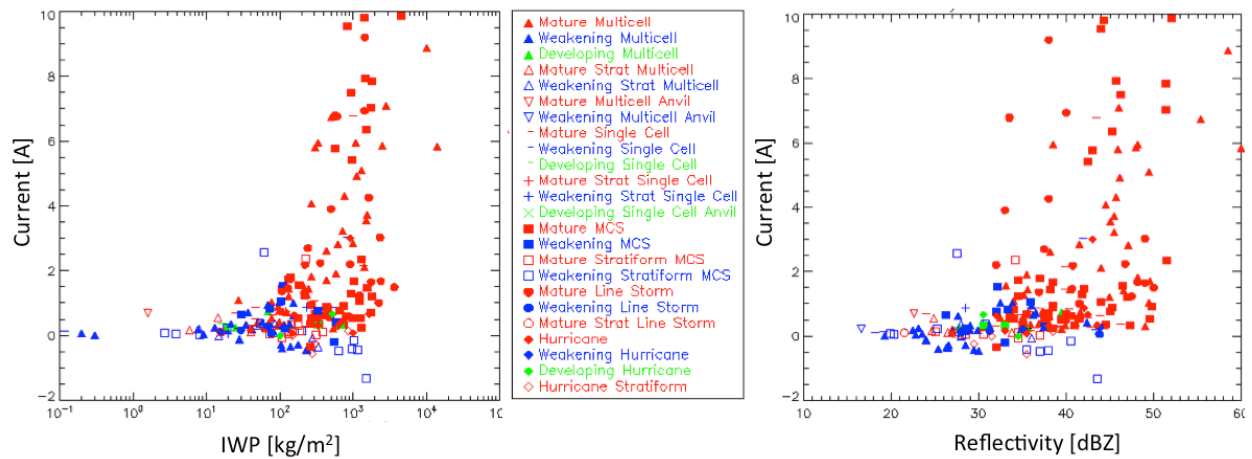


Figure 8: IWP versus Wilson currents (left), max. radar reflectivity versus Wilson currents (right) for different storm types and phases. Green colors mark the developing storm phase, red marks the mature storm phase, and blue marks the dissipation phase. The different symbols reflect different storm types.

Figure 8 shows IWP and maximum radar reflectivity versus total storm currents for all overflights where ground radar data were available. The different symbols represent different storm types, and the different colors represent different stages in a storm's lifecycle, with red representing mature, blue dissipating, and green the developing storm phase. As indicated by the case studies, the IWP (and 35 dBZ radar reflectivity volume which is not shown) exhibits the strongest (exponential) relationship to Wilson currents. The majority of storms that are in a weakening or developing phase occur with currents less than 2 A, and the majority of storms with large currents and large ice water paths are mature multicells, MCS's, and line storms. Maximum radar reflectivity and echo top height (not shown) exhibit more scatter than the IWP and radar reflectivity volumes exceeding 35 dBZ. Also, storms with the largest Wilson currents and radar reflectivities are from mature multicells, MCS's, and line storms.

To focus in more depth on storm type relationships, Figure 9 shows scatter plots of IWP versus Wilson currents for single and multicell storms (upper panel), MCS's and line storms (middle panel), and stratiform regions (lower panel) for oceanic (blue), coastal (green) and continental (red) storms. The strongest relationships are found between IWP and Wilson currents for single and multicell storms. The relationship appears more complicated for MCS's and line storms and non-existent for stratiform regions as a large range of IWP values is associated with small Wilson currents.

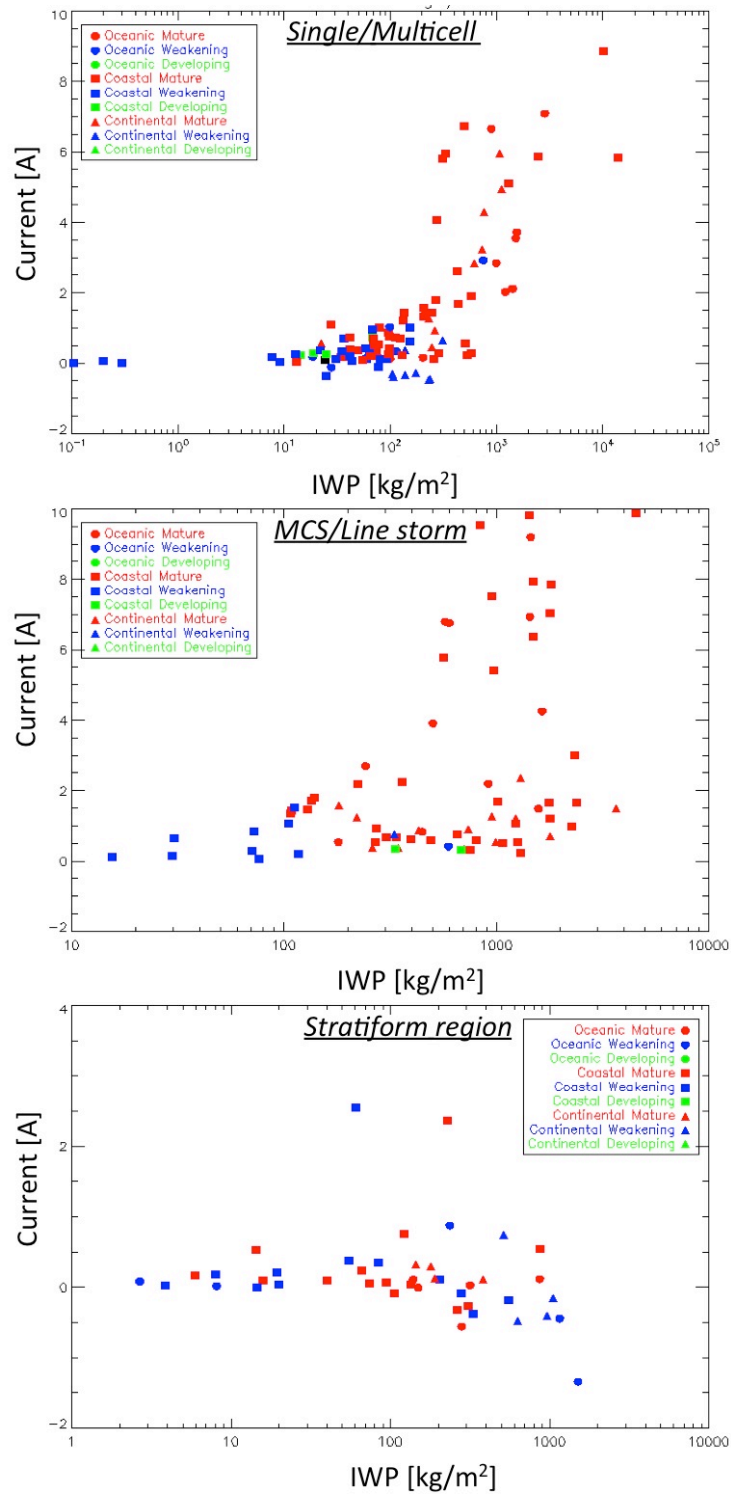


Figure 9: IWP versus Wilson currents for single and multicells (top), MCS and line storms (middle), and stratiform cases (bottom). Data from oceanic storms are in blue, coastal storms are in green, and continental storms are in red.

SUMMARY

In this study the variability of Wilson currents by cloud type and phase was investigated. Radar derived microphysical storm properties were also compared with Wilson currents to investigate whether these storm properties can be used to describe the current variability of different electrified clouds.

Results show that Wilson currents vary significantly during a storm's lifetime. Highest currents are found during the mature phase of the storm, while currents are very low and often times negative during the storms dissipation phase. Convective regions of storms are associated with highly variable but generally high Wilson currents, whereas stratiform regions exhibit low currents. Furthermore comparisons of total storm currents with microphysical storm properties suggest that some correlations between currents and some storm properties such as IWP and 35dBZ radar reflectivity volume from the cold part of clouds exist. The best correlation is found for developing and mature single/multicell convective storms, whereas no good correlations are found between any storm parameters to Wilson currents for stratiform cases.

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