Ground-level Atmospheric Electricity Under Low-level Stratiform Clouds

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ABSTRACT: This paper summarises main results of a two-year research project on the electricity of low-level clouds such as Nimbostratus and Stratus, observed at the Geophysical Observatory Swider, Poland, and at the Arctic station in Hornsund, Spitsbergen. The cloud occurrences over recent years are analysed as well as the characteristics of the ground-level electric field and current density measured at ground-level under these clouds, depending on season and accompanying meteorological phenomena. Simplified engineering models of the electrical structure of raining and snowing Nimbostratus clouds are proposed in order to use them in models of the global atmospheric electric circuit.

INTRODUCTION

The electricity of non-thunderstorm clouds has always been an interesting topic for the atmospheric electricity community, always presented and discussed at ICAE conferences. The role of non-thunderstorm shower clouds as current generators has been proposed by *Wilson* [1920] in his hypothesis on the global atmospheric electric circuit (GEC). Both convective and layer clouds have since been investigated by modelling and atmospheric electricity observations from ground level and aloft [e.g. *Chalmers*, 1956, 1958; *Reiter*, 1958; *Anderson*, 1966; *Imyanitov and Chubarina*, 1967; *Reiter*, 1968; *Takahashi*, 1976; *MacGorman and Rust*, 1998; *Harrison and Nicoll*, 2008; *Mach et al.*, 2009; *Harrison*, 2011], to understand their electrification and contribution to the global atmospheric current. Estimation of the role of such clouds in the GEC has also been attempted [e.g. *Williams and Heckman*, 1993; *Price et al.*, 1997; *Rycroft et al.*, 2007; *Mach et al.*, 2010; *Liu et al.*, 2010; *Odzimek et al.*, 2010].

In December 2011 we started a two-year research project on the electricity of layer clouds, specifically Nimbostratus (Ns) and Stratus (St), observed at our mid-latitude atmospheric electricity station Swider (52.12°N, 21.24°E) and the Polish Polar Station Hornsund (77.00°N, 15.50°E). Our motivation for the undertaking the project can be summarised as follows:

- The electrical structure is of low-level, layer clouds is not sufficiently understood and investigated, and modern models of the global atmospheric electric circuit (GEC) require parametrisation of such clouds.
- Layer clouds are spread over large area, compared to convective clouds, and this factor may contribute to the total current generation in the GEC via conduction or precipitation.
- Atmospheric electricity measurements are run at Swider (and Hornsund), simultaneously with meteorological observations, including cloudiness and cloud cover which allows the studies of the atmospheric electricity of these clouds, and this has not been performed so far.

STRATUS AND NIMBOSTRATUS CLOUD CASES IN SWIDER AND HORNSUND

We have considered Nimbostratus and Stratus cases in Swider (SWI) observations between 2005-2013 and, additionally, we analysed cases of Ns and St observed in Hornsund (HRN) in 2007-2010 (not whole year 2013 have been analysed for SWI and not whole 2007 for Hornsund). Seasonal distributions

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of the observed cases (divided into separate days) for both SWI and HRN are shown in the first row of Fig. 1. There were on average about 50 cases of both Ns and St observed at Swider each year. In Hornsund stratus seems to be much more frequent, however the number of St lasting at least for six hours over the period per year is almost the same at SWI and HRN and equals approximately 20 (days with $\geq$ 6h St *opacus*). There are only a few cases of Ns per year from Hornsund in this database. The most frequent meteorological phenomenon accompanying these clouds is precipitation in the form of rain and snow for Ns, both at SWI and HRN, and drizzle and granular snow for mid-latitude St at Swider, also snow at HRN. Seasonal distributions of these cases are shown in Fig. 1 in the second and third row of the plots.

The geoelectric vertical field Ez is measured continuously at ground level in Swider and in Hornsund [*Kubicki*, 2005; *Dziembowska*, 2009]. In the analysed period at Swider continuous measurements of the Maxwell current density, Jz, were made over years 2005-2006 and since the autumn of 2012. In 2013, for the purpose of this project, we have performed some measurements of precipitation (or convection) current density with a screened Wilson antenna. Unfortunately, no current density measurements have been available for the analysed period from Hornsund. Examples of Ez measurements for selected Ns and St cases with an analysis of Ez and Jz from Swider were presented at ICAE organised session at Atmosphere and Cryosphere Assembly in Davos (DACA-2013), and at the UK Arctic Science conference last year, including examples from Hornsund. More detailed description of the cloud and atmospheric electricity database is prepared for publication in *Odzimek et al.*, 2014 (*in preparation*).

STATISTICAL FEATURES OF GROUND-LEVEL Ez and Jz UNDER Ns AND St CLOUDS

We have also made a statistical analysis of the Ez variation under Ns and St clouds from the created cloud database. Statistical characteristics such as the minimum and maximum Ez value, percentage of the duration when Ez remains positive or negative, number of sign changes, mean and median Ez value, have been calculated. More detailed analysis of these parameters for the cases of Ns and St at Swider are also summarised in the paper in preparation.

The main conclusions from our analysis, in agreement with earlier surveys at mid-latitudes, is that taking into account cases from both Swider and Hornsund, on average, only raining Nimbostratus produces a negative electric field at the ground level (according to the sign convention that the downward electric field is positive). At Swider such cases occur throughout the whole year with a higher number of cases over the summer (Fig. 1). An average field under snowing Ns is positive, and obviously this mostly happens in the winter. The ground-level electric field under Stratus, is almost always positive, negative values occur sometimes during short episodes with drizzle. Table 1 summarises the sign of the median ground-level electric field under Nimbostratus and Stratus clouds at Swider and Hornsund station during analysed periods. Main conclusions from the analysis of Ns and St cases can be summarised as follows:

- The Arctic Nimbostratus (Hornsund) is usually associated with snow or heavy snow, and at mid-latitudes (Swider) rain, including heavy rain cases. The rain usually carries negative charge towards the Earth by the precipitation current (which then is negative) but also the conduction current is often negative.
- More investigation into the electrical behaviour of Arctic clouds (at Hornsund) is required.
- Results of observations confirm that the raining Nimbostratus, particularly at mid-latitudes (Swider) should be considered as potential electric cloud generator which can charge the Earth's global atmospheric circuit. However, the contribution of such clouds as generators at middle and higher latitudes in the EGATEC model of GEC [*Odzimek et al.*, 2010] has rather been overestimated.

Below we consider the statistical behaviour of the current density under Ns and St at Swider, with a separation into its three main components: the conduction current density, Jc, precipitation or convection

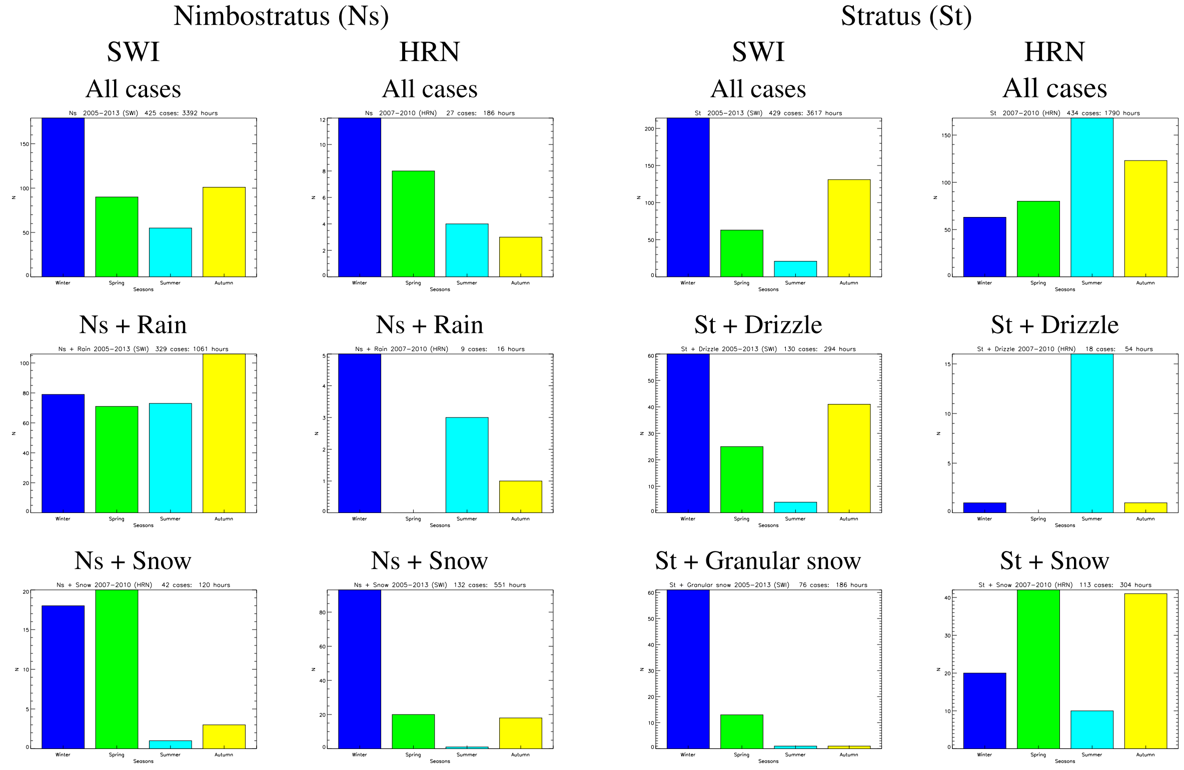

Figure 1: Seasonal distribution of cases (days) with Nimbostratus (left six panels) or Stratus (right six panels) observed at Swider (SWI) in 2005-3013 and Hornsund (HRN) in 2007-2010. Total number of hours is displayed in each plot's title. Only periods with certain occurrences of these clouds have been taken into account, no transitional periods or when the times were not precisely determined. Seasons for the Northern Hemisphere: winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug), autumn (Sep-Nov). First row: all cases, second row: Ns + rain, St + drizzle, third row: Ns + snow, St + granular snow or snow.

current density, Jp, and displacement current density, Jd. The conduction and displacement current densities have been calculated (Jc = λ Ez, Jd = $\varepsilon_0 \Delta$Ez/Δt) obtained from measurements of Ez and conductivity λ (positive and negative) at Swider. As already mentioned, in several cases Jp has been measured but in the most cases the total Maxwell current density has been measured and the remaining unknown component has been obtained by subtraction (Jp = Jz - Jc - Jd) or, adding the three components (Jz = Jc + Jd + Jp), for cases where Jp has been measured. A mean average and median of the all components have been calculated, separately for cases of all cases of Ns and St and Ns with rain and Ns with snow. A summary of these results is presented in Table 2.

A mean negative conduction current density occurs in raining conditions, under Ns, while the precipitation or convection current may be positive. In some cases though, with heavy rain, the precipitation current is also negative, resulting in the mean negative total current density (average value of the displacement current is usually close to zero). For the Nimbostratus with snow, the total current density is positive, as is the conduction current density but the precipitation/convection current is negative. With stratus, the mean value of the the current components are positive, with almost zero average value of the displacement current density.

Table 1: Sign of the average ground-level electric field under Nimbostratus (Ns) and Stratus (St) clouds at Swider (SWI) and Hornsund (HRN) stations. 1 All seasons average for SWI, 2 - All seasons average for HRN. For clouds at SWI separate sign distribution are included for precipitating clouds: Ns with rain or snow, St with drizzle or granular snow, the most frequent cases of precipitation from Ns or St at the station location. Legend: + positive, – negative sign, –/+ mean average is negative but median is positive, 0+ positive but much smaller than fair-weather value.

Cloud (SWI)	1	Cloud (HRN)	2
Nimbostratus (Ns)	–/+	Nimbostratus (Ns)	+
Ns + Rain	–		–
Ns + Snow	+	Ns + Snow	+
Stratus (St)	+	Stratus (St)	+
St + Drizzle	+	St + Drizzle	+
St + Granular Snow	+	St + Snow	0+

GROUND-LEVEL Ez UNDER Ns AND St CLOUDS - GLOBAL CIRCUIT EFFECTS

An engineering model of a cloud embedded in the global circuit [see details in *Rycroft et al.*, 2007; *Rycroft and Odzimek*, 2010] have been used in which the results from the previous section have been incorporated. In this model, the portion of the atmosphere from the ground-level through the cloud up to the ionosphere is modelled by resistances and capacitances, and two separate current sources have been introduced (see Fig. 2). Three model scenarios for the Ns cloud have been proposed.

The first current source, I_C, is localised inside the cloud, between bottom and its middle, and is responsible mainly for the effect of the conduction current (produces a separation of charge inside the cloud, with an excess of charge below affecting the direction of the electric field at the ground. The second, I_P, localised between the ground and bottom of the cloud is responsible for the transfer of charge via precipitation or convection below the cloud. It is has not been precisely determined where in the cloud these current sources should be located but calculations results do not differ significantly when the locations of the sources are changed as long as the main structure remains unchanged. Various amplitudes and polarisation have been used to recreate the conditions described in Table 2, in the way that Jc is of similar direction and amplitude as current density in resistors R_i, Ip is responsible for the production of Jp, and the sum of these two components broadly agrees with the direction and amplitude of Jz. After simulation of each model circuit, the amplitude and direction of the current flowing to the ionosphere has been obtained. Below we only summarise the main features in Table 3. It is worth noting that the current through the snowing Ns cloud discharging the global circuit (in this case negative as the convention in the model used is that upward vectors are positive) is larger than in the situation when the cloud was completely passive, i.e. there were no internal current sources associated with the cloud. This may be understood as such clouds can also be generators but are ‘’negative” generators, i.e. discharging the global circuit. This could further complicate the issue of the role of such clouds in the global circuit.

Table 2: Sign of the mean ground-level electric field Ez, and Maxwell current density Jz - 1, and its three main components, 2 - Jc, 3 - Jp, 4 - Jd, i. e. conduction, precipitation or convection, and displacement current densities, respectively, under Nimbostratus (Ns) and Stratus (St) clouds at Swider (SWI). Atmospheric electricity sign convention is used

Conditions at SWI	Jz 1	Jc 2	Jp 3	Jd 4
Nimbostratus (Ns)	+	–	+	0
Ns + average Rain	+	–	+	-0
Ns + strong Rain	–	–	–	-0
Ns + Snow	+	+	–	0
Stratus (St)	+	+	+	0

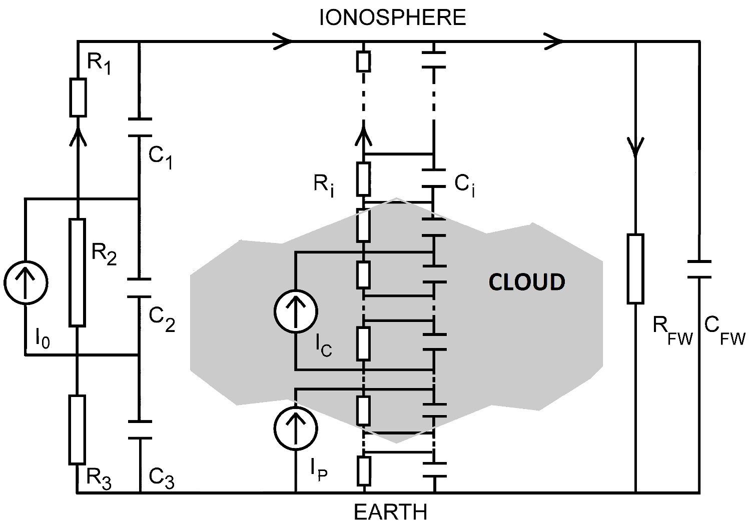

Figure 2: Circuit diagram of an isolated Nimbostratus cloud embedded in the global atmospheric circuit. The cloud is represented by the series of resistances R_i in parallel with capacitances C_i, each for a 0.1km-thick volume of the atmosphere of the area of the cloud from the ground level up to the ionosphere. The current source I_C produces charge separation and a vertical potential difference inside the cloud. The polarity of the current source I_C and I_P can be reversed to represent different model scenarios for the electrical behaviour of the cloud reflecting the observed Ez and Jz at ground level. Current source I_0, and resistances R_1, R_2, R_3 represent cloud generator regions in the global circuit, maintaining the positive potential of the ionosphere, and the resistor R_{FW} is for the resistance of the remaining regions.

SUMMARY

- Our analysis of the electric field, Ez, and current density, Jz, under Nimbostratus and Stratus cloud over recent years at Swider, Poland, and in Hornsund, Spitsbergen, confirm that these parameters behave differently during rain and snow, the most frequent precipitation from these clouds. It also confirms that raining Nimbostratus may be a current generator in the GEC and proposes a negative

Table 3: Characteristics of the current sources: 1 - I_C and 2 - I_P for the Ns cloud model (Fig. 2), and 3 - ‘’Effect on GEC” the effect on GEC understood as the sign of the current flowing from the cloud up the ionosphere. Legend: + positive, – negative, –/+ negative or positive depending on the ratio of I_C/I_P. The convention here is that upward current is positive (and increasing the potential of the ionosphere), opposite the AE convention used earlier. The polarity of the current sources are also in this convention.

Model	I_C 1	I_P 2	Remarks	Effect on GEC 3
Ns + average Rain	+	–		–/+
Ns + heavy Rain	+	+		+
Ns + Snow	–	+	$\lvert I_C \rvert \simeq \lvert I_P \rvert$	–

generator role for snowing Nimbostratus.

- Simple engineering models have been proposed to model those two different cases which may be used for the cloud parametrisation in models of the GEC.
- The parametrisation used in the EGATEC model [*Odzimek et al.*, 2010] for clouds such as Nimbostratus overestimates the related generator current, at least at middle latitudes and high latitudes. It may also be necessary to introduce a current source for snowing Nimbostratus, of opposite polarisation to that for raining Nimbostratus.

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