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General method for calculating polarization electric fields produced by auroral Cowling mechanism and application examples

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The Cowling mechanism is characterized by the generation of polarization space charges in the ionosphere in consequence of a partial or total blockage of FAC flowing between the ionosphere and the magnetosphere. Thus a secondary polarization electric field builds up in the ionosphere, which guarantees that the whole (primary + secondary) ionospheric current system is again in balance with the FAC. In the Earth's ionosphere the Cowling mechanism is long known to operate in the equatorial electrojet, and several studies indicate that it is important also in auroral current systems.

We present a general method for calculate the secondary polarization electric field, when the ionospheric conductances, the primary (modeled) or the total (measured) electric field, and the Cowling efficiency are given. Here the Cowling efficiency is defined as the fraction of the divergent Hall current canceled by secondary Pedersen current.

In contrast to previous studies, our approach is a general solution which is not limited to specific geometrical setups (like an auroral arc), and all parameters may have any kind of spatial dependence. The solution technique is based on spherical elementary current (vector) systems (SECS). This way, we avoid the need to specify explicit boundary conditions for the searched polarization electric field or its potential, which would be required if the problem was solved in a differential equation approach. Instead, we solve an algebraic matrix equation, for which the implicit boundary condition that the divergence of the polarization electric field vanishes outside our analysis area is sufficient.

In order to illustrate the effect of Cowling mechanism on ionospheric current systems, we apply our method to two simple models of auroral electrodynamic situations: 1) a mesoscale strong conductance enhancement in the early morning sector within a relatively weak southward primary electric field, 2) a morning sector auroral arc with only a weak conductance enhancement, but a large southward primary electric field at the poleward flank of the arc.

While the significance of the polarization electric field for maximum Cowling efficiency is large for the first case, it is rather minor for the second one. Both models show that the Cowling effect may not only change the magnitude of the current systems, but also their overall geometry. Further, the polarization electric field may extend into regions where the primary electric field is small, thus even dominating the total electric field in these regions. For the first model case, the total Joule heating integrated over the analysis area decreases by a factor of about 4 for maximum Cowling efficiency as compared to the case of vanishing Cowling efficiency. Further, for this case the resulting total electric field structurally shows a strong resemblance to that frequently observed during auroral omega band events.