Report on the manuscript angeo-2019-108
"Using the Galilean Relativity Principle to Understand the Physical Basis for Magnetosphere-Ionosphere Coupling Processes"
by Mannucci et al.

This reader agreed to review this manuscript because the title sounded very interesting, but the manuscript really had limited new information in it. This review is not of the opinion that this manuscript should not be published (it does in fact make the reader think), but the manuscript could be improved with more focus on attaining information relevant to its title, and more focus on being accurate in its discussion of the behavior of high-latitude ionospheric electrodynamics.

This manuscript fails to fulfill the promise of its title: the manuscript says what is not correct (which has been said before), but does not say what physical processes form the basis for magnetosphere-ionosphere couple. I.e. it is never explained how the magnetosphere drives ionospheric motion and currents (which co-exist). The closest it comes to an explanation is saying that momentum is transferred from the magnetosphere to the ionosphere (Lines 429-436).

What has been said before is (a) that the perpendicular current is caused by the relative motion of plasma and neutrals across the magnetic field, (b) that Joule heating is associated with the work done to move charged particles through the neutrals (cf. the Drude model), and (c) explanations for ionospheric electrodynamics exist that do not focus on electric fields.

This reviewer is aware that clear pictures of cause and effect in plasma electrodynamics are difficult because Maxwell's equations describe consistency, not cause and effect. One should look at the mechanisms that extract energy (and momentum), that convert energy and momentum, and that transport energy and momentum. It seems unwise to use PGR, which only sometimes works, to organize a discussion describing the driving of currents, the transfer of momentum, and the transfer of energy. As Section 2.3 notes, Poynting's theorem does not hold in PGR. Perhaps this is why the title of the article is not fulfilled. The concepts of PGR seem more like handcuffs than tools.

Several times in the manuscript it is stated that "something" is inconsistent with PGR (e.g. lines 164, 166, 304): it is hard to tell if this is a criticism of the "something" or a criticism of PGR.

Lines 165-167: The statement "electric fields that arise due to charge accumulation are inconsistent with the usual field transformation equations…" is not true. For example, there is charge density in the ionosphere wherever there is plasma vorticity that is parallel to the magnetic field (i.e. a shear in a perpendicular flow v_{perp}), and that charge density cannot be transformed away. There is an electric field (and a nonzero divergence of the electric field) associated with that charge density (and associated with the shear flow). The motion of the charge density does make a perturbation to B, but its magnitude is $\Delta B = (v_{perp}/c)^2 B$: it is consistent with PGR to ignore this change in B.

Lines 199-207: This reader is uncertain as to the purpose of this paragraph. Landau damping involves an electric field that is parallel to the velocity of interest and that parallel electric field does not change with reference frame as you go to the particle's frame.

Line 225: “For electromagnetic waves,” should be “For electromagnetic waves in vacuum,”

Lines 238-241: This reader is completely confused by this paragraph.

Lines 304-306: The statement “requires the creation of polarization charge, which is inconsistent with the Galilean invariance of the magnetic field” is not correct. Polarization charge is in fact created at the edges any spatially limited flow (plug in Coulomb’s law for a shear flow where the flow is described by ExB drift). As noted above, advection of such charge density creates a perturbation to be that is of order $(v/c)^2B$ (where v is the advection velocity), which is ignorable in PGR and not “inconsistent” with PGR.

Lines 459-480: This is a misleading calculation: no one would believe that the parallel-to-B momentum of the magnetospheric charge carriers has anything to do with the perpendicular-to-B momentum of the ionosphere. This is like calculating the momentum of electrons in a wire to explain momentum provided by an electric fan or the momentum of an electric car. Further, what does this calculation have to do with an electric field? The way to look at the momentum change of the ionosphere is to look at the surface integral of the Maxwell stress tensor, but since Poynting’s theorem is not valid in PGR, this might not work in present study.

Lines 521-522: “Thus it is problematic to assert that the cause of high velocity plasma flows known as SAID are horizontal currents closing in the ionosphere”. You are saying what it is not the cause, but never saying what is the cause!

The manuscript repeatedly criticizes the electric field because it differs from frame to frame, asserting therefore that it cannot be the explanation (cause) of things. One should assume that if a problem is worked correctly in two different reference frames, one should get two answers that agree. (Principle of invariance of proper physical description in relativity.) Maybe PGR is not the right way to think about high-latitude electrodynamics.

Here is a gedanknenexperiment in support of the ionospheric electric field. Call it the cold-Earth problem. Let’s say that the high-latitude ionospheric plasma and neutrals are absolutely cold (no collisions) and that the ions, electrons, and neutrals are all at rest (no wind). The one frame that makes sense to use to look at this is the frame of the observer on the ground, the neutrals, the ions, and the electrons (all the same frame). If from this cold start I want to get the plasma to flow relative to the neutrals, and to get a horizontal current that is associated with the plasma flow through the neutrals, by charged-particle orbit theory I must get a horizontal electric field into the ionosphere to start the ExB drifting of the ions and electrons, which collisions with the neutrals will disrupt and form a Pedersen and/or Hall current. When everything is at rest, there can be no other force on a charged particle than the electric field force. The explanation of how the magnetosphere drives the ionosphere in this cold-Earth gedankenexperiment is explaining how the magnetosphere got that needed electric field into the ionosphere.

This reviewer looks forward to reading an improved draft. (Thinking is good!)