Radar Measurements and the Volumetric Electric Field

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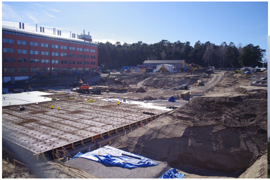
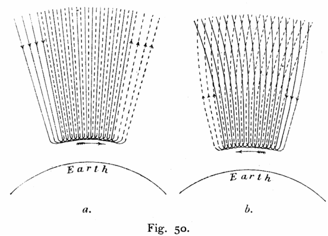
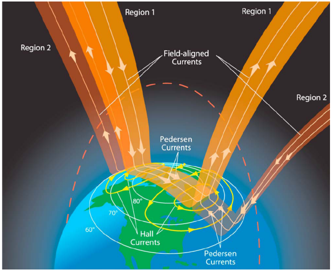


Magnetosphere-Ionosphere Coupling Equation



By Kristian Birkeland - Scanned by Ian Tresman from The Norwegian Aurora Polaris Expedition 1902-1903



By Le, G., J. A. Slavin, and R. J. Strangeway (2009), JGR, doi:10.1029/2009JA014979

- Ionospheric Ohm's law for perpendicular currents $\vec{J}_\perp$,
- Birkeland $j_\parallel$ by current continuity

$$j_\parallel = -\nabla \cdot \left(\Sigma_P \vec{E}_\perp + \Sigma_H \hat{\vec{b}} \times \vec{E}_\perp \right) \quad (1)$$

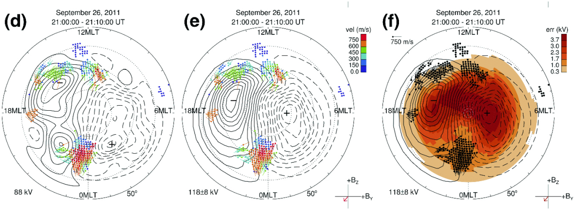
$\vec{E}_\perp$	electric field
Σ_P	Pedersen conductance
Σ_H	Hall conductance
$\hat{\vec{b}}$	unit vector along $\vec{B}$
$j_\parallel$	field-aligned current

Magnetosphere-Ionosphere Coupling

- first use of (1) with experimental data by Kamide, Richmond, and Matsushita (KRM, 1981): Estimation of ionospheric electric fields, ionospheric currents, and field-aligned currents from ground magnetic records, JGR. With $\vec{E}_\perp = -\Phi$

$$j_\| = \Sigma_P \nabla^2 \Phi + \nabla \Sigma_P \cdot \nabla \Phi + \nabla \Sigma_H \cdot \hat{\vec{b}} \times \nabla \Phi \qquad (2)$$

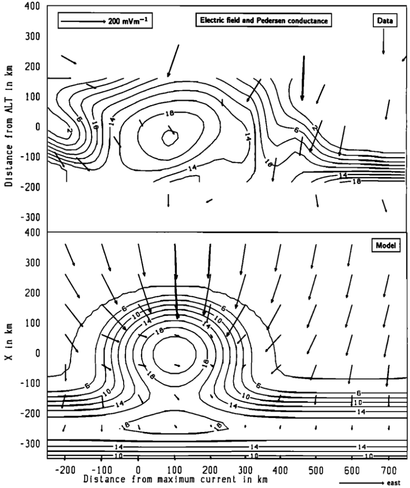
  a solve for $\vec{E}_\perp$ for estimated $j_\|$.
- basis for AMIE[1] procedure which can use several data sources (here SuperDARN)



Matsuo, T. (2019), ISSI

[1] Assimilative Mapping of Ionospheric Electrodynamics

Ω-bands with EISCAT



Buchert et al. (1990)

- can be scanned with the UHF in the north-south direction,
- they convect east-west;
- with tri-static IS we can estimate both $\vec{E}_\perp$ and $\Sigma_{P,H}$;
- this should work much better with E3D!
- but what else should we consider/need to think about?

Assumptions

- $\vec{B}$ is vertical (to get $j_{\|}$ from equivalent currents): $j_{\|} \to j_{\|} \cos\chi$, χ magnetic co-inclination (except near the equator)
- neutral wind $\vec{u}_n = 0$;
- Corrected Ohm's law/MI coupling:

$$j_{\|} = -\nabla \cdot \left(\Sigma_P \left(\vec{E}_\perp + \vec{u}_n \times \vec{B} \right) + \Sigma_H \hat{\vec{b}} \times \left(\vec{E}_\perp + \vec{u}_n \times \vec{B} \right) \right) \tag{3}$$

- $\vec{E}_\perp + \vec{u}_n \times \vec{B}$ is the electric field in the local neutral reference frame

Problem:

- E3D measures neither $\vec{E}_\perp$ nor $\vec{u}_n$, only the ion velocity $\vec{v}_i$ (in an Earth-fixed frame)
- satellites: DE-2 measured $\vec{E}_\perp$, 1 component, and $\vec{u}_n$;
- Demeter measured $\vec{E}_\perp$, both at high altitudes.

Solution

- Ion force balance (steady-state momentum equation):

$$e\left(\vec{E} + \vec{v}_i \times \vec{B}\right) = m_i \nu_{in} \left(\vec{v}_i - \vec{u}_n\right) \tag{4}$$

- which becomes $\vec{E} = -\vec{v}_i \times \vec{B}$ for $\nu_{in} \ll eB/m_i$,
- so obtain $\vec{E}_\perp$ from $\vec{v}_i$ data at altitudes higher than ~ 180 km.
- assume equipotential fieldlines and estimate

$$\vec{u}_n = \vec{v}_i - \frac{\Omega_i}{\nu_{in}} \left(\vec{E}_\perp / B + \vec{v}_i \times \hat{\vec{b}}\right) \tag{5}$$

- the method has been used with EISCAT_1D in several studies: Nozawa and Brekke, 1995, 1999; Heinselman and Nicolls, 2008; Nygrén et al., 2011; ...

Example with E3D

- assume a zonal wind with latitudinal dependence, e.g. a jet-like increase
- does the magnetosphere adjust to this forcing by the thermosphere?
  - yes: also the ion drift in the F region and upward need to show the latitudinal structure mapped upward;
  - no: ion drift and neutral wind structure differ, $\vec{E}_\perp \neq 0$ in the neutral frame, FACs, $j \times B$ force, Poynting flux ...

Summary

- magnetosphere-ionosphere-thermosphere coupling is an interesting subject to be studied with E3D,
- with a promise for fresh views and ideas;
- care must be taken when applying Ohm's law in the 3-d ionosphere,
- $\vec{E}$ in the local neutral frame is relevant;
- while mapping of the electric potential has to be done in a constant reference frame;
- even when E3D does not directly measure $\vec{E}$,
- established methods can be extended and combined to estimate both $\vec{E}$ and $\vec{u}_n$.