Influence of Alfvén Wave Coupling on the Ionosphere

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Introduction

Three regions at stake to understand auroral process:

- *Ionosphere*: ionized plasma in the high atmosphere (80 km to 400 km above Earth's surface)
- *Acceleration region*: particles are expected to gain energy (several 1,000 km above Earth's surface)
- *Generator*: conversion of mechanical energy to electromagnetic energy (around 8 Earth's radii).

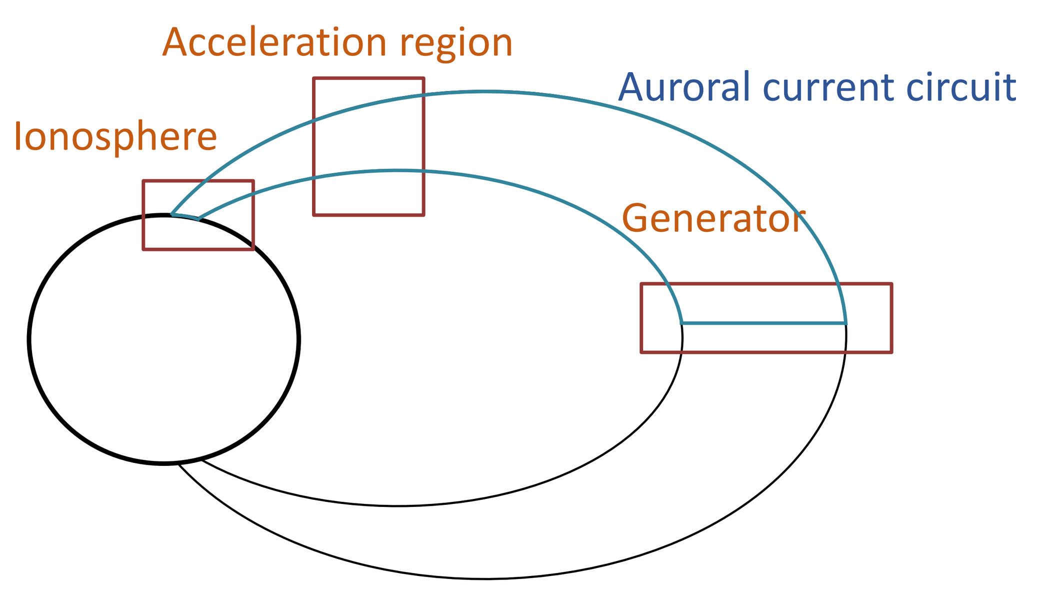

Figure: The three key regions in the auroral current circuit

Objectives

Goal: study of the magnetosphere-ionosphere coupling via field-aligned currents (FAC) carried by shear Alfvén.

Hypothesis:

- The acceleration region is inside the ionosphere
- The geomagnetic field lines are supposed to be straight lines with a dip angle I such that in a non-tilted dipole approximation

$$\sin I = \frac{2\cos\theta}{\sqrt{1+3(\cos\theta)^2}}$$

with θ the colatitude.

Notations:

- $\overrightarrow{E_\perp}$ and $j_\parallel$ the electric field orthogonal and the current parallel to the magnetic field lines
- $\Sigma_\parallel, \Sigma_P, \Sigma_H$ parallel, Pederson and Hall height-integrated conductivities
- Σ_A Alfvèn conductance $\left({}^{1}/_{\mu_0 V_A}\right)$
- K a constant such that $K \sim 10^{-10}\ \Omega^{-1}\cdot m^{-2}$.

Model & Methods

Model for the reflection at the ionosphere

The reflection at the ionosphere is governed by:

$$\vec{\nabla}_\perp \cdot \left(\Sigma^+ \cdot \overrightarrow{E_\perp}^+ + \Sigma^- \cdot \overrightarrow{E_\perp}^- - \Sigma \cdot \vec{\nabla}_\perp \left[-\frac{j_\parallel}{K}\right]\right) = 0$$

with

$$\Sigma^\pm = \begin{pmatrix} \Sigma_{\theta\theta} \pm \Sigma_A & \Sigma_{\theta\varphi} \\ \Sigma_{\theta\varphi} & \Sigma_{\varphi\varphi} \pm \Sigma_A \end{pmatrix}, \qquad \Sigma = \begin{pmatrix} \Sigma_{\theta\theta} & \Sigma_{\theta\varphi} \\ \Sigma_{\theta\varphi} & \Sigma_{\varphi\varphi} \end{pmatrix}$$

where

$$\begin{cases} \Sigma_{\theta\theta} = \dfrac{\Sigma_P \Sigma_\parallel}{\Sigma_P + (\Sigma_\parallel - \Sigma_P)(\sin I)^2} \\ \Sigma_{\theta\varphi} = \dfrac{\Sigma_P \Sigma_\parallel \sin I}{\Sigma_P + (\Sigma_\parallel - \Sigma_P)(\sin I)^2} \\ \Sigma_{\varphi\varphi} = \Sigma_P + \dfrac{\Sigma_\parallel^2 (1 - (\sin I)^2)}{\Sigma_P + (\Sigma_\parallel - \Sigma_P)(\sin I)^2} \end{cases}$$

Developing leads to an equation of type (1)

$$A(\theta,\varphi)\frac{\partial^2\phi}{\partial\theta^2} + B(\theta,\varphi)\frac{\partial\phi}{\partial\theta} + C(\theta,\varphi)\frac{\partial^2\phi}{\partial\varphi^2} + D(\theta,\varphi)\frac{\partial\phi}{\partial\varphi} = F(\theta,\varphi)$$

in spherical coordinates.

Resolution

The equations of type (1) are solved with *finite differences* and the time-dependent equation with a *forward integration in time*.

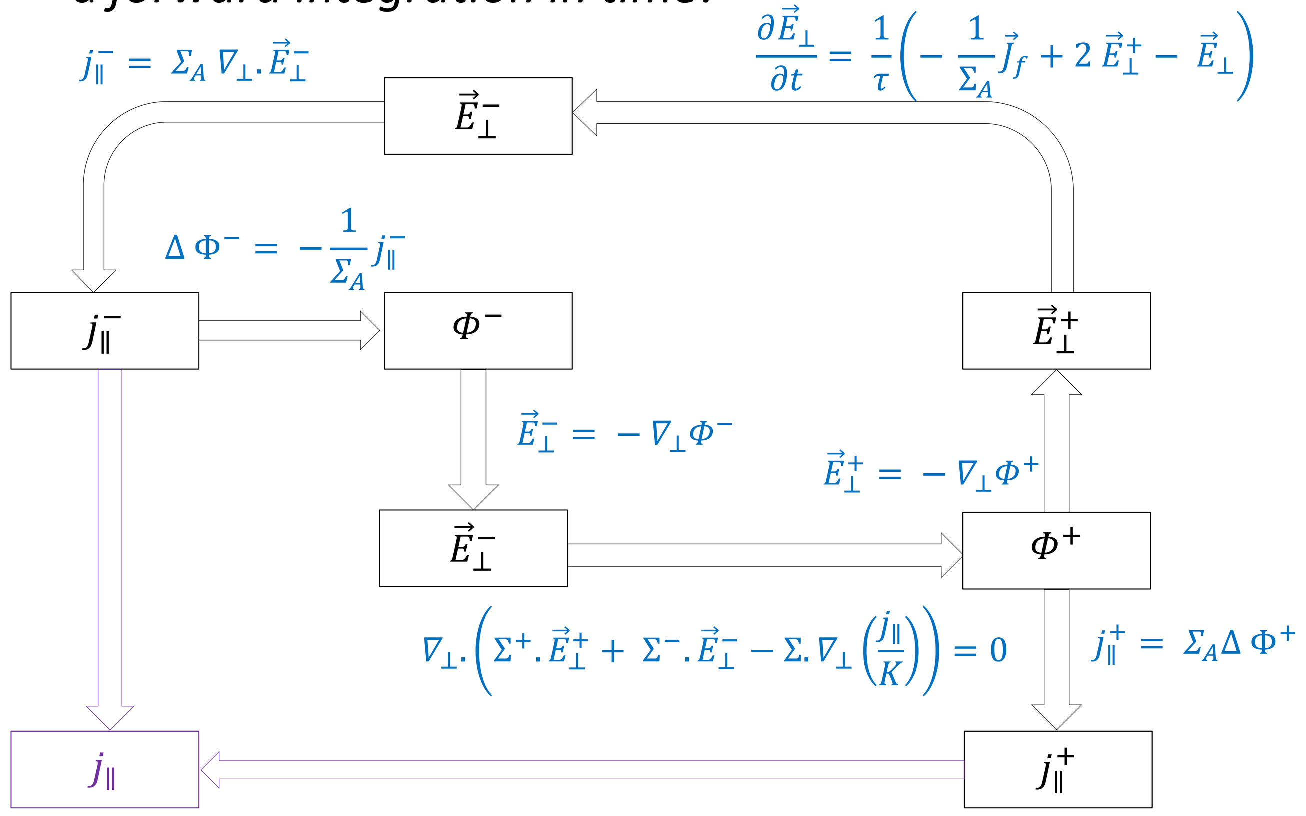

Figure: Summary of the equations to solve in the MI-coupling. The process starts with a given $j_\parallel^-$ and ends when it has converged

Height-integrated conductivities

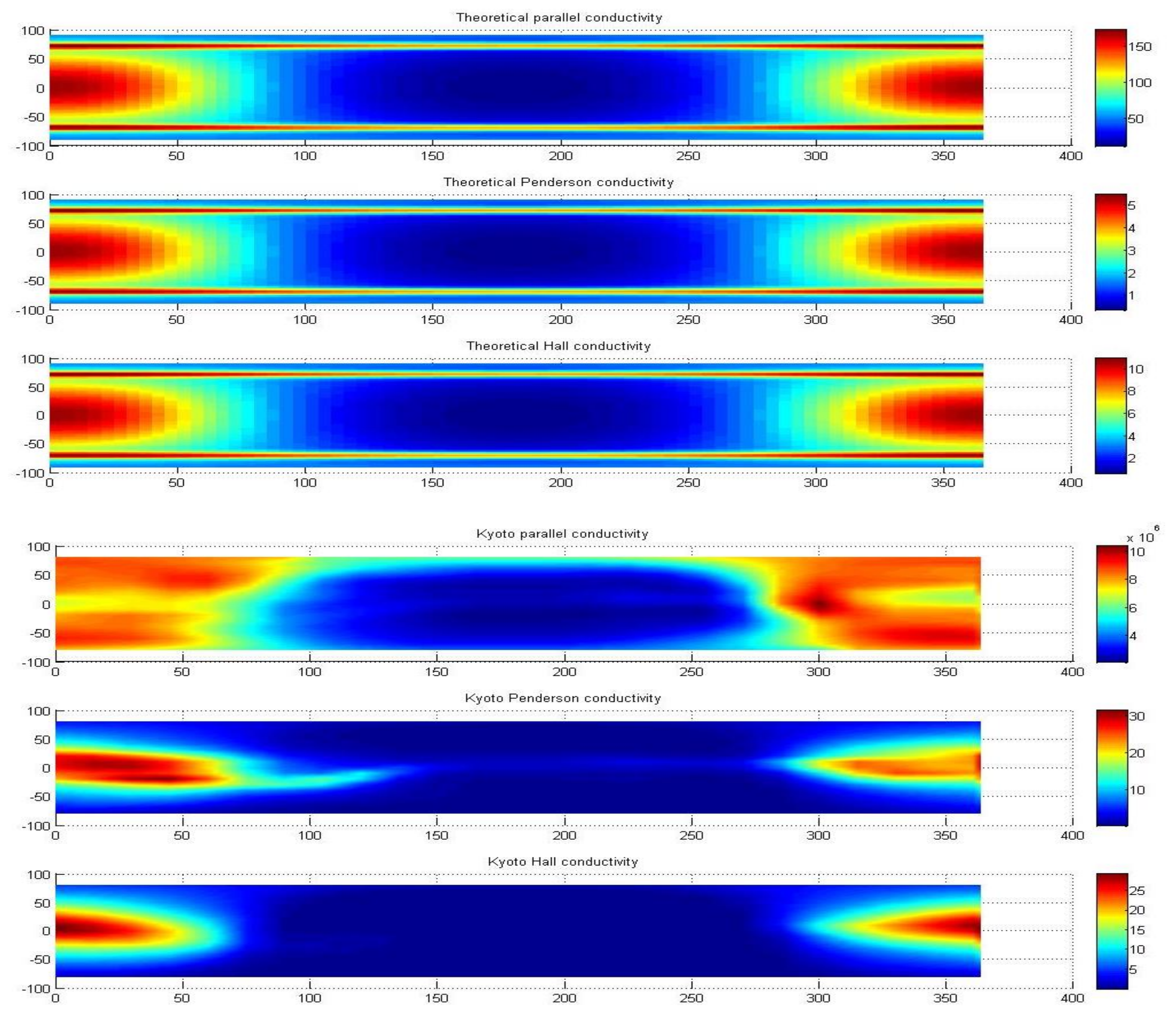

Figure: Height-integrated conductivities profiles: theoretical (top) and based on International Reference Ionosphere (bottom)

Results

Evolution of field-aligned currents

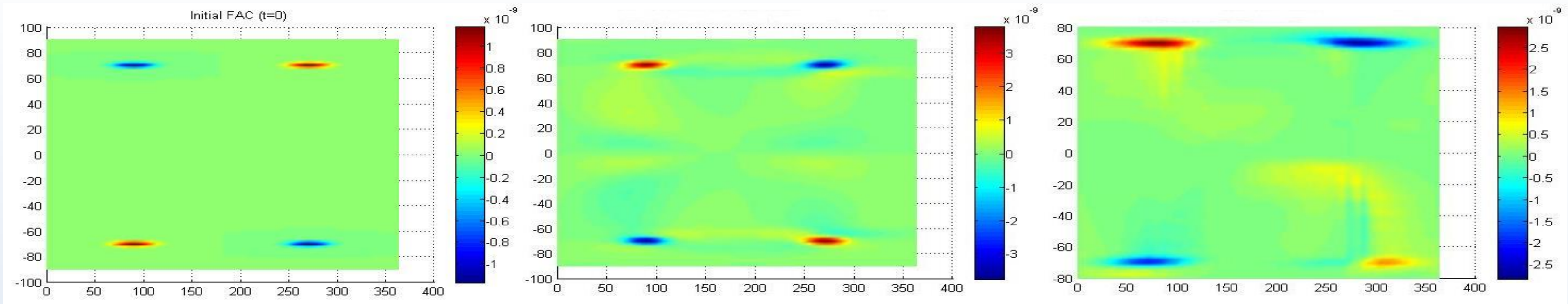

Figure: Initial FAC (left) and after MI-coupling with theoretical (middle) and IRI (right) conductivities

Potential in the ionosphere

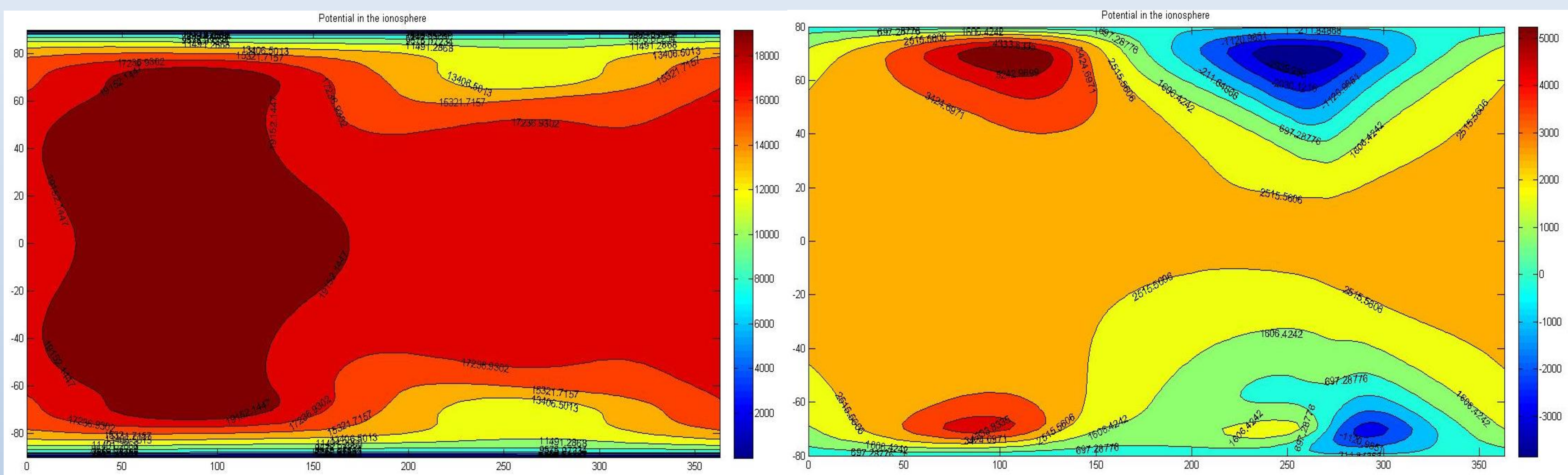

Figure: Potential in the ionosphere with theoretical (left) and IRI conductivities (right)

Conclusion

Two major differences:

- Field-aligned currents reach lower latitudes with IRI conductivities
- The potential is greater and iso-potential lines reach lower latitudes with theoretical conductivities.

Limitations:

- Key regions are supposed to be thin sheets parallel
- Field lines are modelled by straight lines
- Fluid description not always valid

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References

[1] Joachim Vogt. Alfvén wave coupling in the auroral current circuit. Surveys in Geophysics, 23:335–377, 2002.
[2] Jr R.W. Nopper and R.L. Carovillano. Polar-equatorial coupling during magnetically active periods. Geophysical Research Letters, 5(8):699–702, 1978.
[3] Kyoto University. IRI model for the conductivities. http://wdc.kugi.kyoto-u.ac.jp/ionocond/sightcal/index.html.
[4] Asgeir Brekke. Physics of the Upper Polar Atmosphere. Springer, 2013 edition (December 30,2012)