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Electric Field-Driven Currents in the Ionosphere of Mars

M. O. Fillingim[1] (matt@ssl.berkeley.edu), R. J. Lillis[1], Y. Ma[2]

[1]Space Sciences Laboratory, University of California, Berkeley

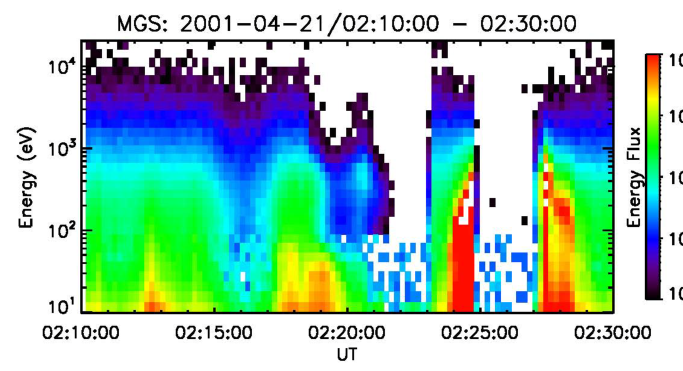
[2]Institute of Geophysics and Planetary Physics, University of California, Los Angeles

Abstract

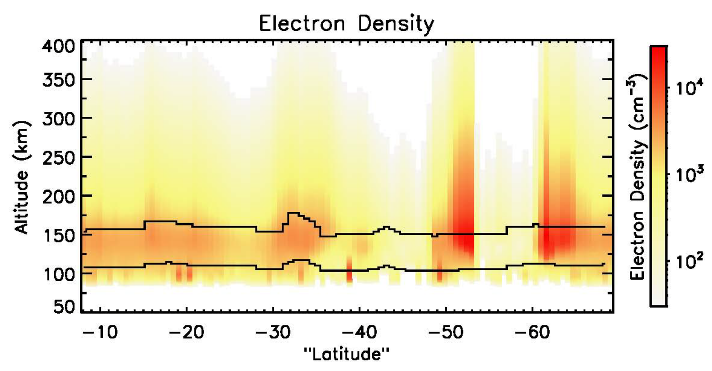
- Previously, we modelled the nightside ionosphere of Mars using precipitating particle data as input to an electron transport model [Fillingim *et al.*, 2007]
- We also calculated horizontal ionospheric currents driven by thermospheric neutral winds [Fillingim *et al.*, 2010]
- Additionally, we estimated the strength of wind-driven electrojets at magnetic cusps created by polarization electric fields formed in the presence of conductivity gradients [Fillingim *et al.*, 2011, in press]
- Here, we extend this previous work by considering ionospheric currents driven by external electric fields
- In the absence of electric field observations, we use the electric field calculated from a global MHD model

Introduction and Previous Work

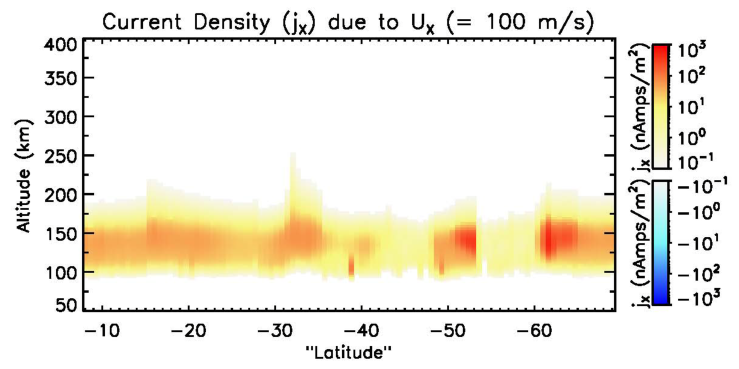
- Start with observed electron energy spectra

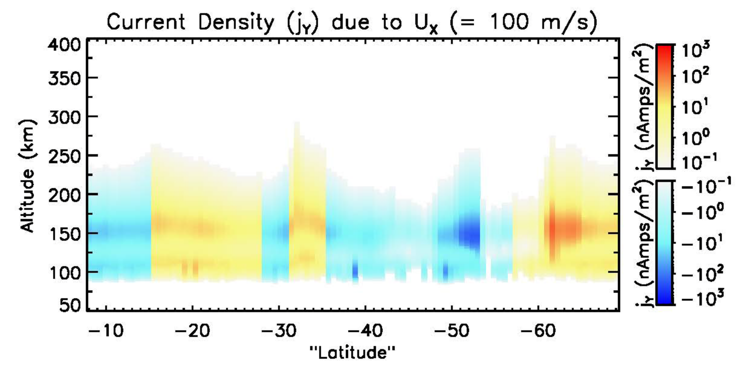


- Calculate ionization rate (Lummerzheim & Lilensten [1994])
  → neutral atmosphere (MTGCM of Bougher *et al.* [2009])
  → magnetic field model (Cain *et al.* [2003])
- Compute electron density assuming photochem. equilibrium
  → $n_e = \sqrt{P(z)/\alpha_{eff}(z)}$, where $\alpha_{eff}(z)$ is O_2^+ recombination rate

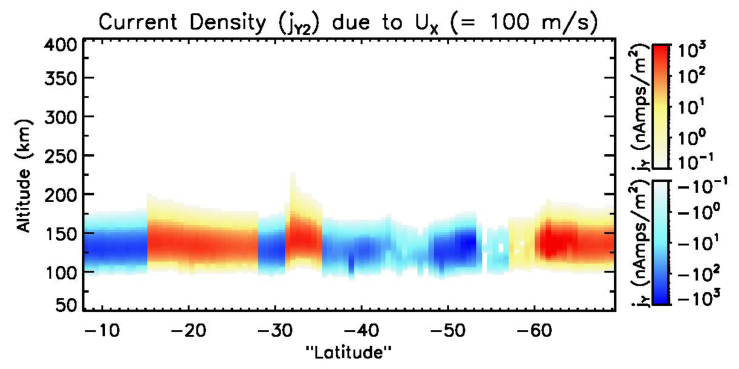


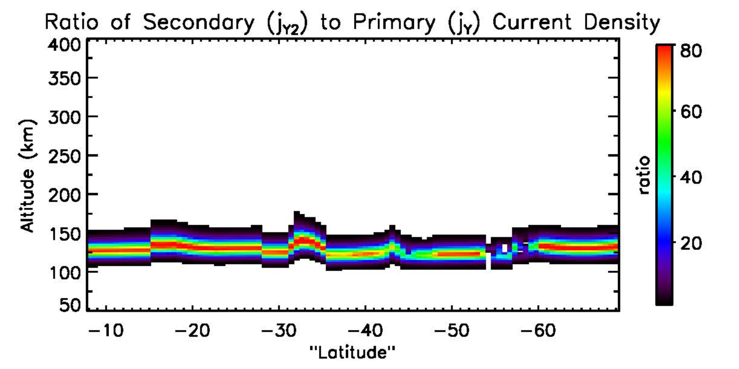
- Add external force (e.g., neutral wind, electric field)
- Calculate particle velocities, $\mathbf{v}_{i,e}$, from equations of motion
  → $1/n_{i,e}\nabla(n_{i,e}kT_{i,e}) + m_{i,e}\mathbf{g} + q(\mathbf{E} + \mathbf{v}_{i,e}\times \mathbf{B}) - m_{i,e}\nu_{in,en}(\mathbf{v}_{i,e} - \mathbf{u}) = 0$
- Calculate currents: $\mathbf{j} = nq(\mathbf{v}_i - \mathbf{v}_e)$





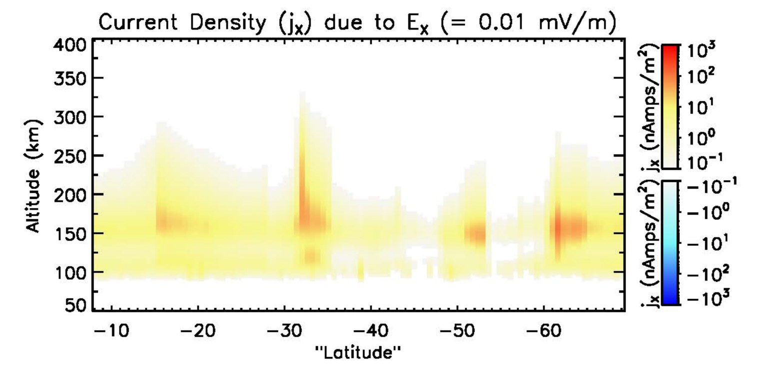
- Assuming $\mathbf{j}_\perp$ constant across conductivity gradients and $j_{//} = 0$
  → $E_{\perp 1}' = \Delta j_{\perp 1}/\sigma_P$; $j_{H\perp 2}' = E_{\perp 1}'\sigma_H = \Delta j_{\perp 1}\sigma_H/\sigma_P$; $j_{H\perp 2}'/j_{\perp 2} \approx \sigma_H^2/\sigma_P^2$

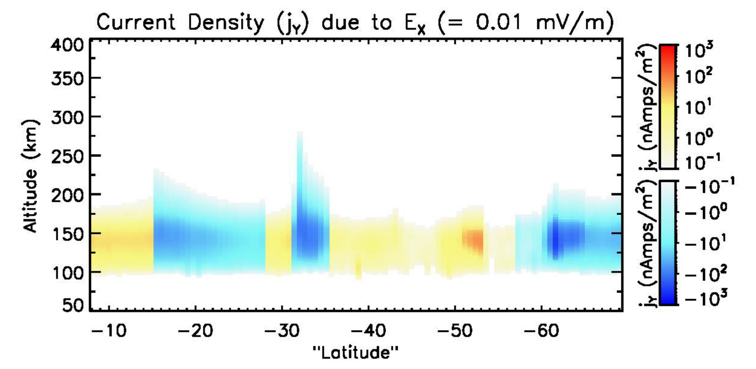




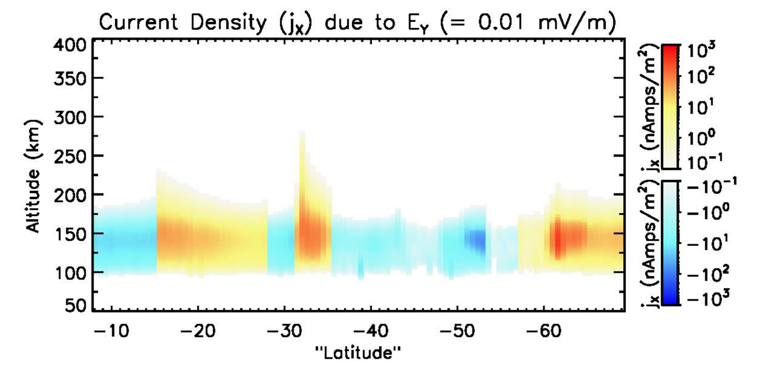
Methodology and Results

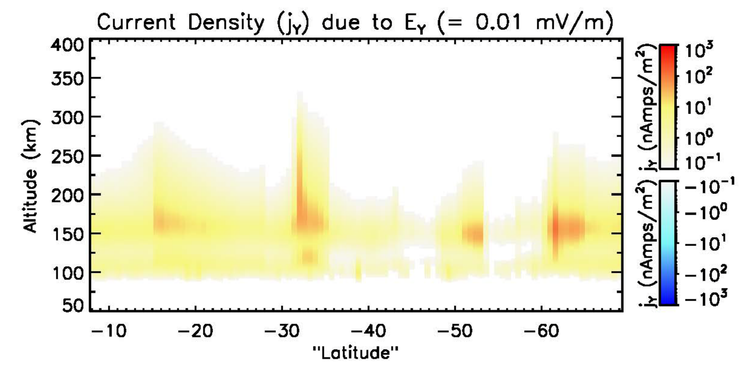
- Perform a similar calculation driven by an externally imposed electric field, **E**, based on Ma *et al.*'s [2004] MHD simulation
- (Grossly over-) Simplifying assumptions:
  - magnetic field is vertical (**B** = B_Z) and constant with altitude
  - magnetic field lines are equipotentials
    → electric field is horizontal and constant with altitude
  - electric field is constant with latitude on the nightside (actually, **E** varies with latitude, longitude, and time)
- Consider two cases: **E** = E_X = 0.01 mV/m (northward field)



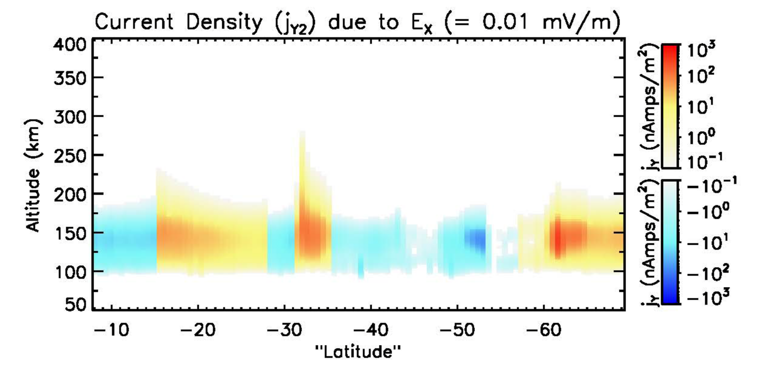


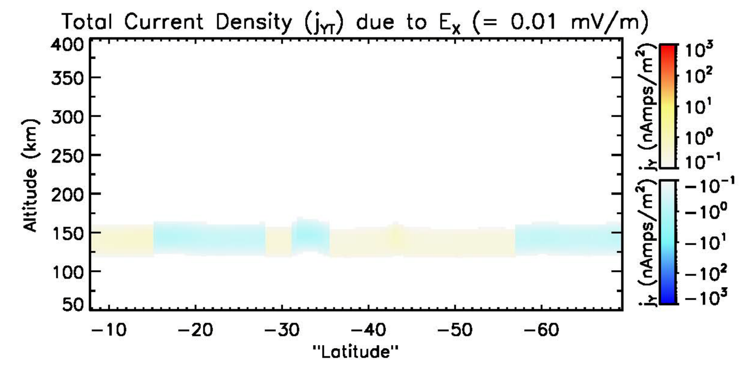
- Case 2: **E** = E_Y = 0.01 mV/m (westward electric field)



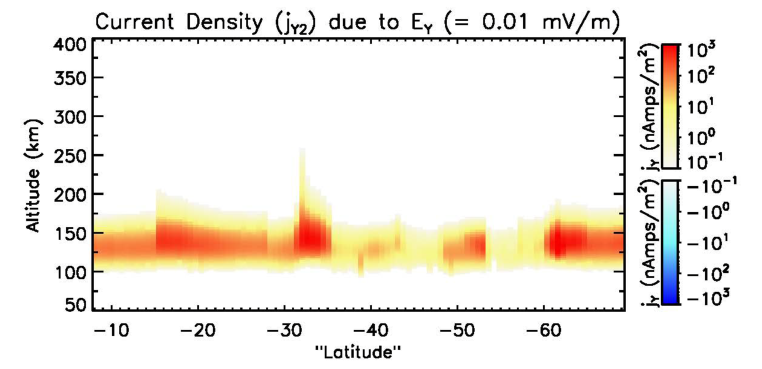


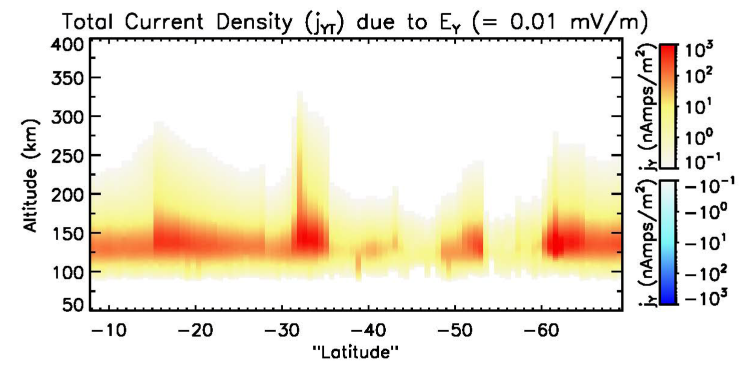
- In both cases, we see two peaks in the Pedersen current as a function of altitude (cf. Opgenoorth et al., 2010) and a change in sign of the Hall current as the polarity of **B** changes
- If we assume $j_{//} = 0$, then in steady state $\nabla\cdot\mathbf{j}_\perp = 0$ → $dj_X/dx = 0$
  → gradients in conductivity lead to gradients in j_X
  → polarization electric fields balance j_X, induce secondary j_{Y2}
- For Case 1, the secondary j_{Y2} (nearly) cancels the primary j_Y



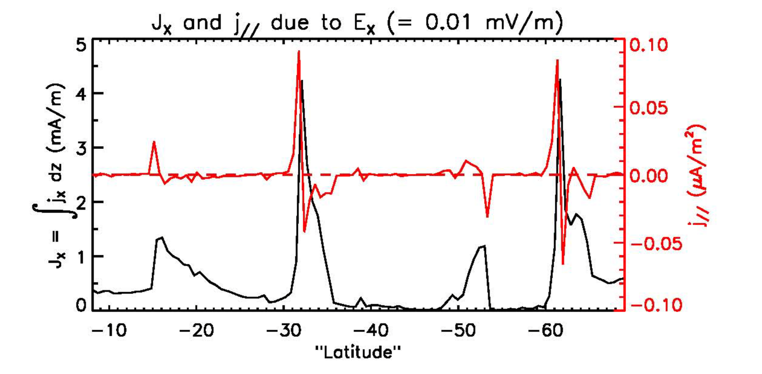


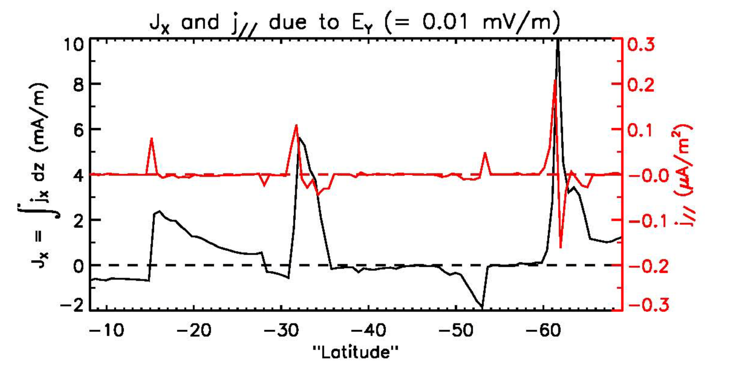
- For Case 2, j_{Y2} strongly reinforces j_Y → "auroral" electrojets





- If we **do not** assume $j_{//} = 0$, then $\nabla\cdot\mathbf{J}_\perp = dJ_X/dx = j_{//}$ where J_X is the height-integrated current





- Parallel current near cusps → may play a role in acceleration
- All cases have significant Joule heating (**J·E** > 0) *except* for Case 1 with polarization electric fields; $j_{//} = 0$ and j_X, E_X → 0