IMPERIAL

Characterising magnetopause surface waves within magnetosphere – ionosphere – ground coupling

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Disturbances to the magnetopause location, described as **surface waves**, are a source of **field-aligned currents** with ionospheric & ground impacts that need to be better understood. We develop a simple **numerical model** to characterise these impacts across a range of wave & system properties, not feasible with global simulations.

Numerical Model

- Simple Cartesian box model with finite wave train of linear surface waves on zero-thickness magnetopause / OCB as shown in Figure 1
  - Uniform, vertical magnetospheric magnetic field
  - Electrostatic ionosphere, uniform Pedersen / Hall conductances
  - Uniform ground conductivity via Complex Image Method
- Solve at single timestep since waves approx. dispersionless
- Vary wave (N, λ, f) and system (Σ_P, Σ_H, σ_g) properties

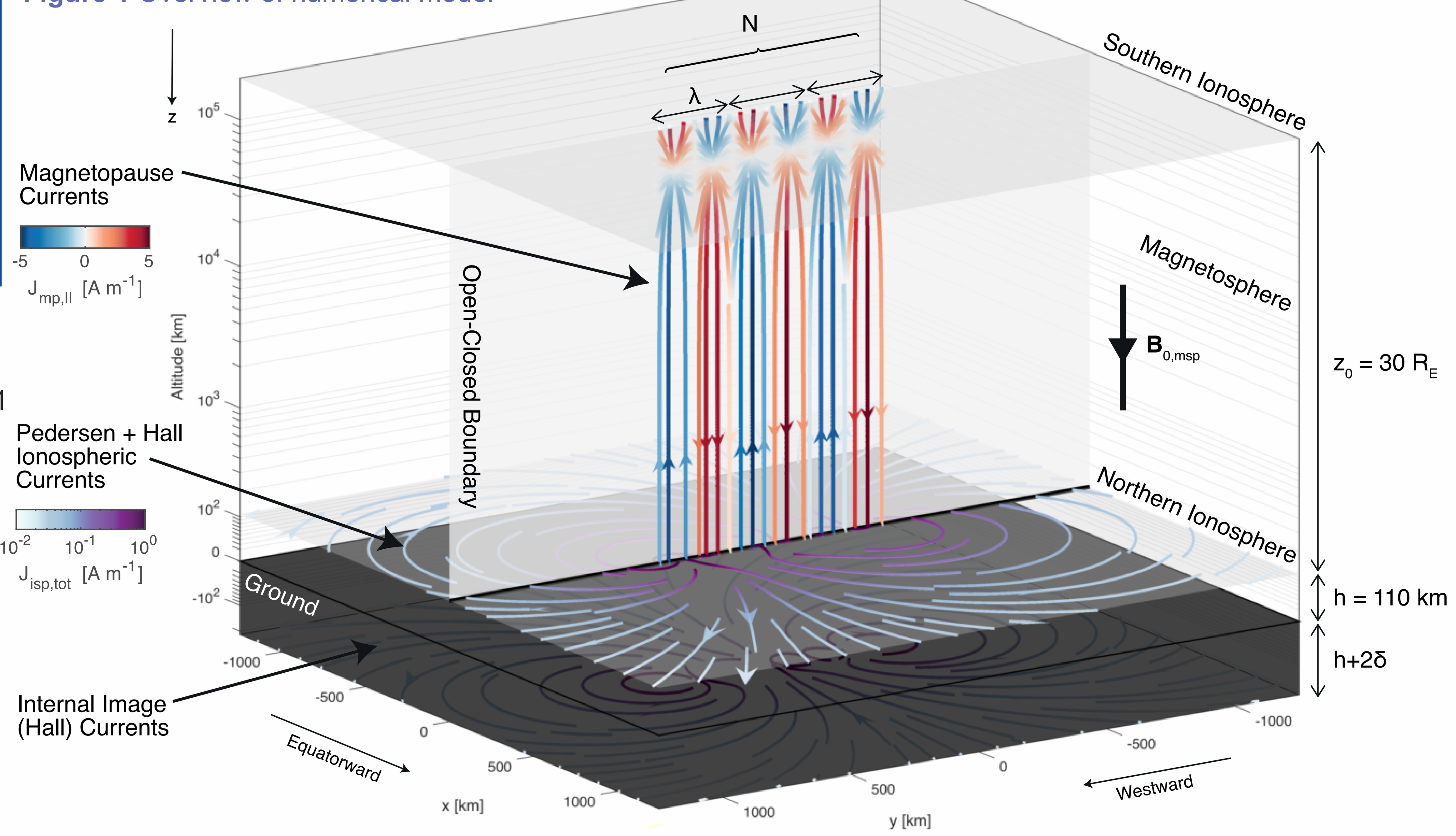

Figure 1 Overview of numerical model

Ionosphere

- Figure 2 shows along OCB, potential is periodic with slight trends due finite wave. Effects exponentially decay with distance from OCB, tending towards infinite wave theory for small $k_y r/N$ (dashed lines).
- Model suggests significant ionospheric convection velocities up to several km/s and **Joule heating** rates up to 100's mW/m² possible.

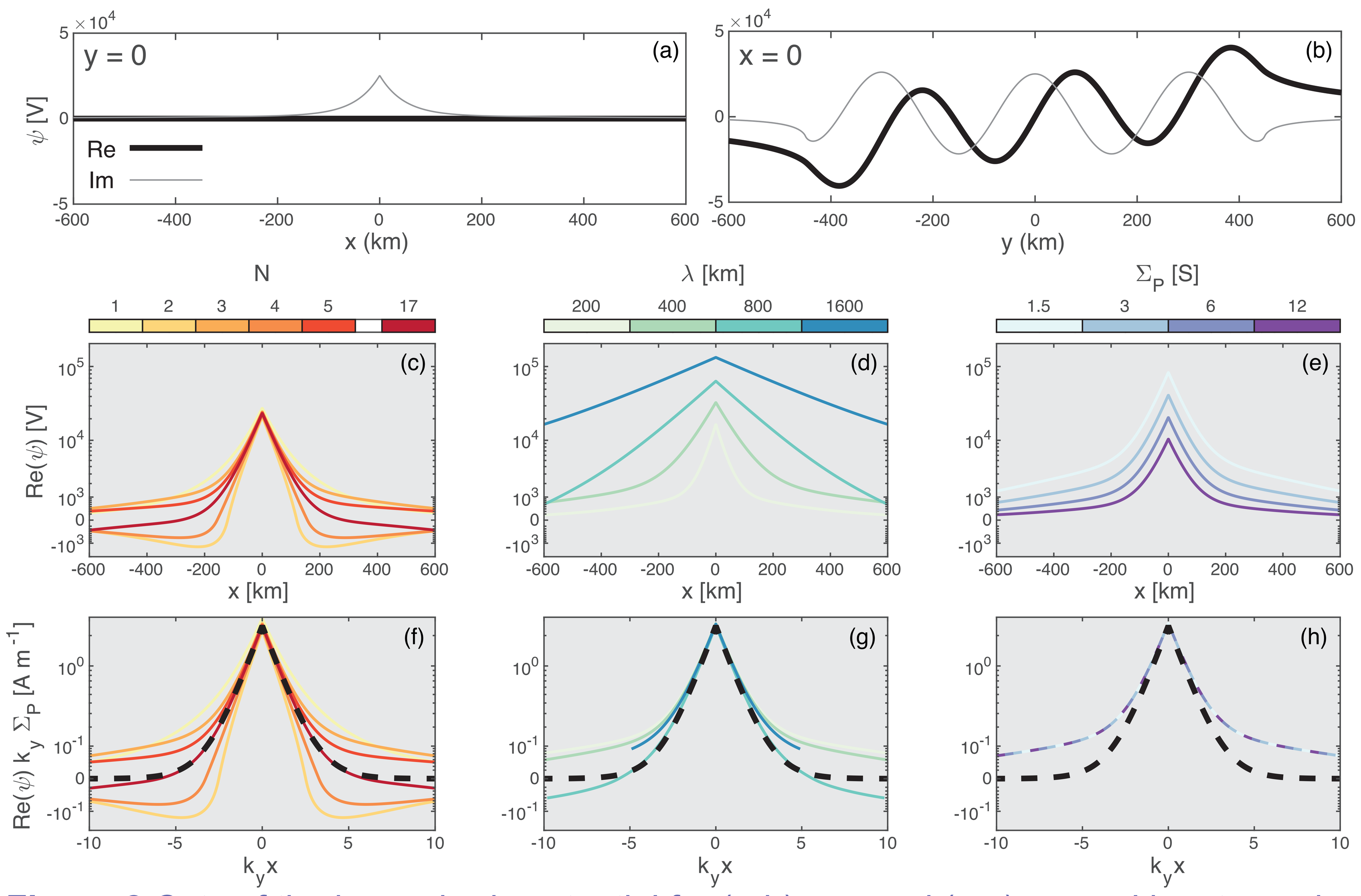

Figure 2 Cuts of the ionospheric potential for (a-b) one and (c-e) several inputs, and (f-h) normalised based on theory (dashed)

Ground magnetic field

- Ground magnetic field perturbations of ~100's nT (Figure 3) varying qualitatively like ionosphere, but more smeared & larger trends due to spatial integration.
- Magnetopause & Pedersen currents cancel to within 1nT, so **Hall currents** dominate. Fukushima's theorem approx. holds as scales along the field >> perpendicular to it.
- Theoretical solution not possible. Find numerically **ionosphere screens amplitudes** with k_y (Figure 4a), though larger e-folding scales than ionospheric altitude (case for plane Alfvén waves; Hughes & Southwood 1974, GRL) which vary by component.
- HWHM scale as power laws with wavelength,varying by component (Figure 4b). Scales ~70-200km motivate need for **denser ground magnetometer networks**.
- Consequence is **ionosphere changes ground polarisation** from magnetosphere.
- Induced ground field depends on $k_y\delta$, for skin depth δ, slowly transitioning between:
  - Perfect conductor ($k_y\delta$<<1) where induced magnetic field cancels vertical and doubles horizontal components due to Hall currents
  - Perfect insulator ($k_y\delta$>>1) where induced magnetic field is weak and large scale

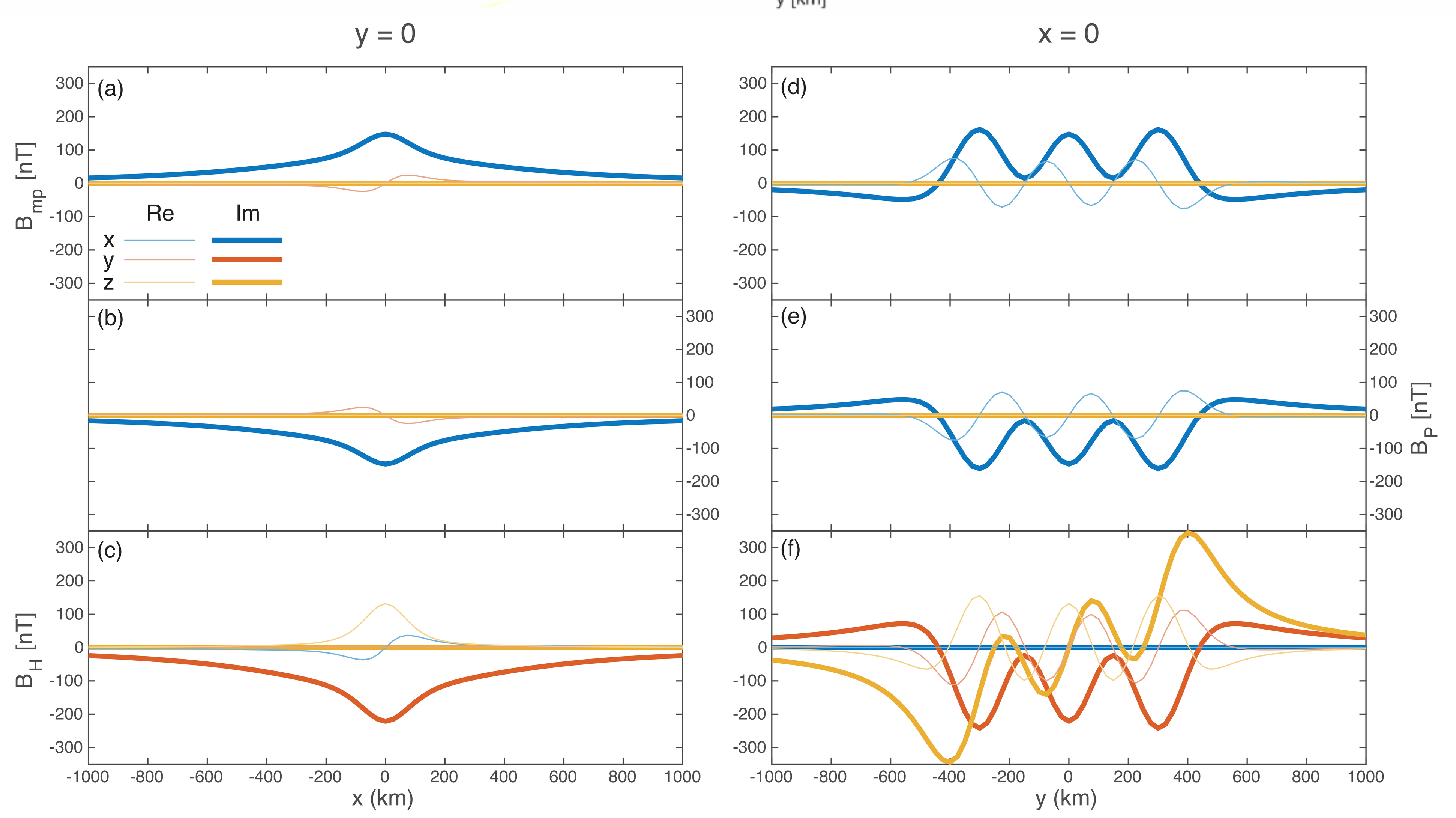

Figure 3 Cuts of the ground magnetic field from MI current systems

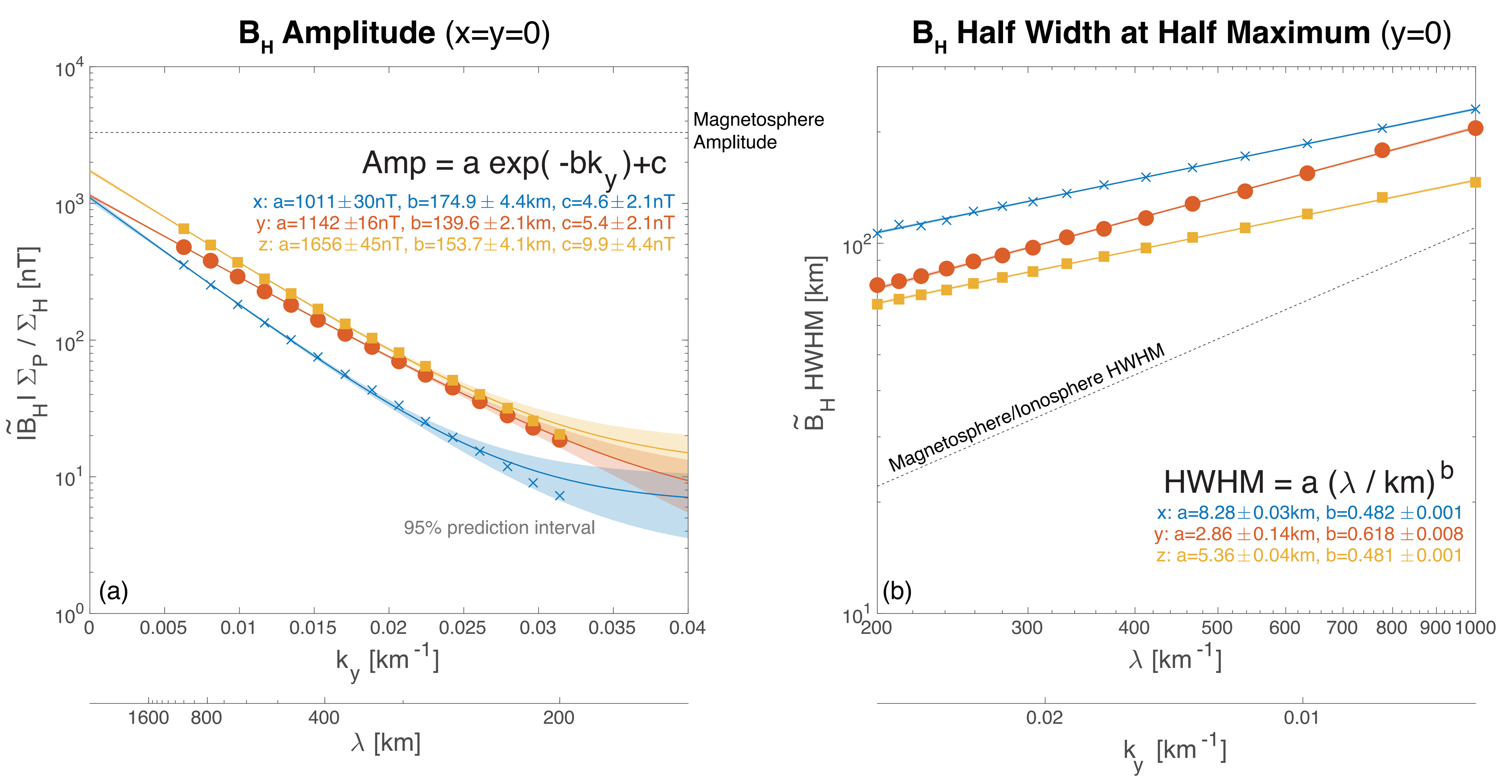

Figure 4 Amplitude and scale of ground magnetic field from MI current systems with wavelength

Geoelectric field

- GICs typically considered only for high frequencies. However, model shows ~mHz surface waves result in **significant geoelectric fields ~1000's mV/m** (Figure 5a-b).
- Amplitudes greatest for large-scale waves, exponentially decaying with wavenumber similar to ground magnetic field but with larger e-folding scale (Figure 5c).
- HWHM also scale as power laws with wavelength, over **larger scales than ground magnetic field**, but still highly localised to OCB (Figure 5d).
- Consequence is **local dB/dt insufficient** for prescribing geoelectric field for localised driving magnetospheric phenomena, such as surface waves.

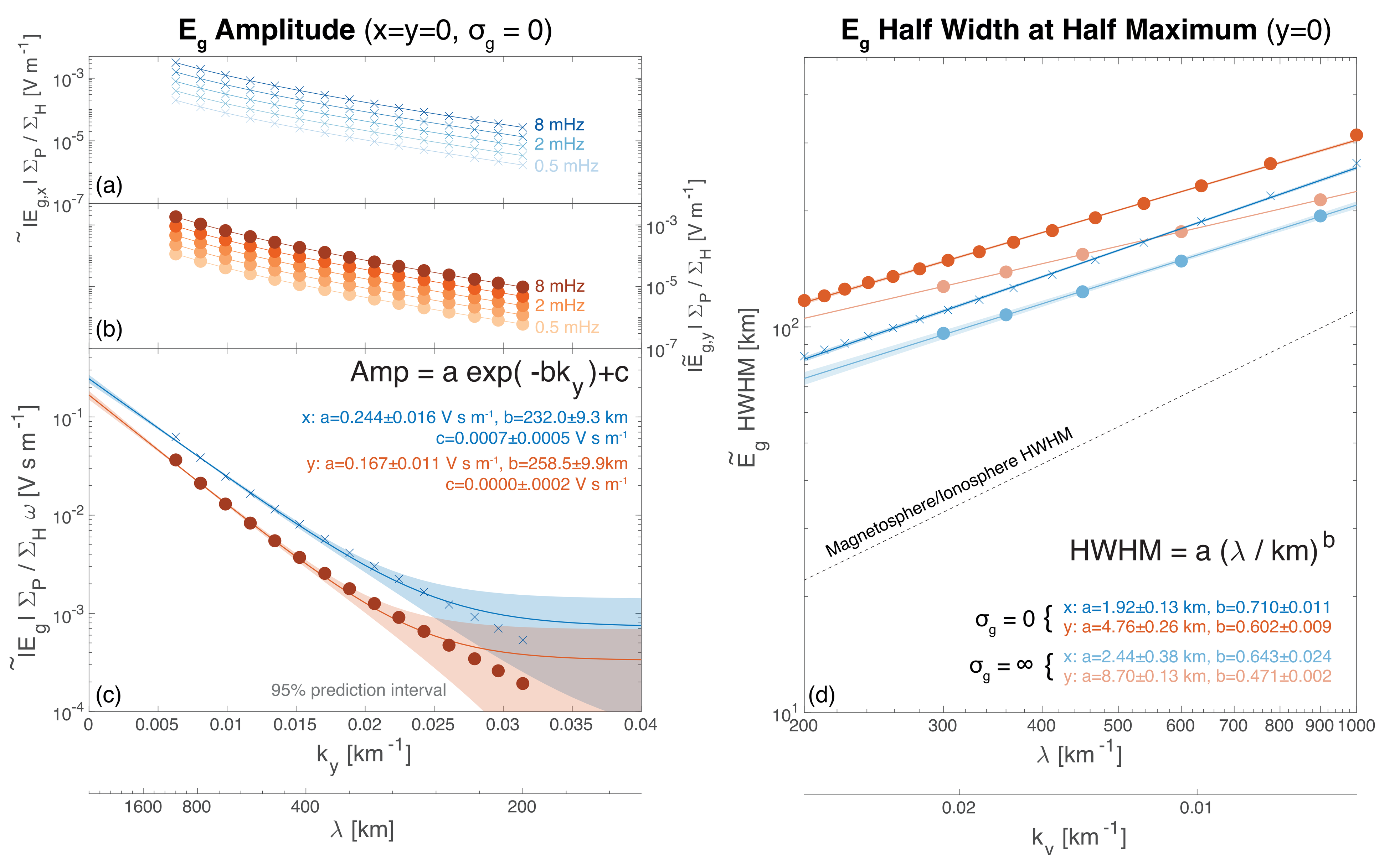

Figure 5 Amplitude and scale of geoelectric field with wavelength for ground conductivity limits

Implications

- Model provides predictions for underpinning ground-based observations, particularly timely for **SMILE ground-space conjunction campaigns** monitoring the magnetopause and the associated ground-based impacts.
- Model might be extended to other mesoscale time-varying phenomena (plasmapause surface waves, field line resonance, flux transfer events) for direct comparison.

The ionosphere modifies the effects of magnetopause surface waves on the ground in more complex ways than infinite plane Alfvén waves, due to spectrum of wavenumbers present.

Surface waves might act as a significant source of space weather, e.g. ionospheric Joule heating or geoelectric fields that drive GICs, which may require more spatially-dense monitoring capabilties.