A note on the flowchart

Figure 1 in the Main Paper presents a abridged flow chart of the unstable wave energy cascade from the solar wind to kinetic and thermal energy dissipation in the ionosphere. The chart simplifies the initial cascade from unstable Kelvin-Helmholtz waves at the boundary of the magnetosphere and ignores some secondary effects such thermal electron precipitation.

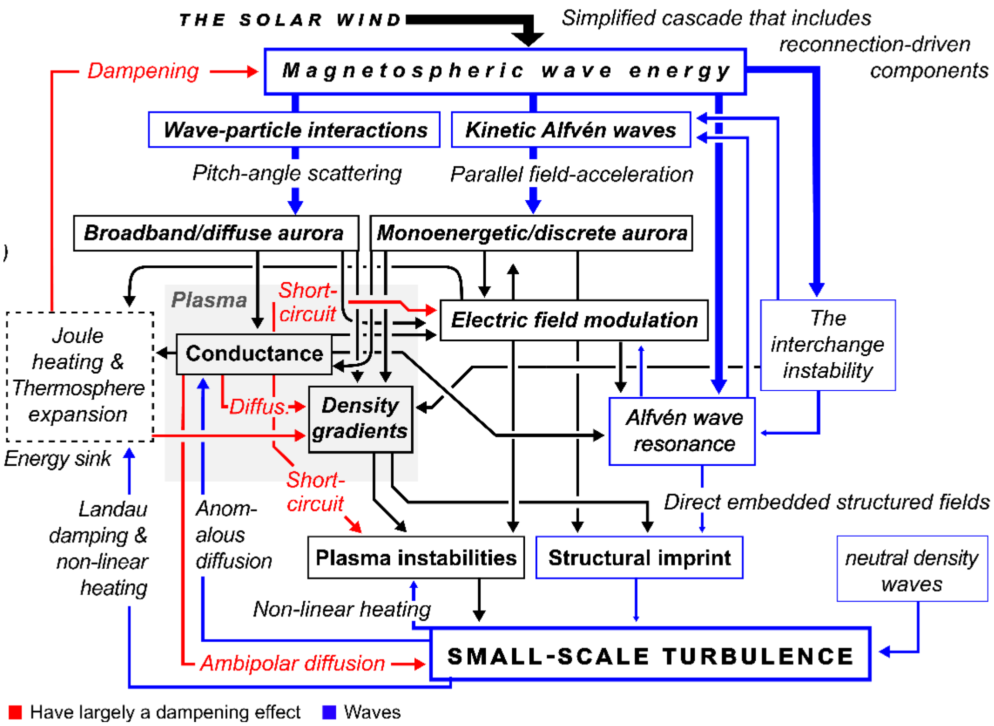

Figure S1: A conceptual snapshot of the unstable wave energy cascade involved in the M-I coupling. See Figure 1 in the Revised Manuscript.

1. The flow chart starts at the top with a cascade from solar wind pushing against the magnetosphere, which generates Kelvin-Helmholtz waves along the various boundaries that feature velocity shear. This interaction generates a variety of large-scale ULF waves, which serve as the primary carriers of energy from the outer magnetosphere toward the high-latitude ionosphere. This cascade is highly simplified in the chart for reasons of brevity.
2. The energy may be transported downwards directly through waves. Here, the interchange instability typically triggers, structuring the density and producing "seeds". The cascade end in kinetic Alfvén waves, which accelerate electrons and modulate the ionospheric ("convection") electric field, often through Alfvén wave resonators set up by the boundary conditions.

3. Another route for the energy is through the powering of plasma waves near the radiation belts, which scatter with hot electrons at certain angles, causing particle precipitation and diffuse aurorae. This route is known to dominate the total energy budget of the particle precipitation observed by DMSP (Newell et al., 2009, 2010).
4. Both routes of energy expenditure move through ionospheric electrodynamics (the nodes Conductance, Density gradients, and Electric field modulation), which conduct electricity, facilitating the Joule heating that eventually expands the thermosphere, dissipating the initial unstable wave energy. The three nodes feature very high connectivity with the rest of the chart and are crucial for both Joule heating rates and the production of small-scale turbulence. Especially ionospheric conductance, which affects the most nodes in the chart, has, historically and at present, been considered a vital variable in geospace, regulating the entire process of energy dissipation (Wiltberger et al., 2017).
5. In the chart, there are several connecting routes to the node Small-scale turbulence, and among them, we find several that directly embed a turbulent pattern or structure into the plasma from the wave organization of the magnetic field-lines (Ivarsen et al., 2024). On the other hand, the node Plasma instabilities has traditionally been considered to be an important cause of structuring in the auroral ionosphere, and may dominate structuring during conditions favourable to their triggering.
6. The blue-colored nodes and arrows are explicitly expressed as waves and other multi-scale oscillatory variations in plasma density, highlighting the critical role of unstable wave energy in the M-I coupling.
7. The red-colored arrows represent dampening effects, and correspond to the fact that conductance regulates the energy expenditure (and therefore causal purpose) of the M-I system.

References:

Ivarsen, M. F., Gillies, M. D., Huyghebaert, D. R., St-Maurice, J.-P., Lozinsky, A., Galeschuk, D., Donovan, E., & Hussey, G. C. (2024). Turbulence Embedded Into the Ionosphere by Electromagnetic Waves. Journal of Geophysical Research: Space Physics, 129(8), e2023JA032310. https://doi.org/10.1029/2023JA032310

Newell, P. T., Sotirelis, T., & Wing, S. (2009). Diffuse, monoenergetic, and broadband aurora: The global precipitation budget. Journal of Geophysical Research: Space Physics, 114(A9). https://doi.org/10.1029/2009JA014326

Newell, P. T., Sotirelis, T., & Wing, S. (2010). Seasonal variations in diffuse, monoenergetic, and broadband aurora. Journal of Geophysical Research: Space Physics, 115(A3). https://doi.org/10.1029/2009JA014805

Wiltberger, M., Merkin, V., Zhang, B., Toffoletto, F., Oppenheim, M., Wang, W., Lyon, J. G., Liu, J., Dimant, Y., Sitnov, M. I., & Stephens, G. K. (2017). Effects of electrojet turbulence on a magnetosphere-ionosphere simulation of a geomagnetic storm. Journal of Geophysical Research: Space Physics, 122(5), 5008–5027. https://doi.org/10.1002/2016JA023700