Ultra Low Frequency Waves: Space Weather and Ionosphere-Thermosphere System Impacts

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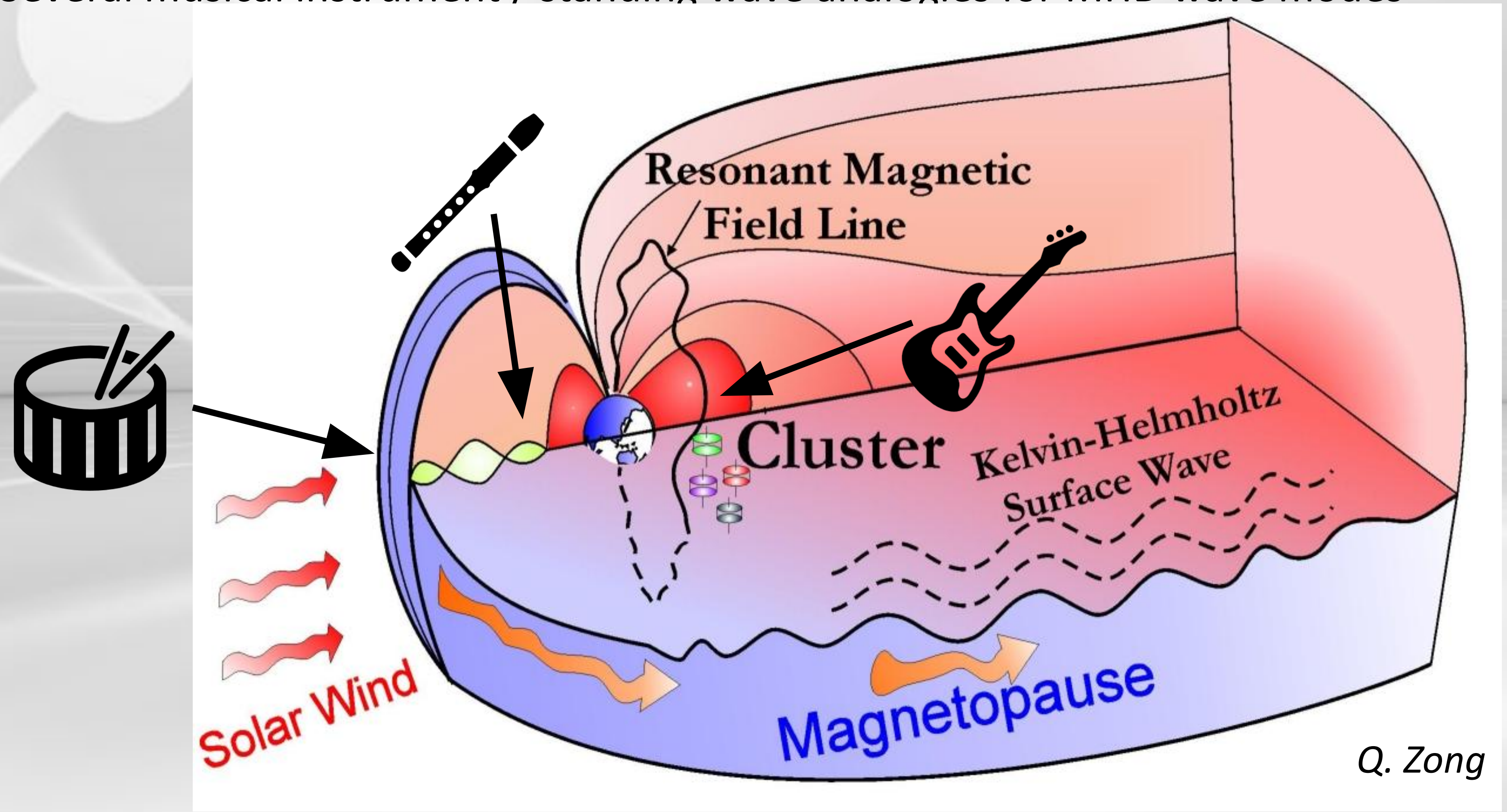
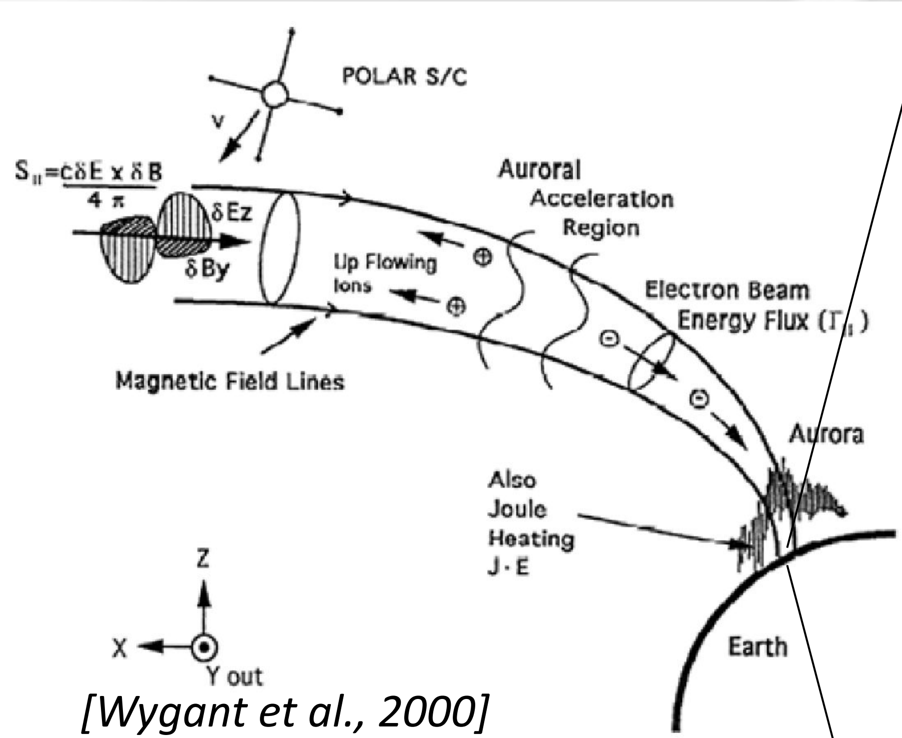
Ultra Low Frequency waves

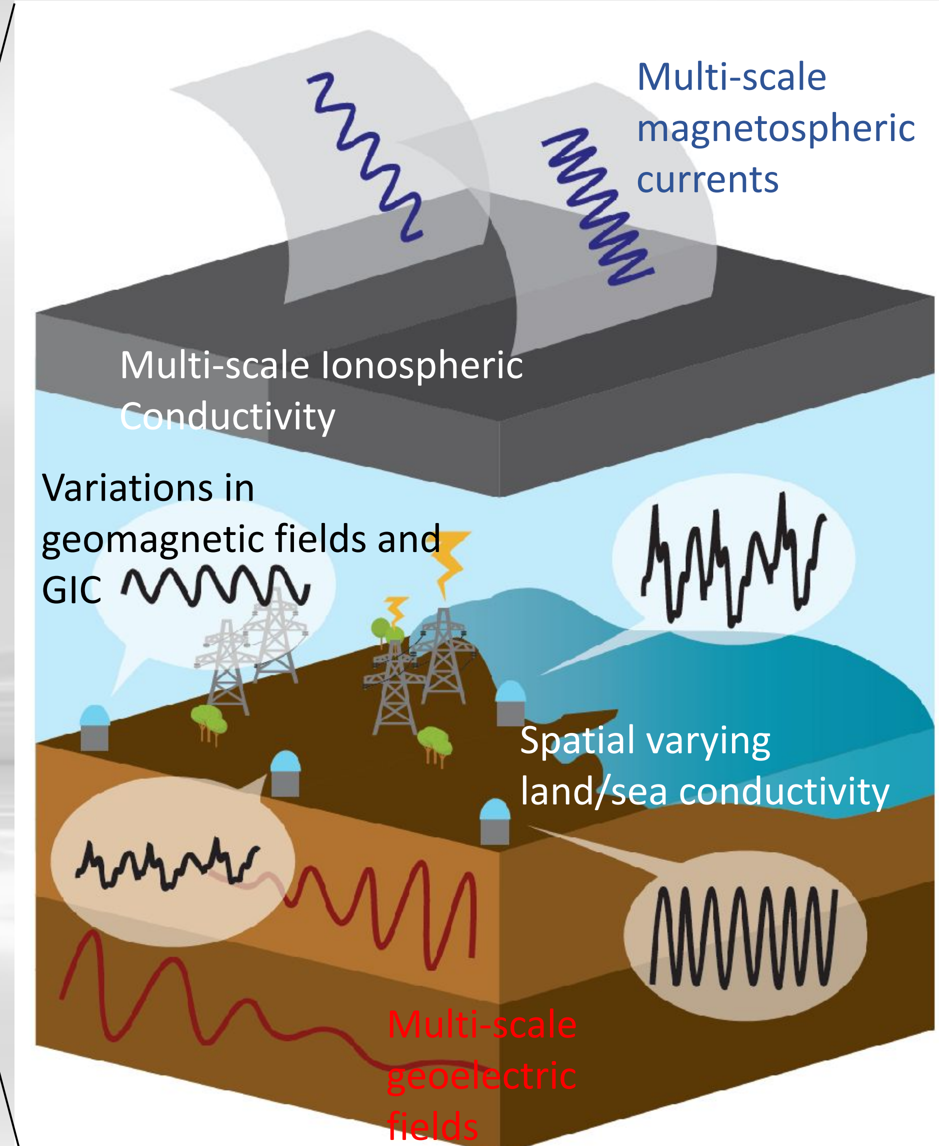
- ULF: frequency band for plasma waves in the Earth's magnetosphere and ionosphere
- Largest spatial scales in the system
- Many (not all) lower frequency ULF waves are well approximated by MHD
- Several musical instrument / standing wave analogies for MHD wave modes



Space Weather and I-T System Impacts



[Wygant et al., 2000]

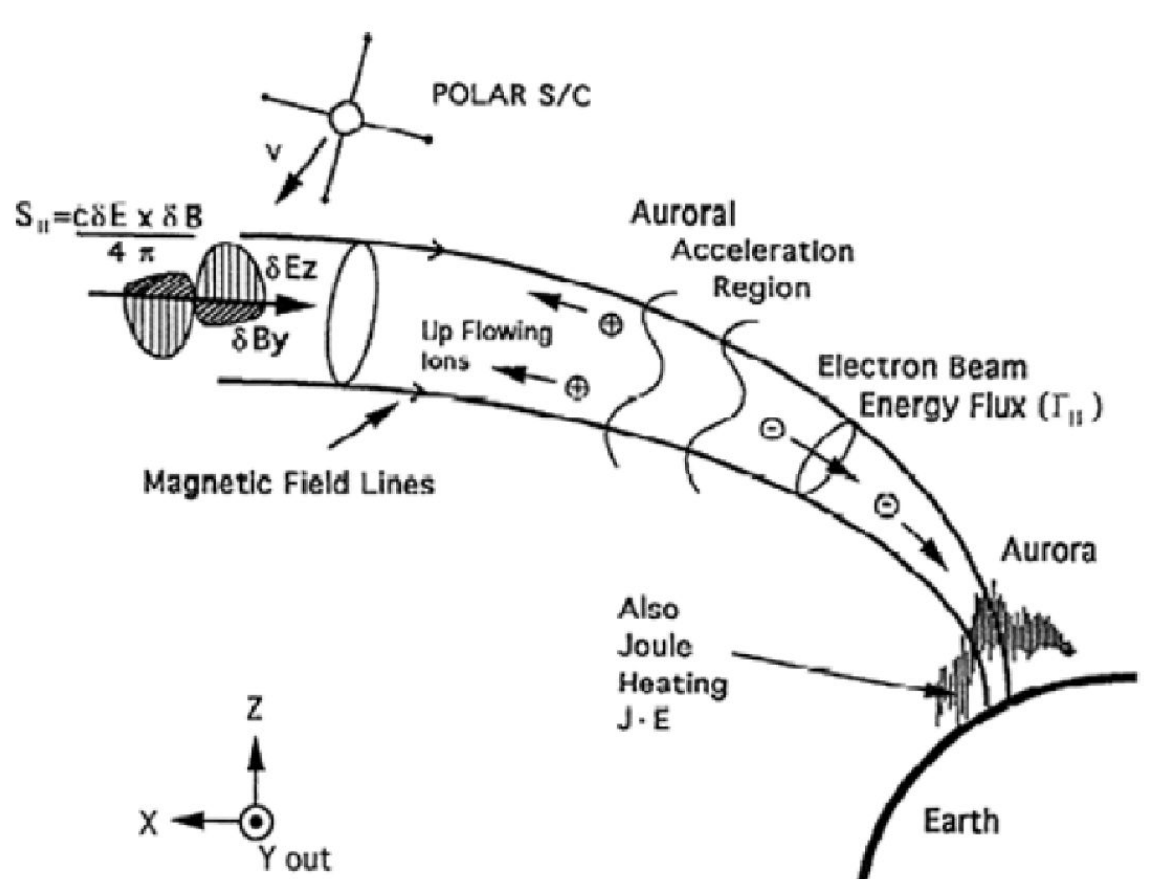


Credit: Michelle Salzano and Ayomide Olabode, Adapted from Gannon 2016

- Energy deposition and Ionosphere-Thermosphere heating
- Geomagnetic/Geoelectric disturbances, Geomagnetically Induced Currents
- Specification of ULF waves in models
- Several topics not covered, including ULF waves in TEC

Energy Deposition and I-T heating

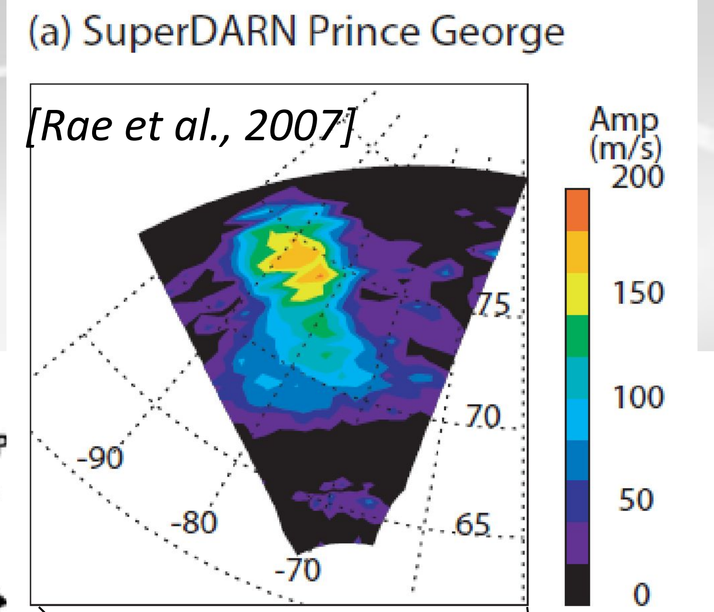
- Energy budget of ULF waves significant energy electromagnetic/kinetic energy deposition, **comparable (~30%) to amount deposited by a substorm** based on models constrained by radars and satellite measurements [e.g., Greenwald and Walker, 1980; Rae et al. 2007]



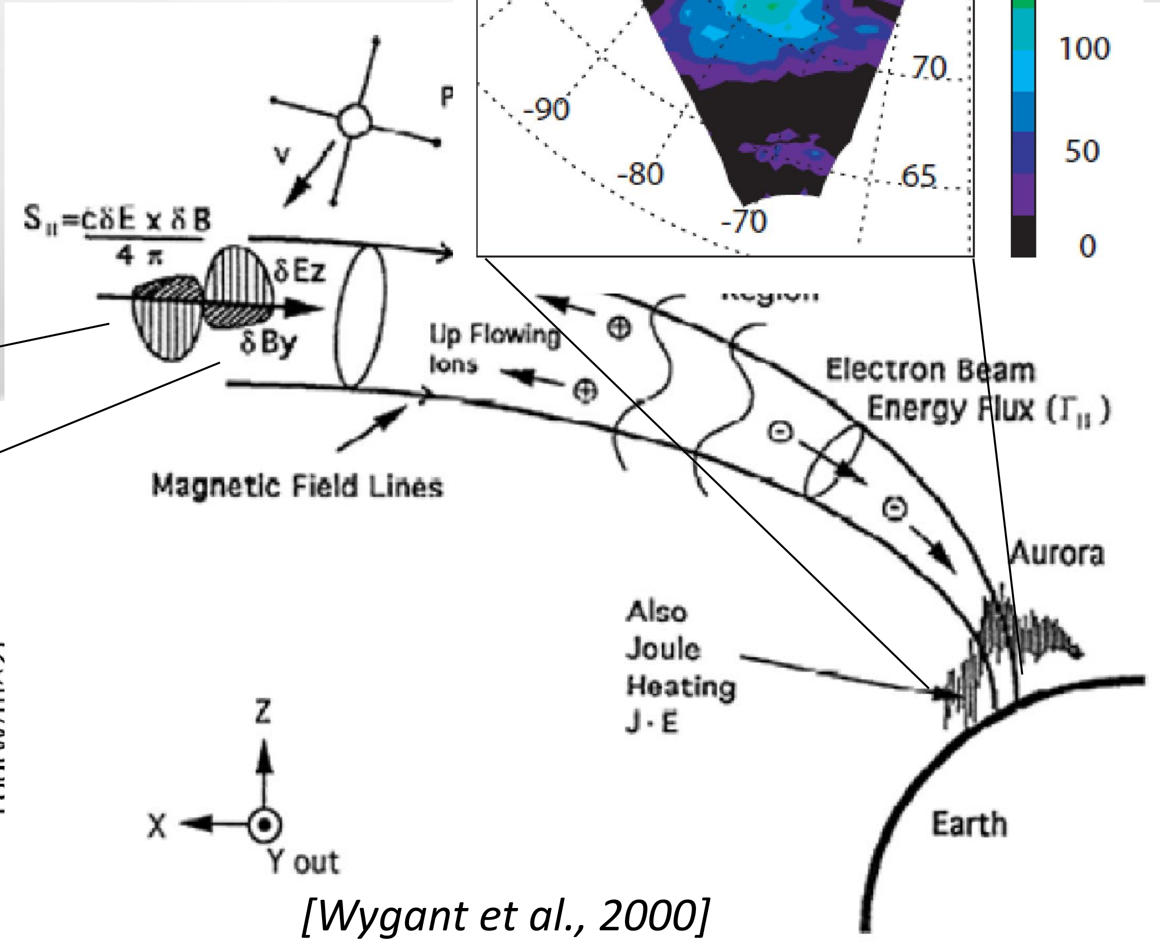
[Wygant et al., 2000]

Energy Deposition and I-T heating

- How often does this occur?
- How much electromagnetic versus kinetic energy is deposited?
- How does the measurement technique and location affect results?



[Rae et al., 2007]



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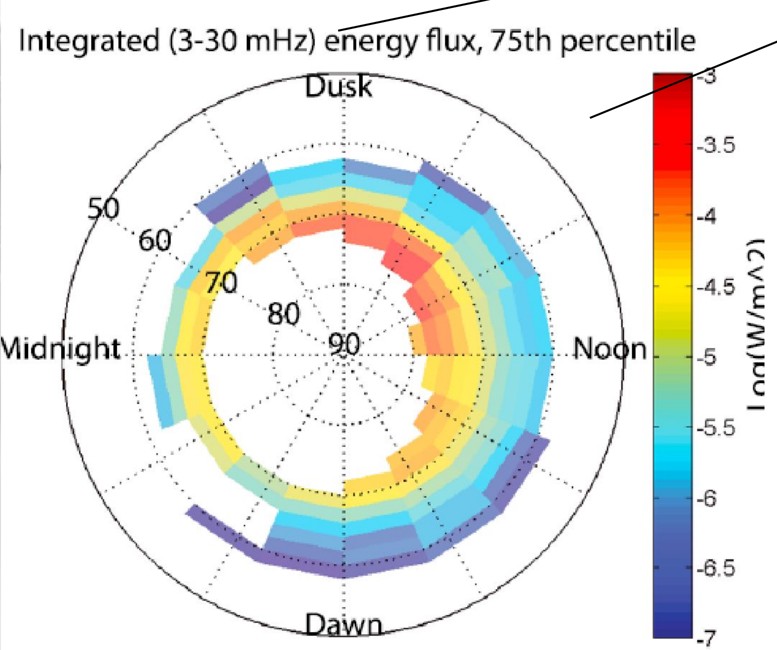

[Hartinger et al., 2015]

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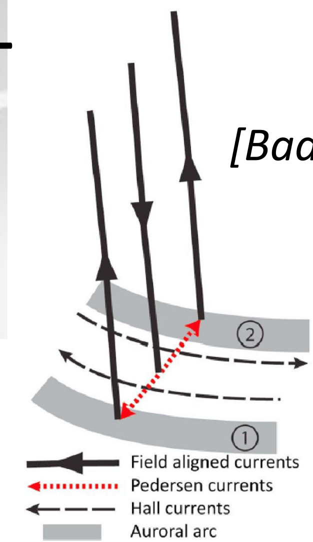
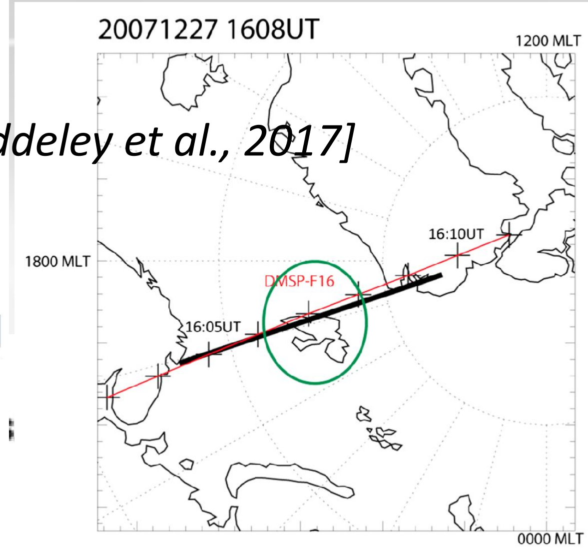
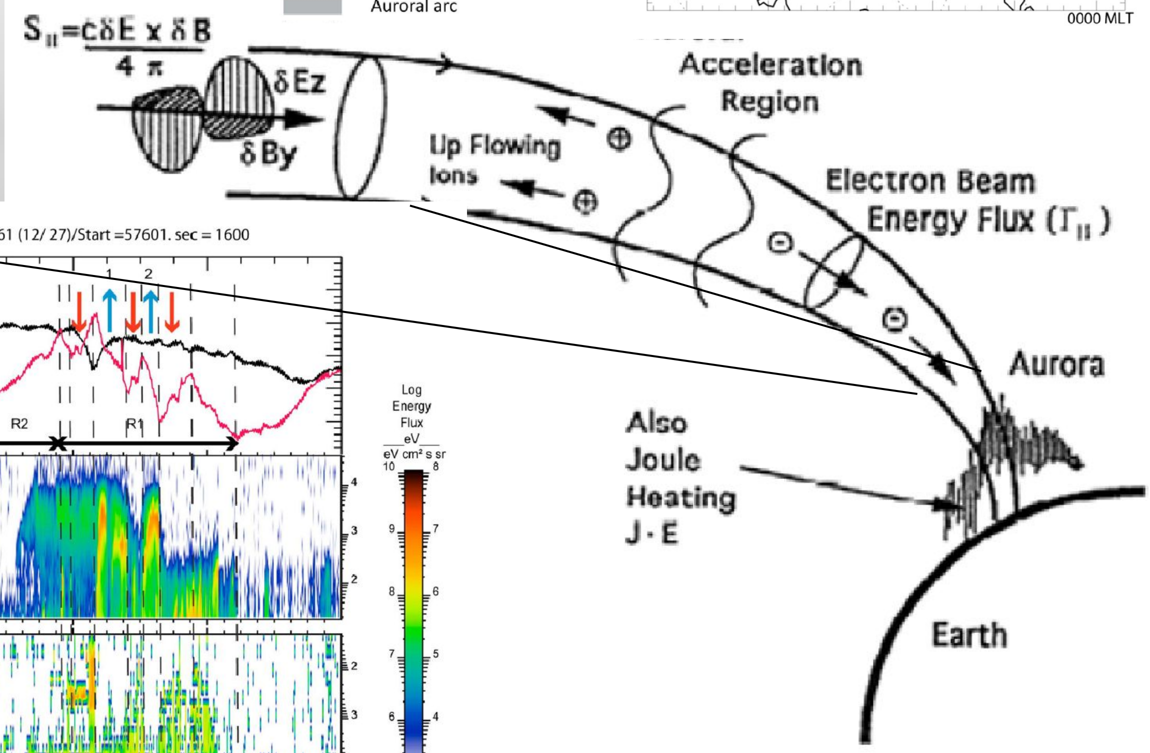
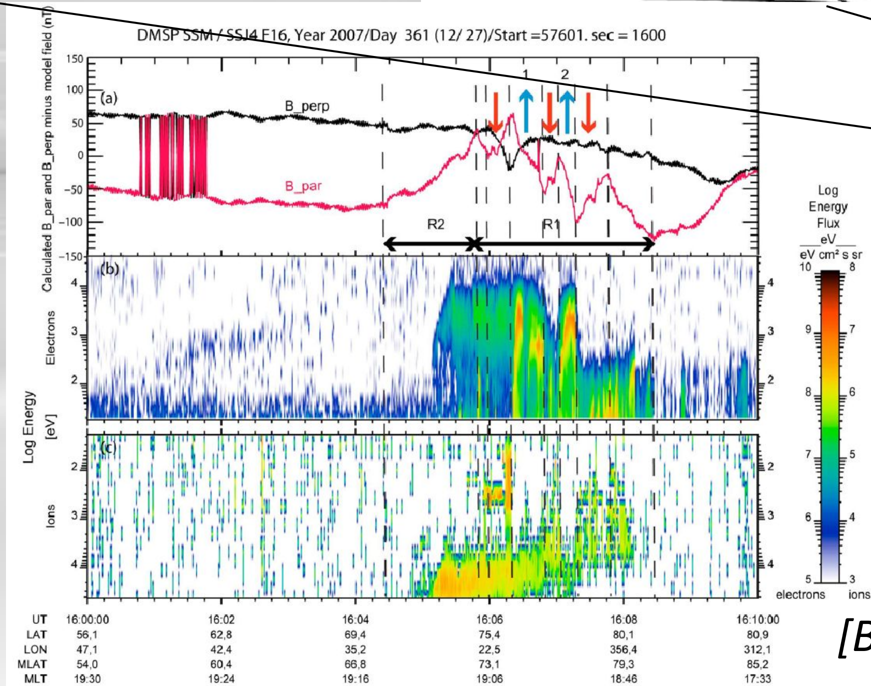




[Baddeley et al., 2017]

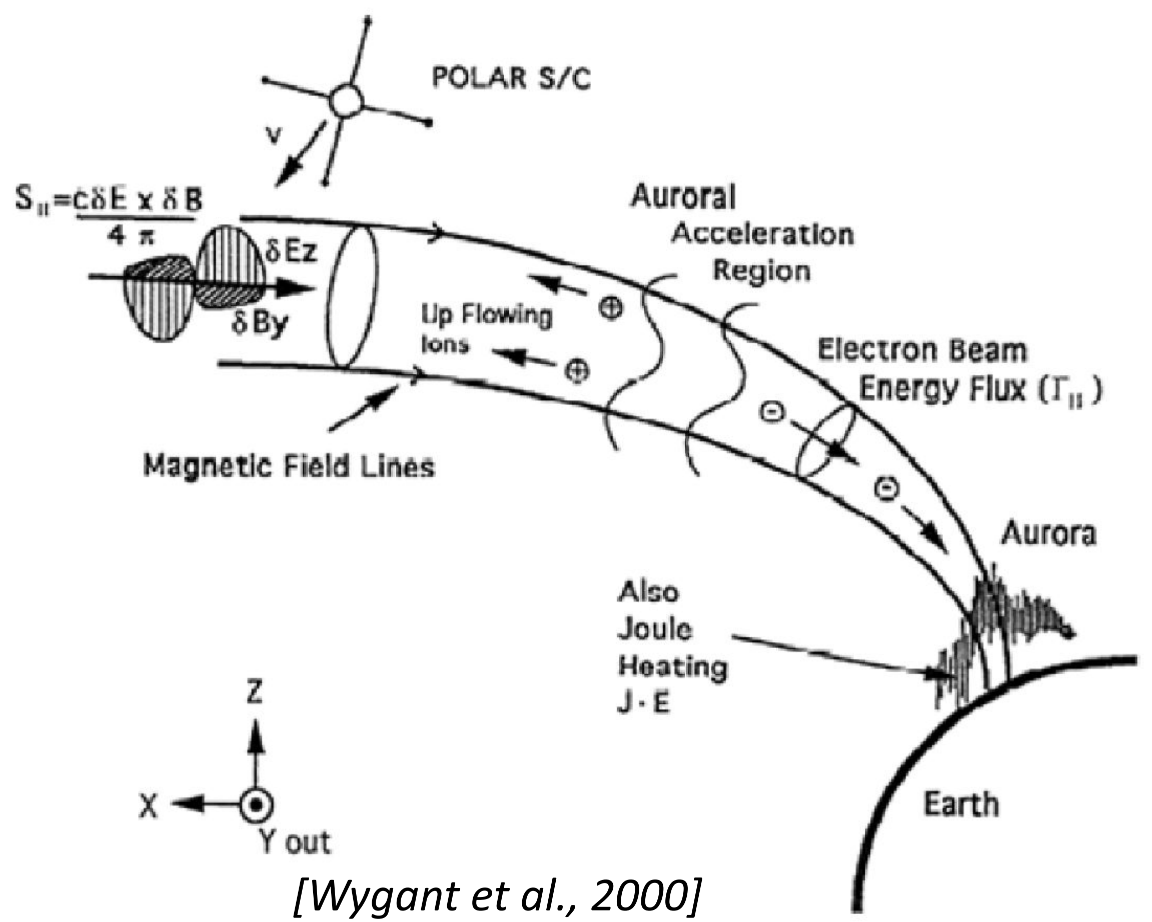




[Baddeley et al., 2017]

Energy Deposition and I-T heating: Future Work

- Statistical analysis of ULF wave energy deposition including historic storms
- Multi-satellite observations in LEO, e.g. GDC, to resolve time-space ambiguity
- Multi-point conjunctions
- Models that can capture ULF wave energy deposition
- See recent review by Kaeppler et al., [2022]



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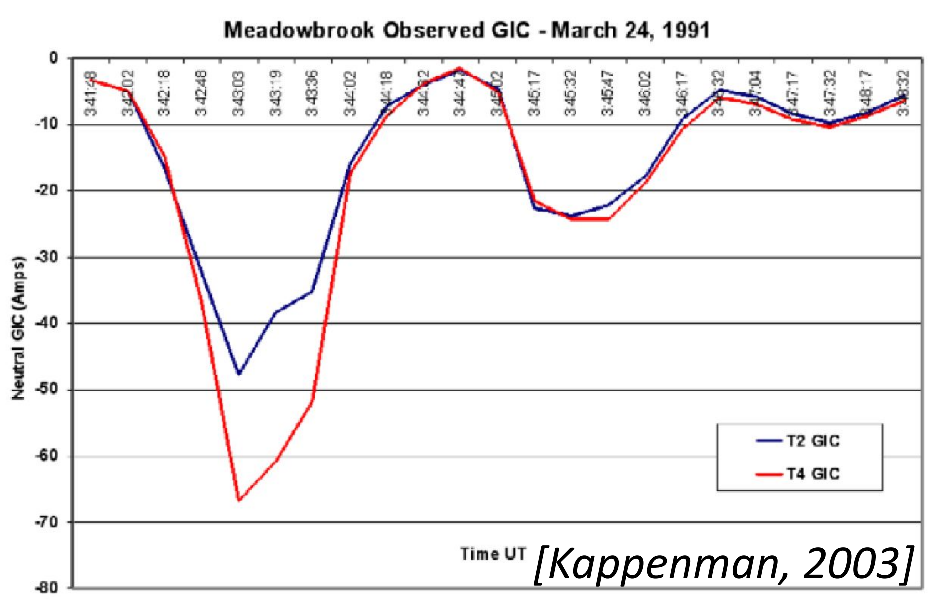
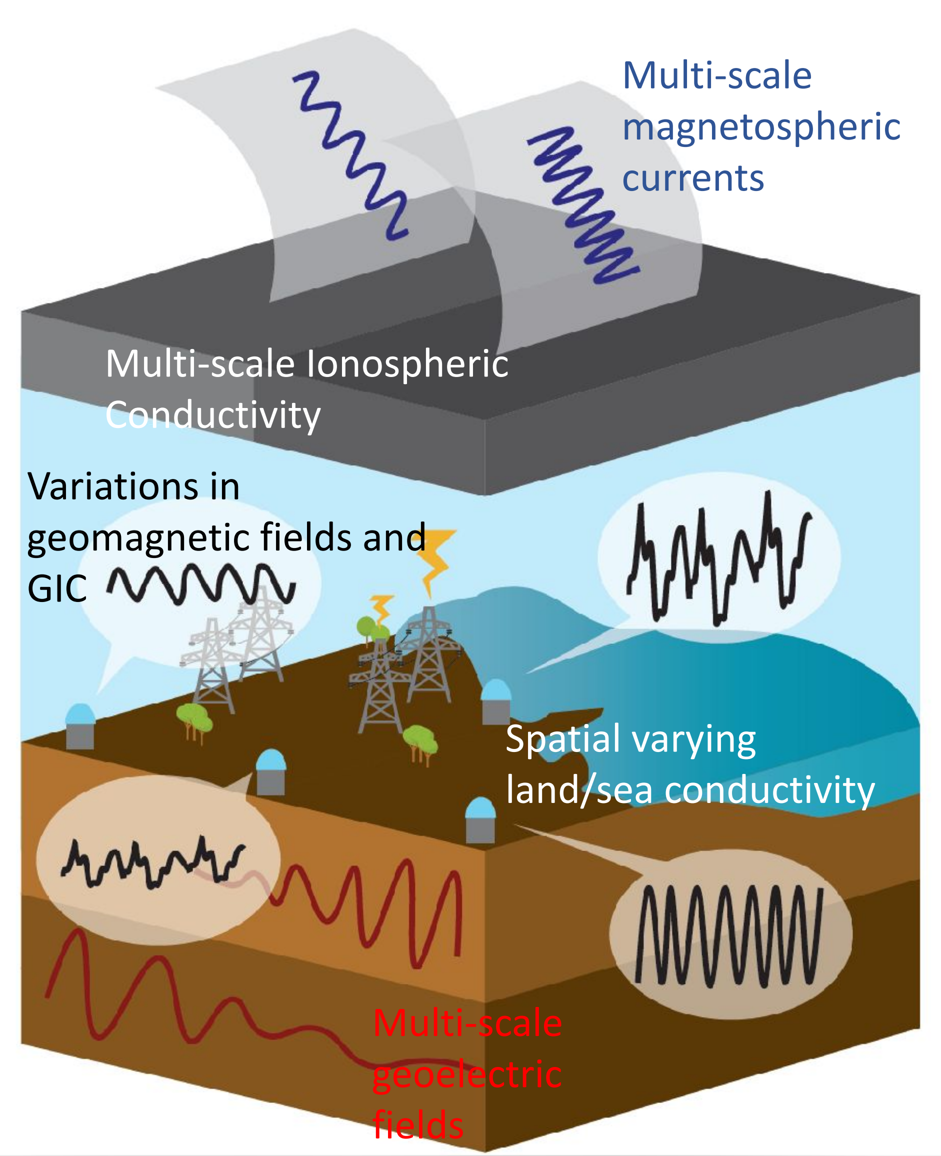
Geomagnetically Induced Currents



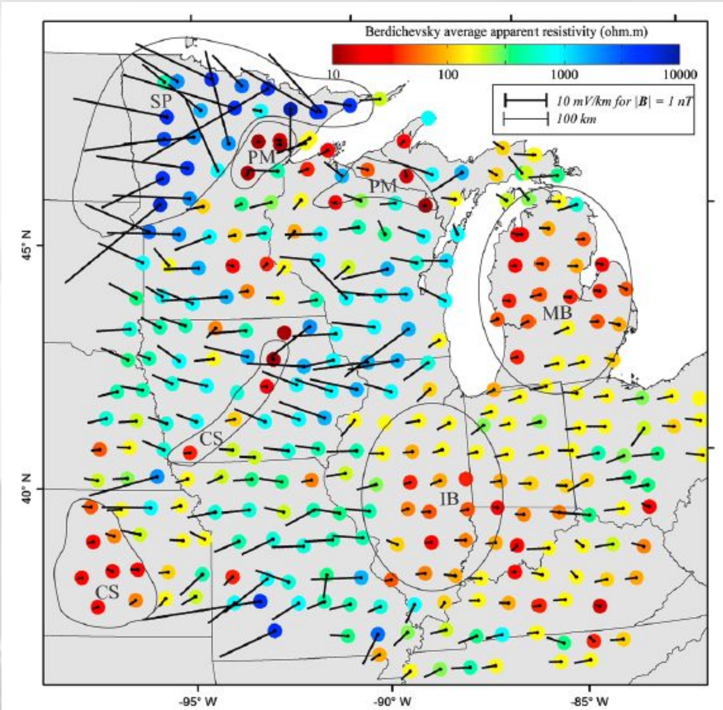
[Kappenman, 2003]

- ULF waves have appropriate frequencies to induce geoelectric fields and create damaging electric currents in power systems
- Some of the most extreme GIC ever reported have a ULF waveform, including those in the USA (above) and New Zealand [Hartinger et al., 2023]



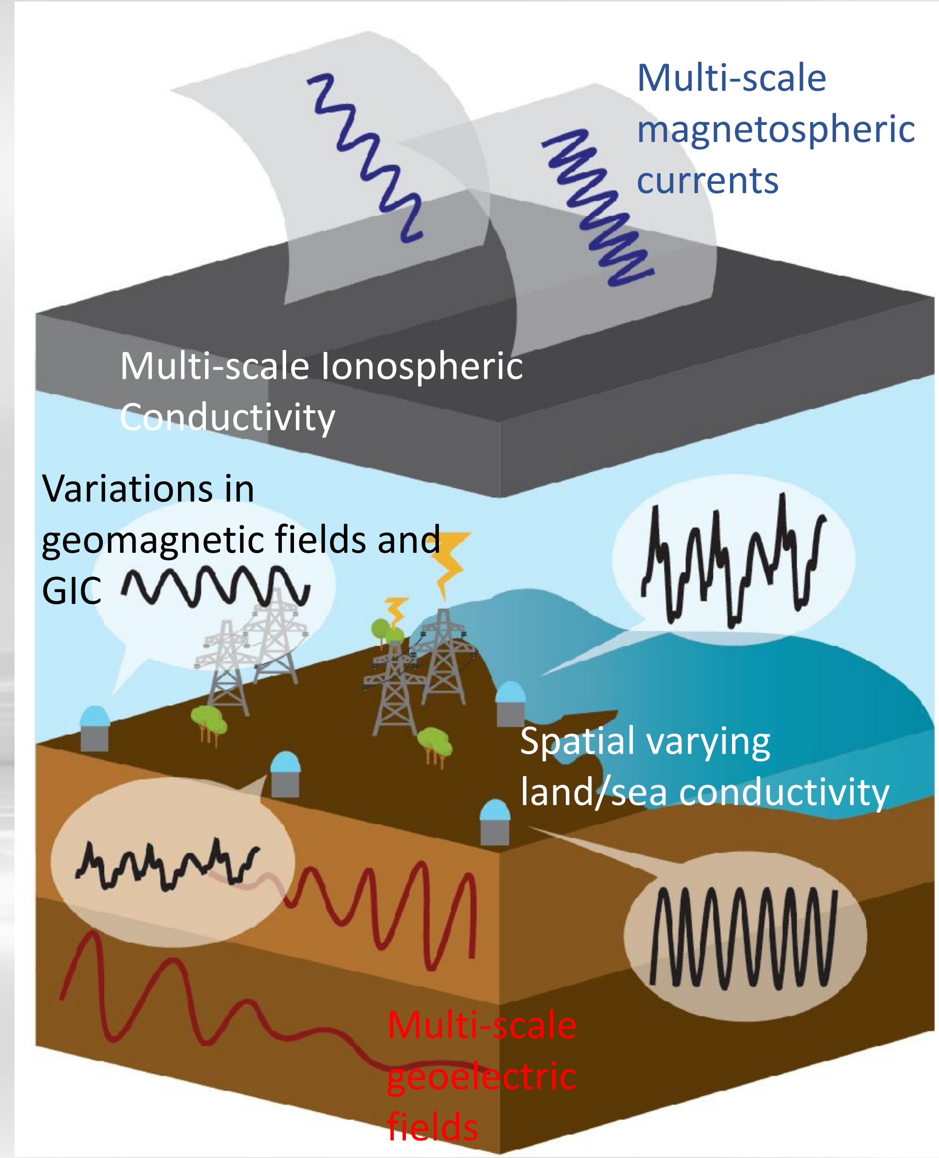
Credit: Michelle Salzano and Ayomide Olabode, Adapted from Gannon 2016

Geomagnetically Induced Currents



Bedrosian and Love, 2015

- For hazard analysis, it's crucial to consider 3D ground conductivity
- Recent magnetotelluric surveys have improved ability to quantify ULF wave induced geoelectric fields and GIC [Hartinger et al., 2020; Shi et al., 2022]



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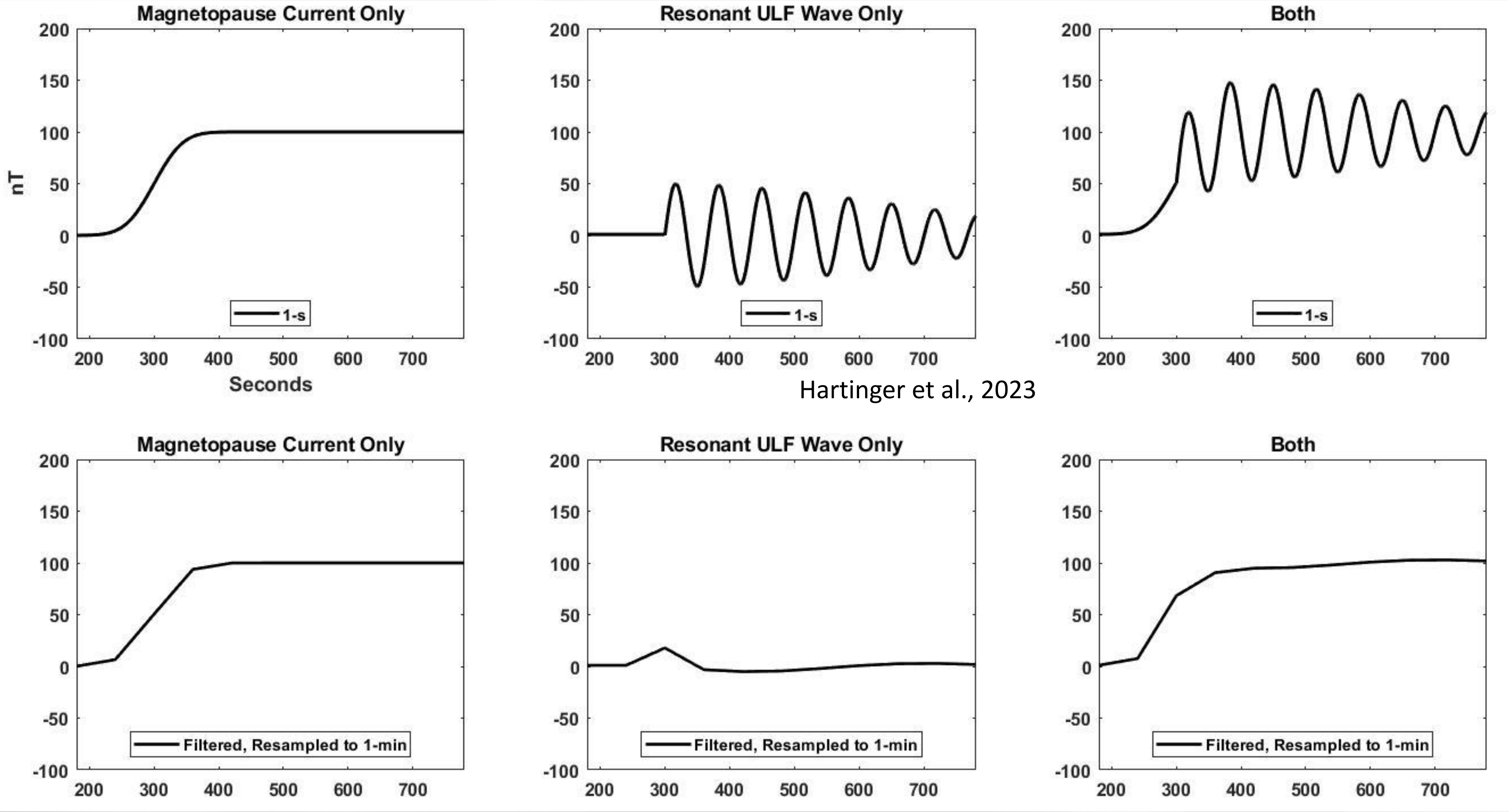
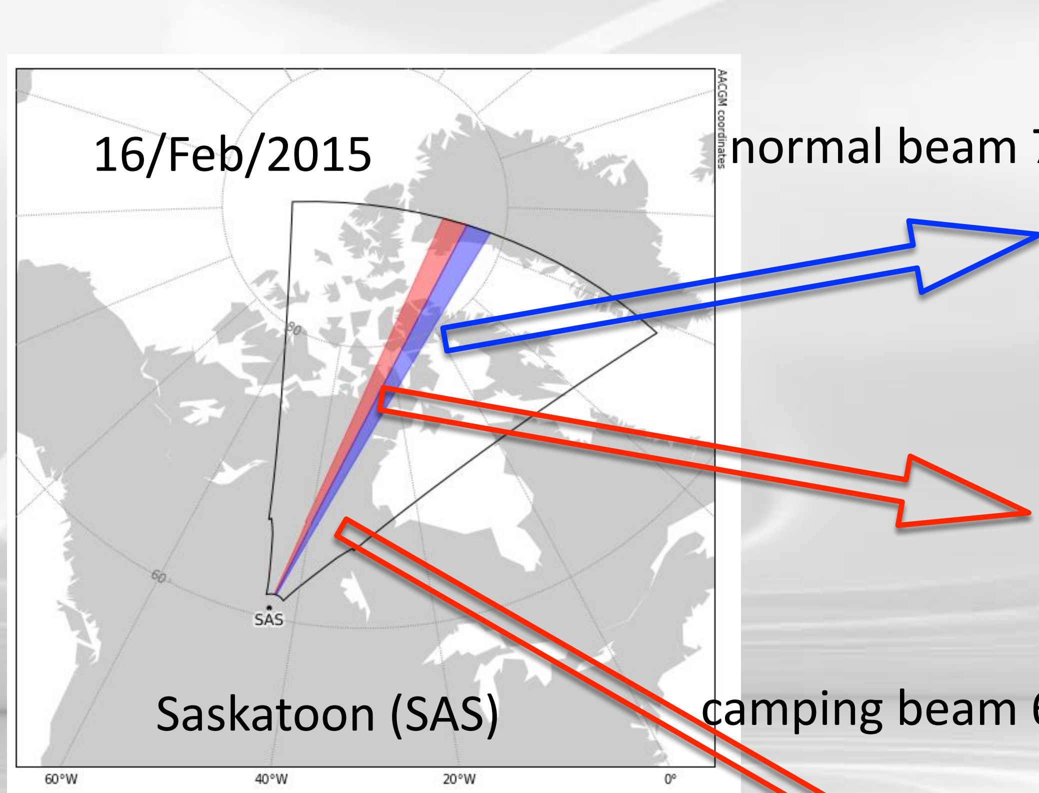
Assessing ULF wave space weather impacts: crucial role of sampling rate

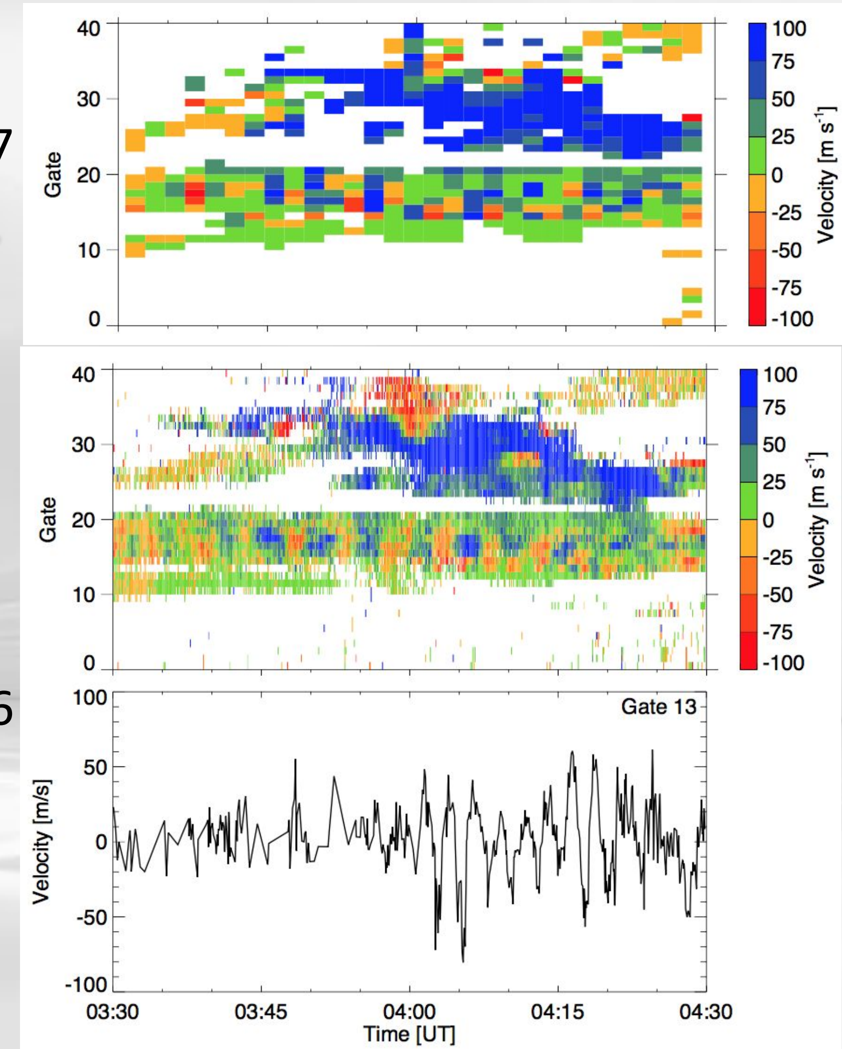


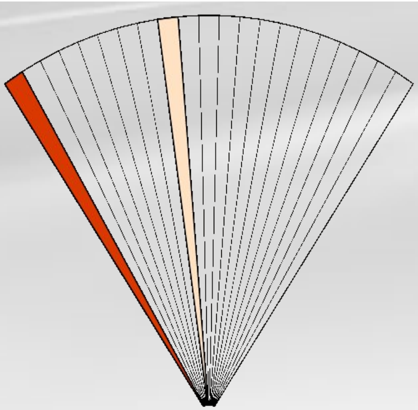
Hartinger et al., 2023

- **Many ULF waves have frequencies above the Nyquist for 1-minute sampling intervals [e.g., Hartinger et al., 2023]**
- This affects GIC, I-T heating, TEC studies,…

Assessing ULF wave space weather impacts: crucial role of sampling rate





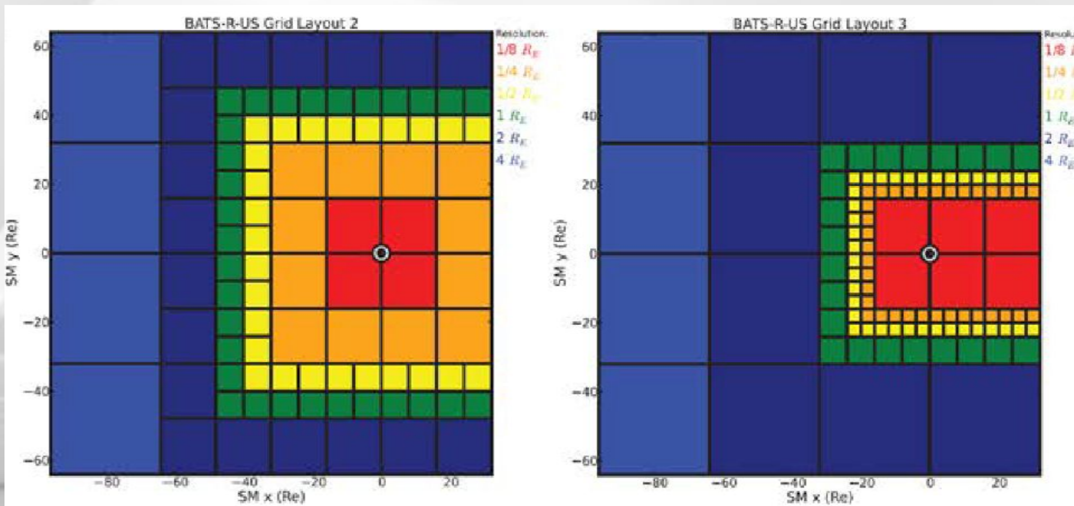


themis mode scan

(~ 6 sec temporal
resolution, resolution)
45 km spatial

Slide Credit: Xueling Shi

Assessing ULF wave space weather impacts: specification in geospace models



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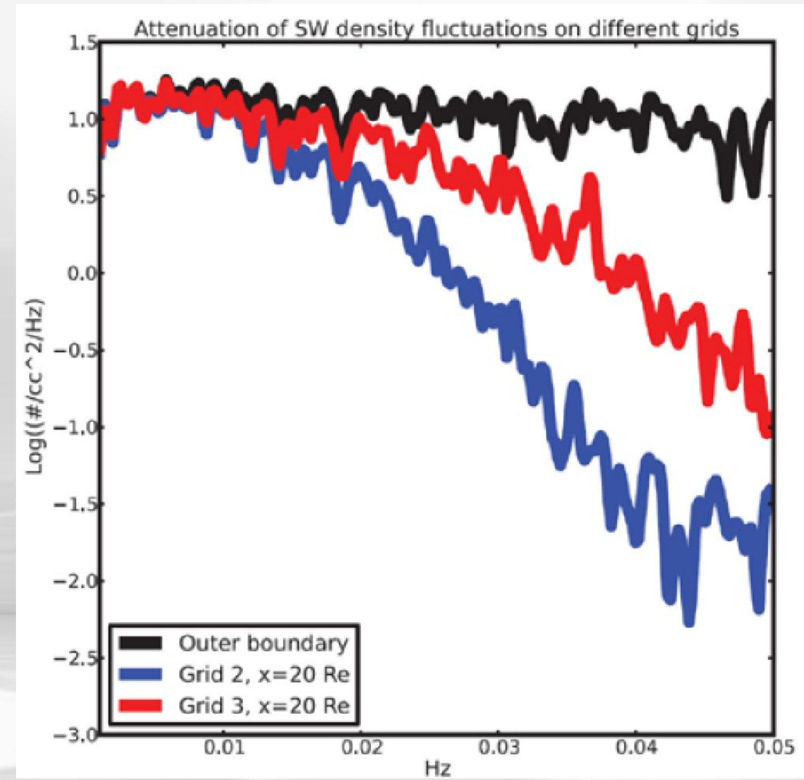
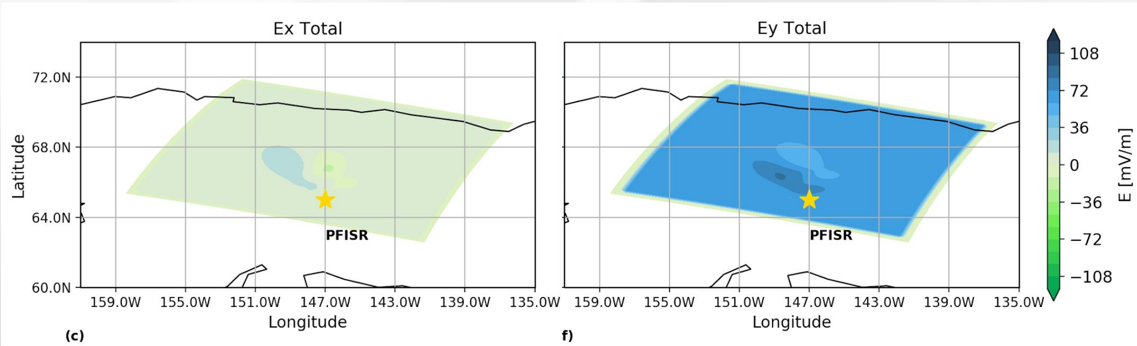
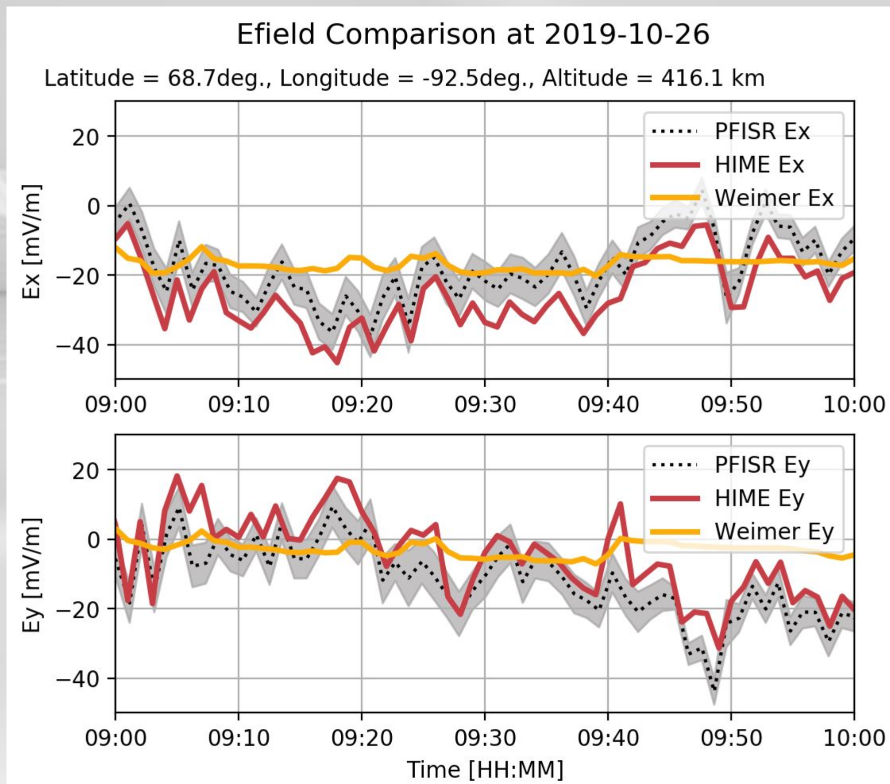


- Many numerical simulations can capture ULF waves, but the choice of configuration – grid resolution, solver, boundary conditions,… - is crucial
- Recent GEM ULF wave modeling challenge [Hartinger et al., 2022]

Assessing ULF wave space weather impacts: specification in geospace models





[Example HIME-GITM model input and output, Credit: Doga Ozturk]

- Need ability to specify mesoscale driving [e.g., Ozturk et al., 2019; Meng et al., 2022]
- Need self-consistent magnetosphere-ionosphere-thermosphere models

Summary

- ULF waves carry significant energy and affect space weather and the overall I-T system: heating, geoelectric fields/geomagnetically induced currents,…
- Measurement challenges: sampling rate, time/space ambiguity, measurement location, lack of historical data/extreme event analysis
- Modeling challenges: numerical effects, boundary conditions, coupling between regions
- Future advances expected from multi-point/multi-instrument studies, improved remote sensing techniques, self-consistently coupled magnetosphere-ionosphere-thermosphere models

Thank you!

Recent ULF wave mini-review: *Hartinger MD, Takahashi K, Drozdov AY, Shi X, Usanova ME and Kress B (2022) ULF Wave Modeling, Effects, and Applications: Accomplishments, Recent Advances, and Future. Front. Astron. Space Sci. 9:867394*