Signatures of Magnetospheric Kelvin-Helmholtz Waves in Ground Magnetometer Data

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Introduction

At the edge of Earth's magnetosphere, the magnetopause separates high velocity plasma in the magnetosheath from low velocity plasma in the magnetosphere. Flow shear at the magnetopause can cause vortices to develop as a result of the Kelvin-Helmholtz (KH) instability [1]. Magnetic field perturbations from KH vortices have been predicted to propagate to the Earth's surface, but no studies have yet shown this conclusively [1]. Observations of these waves at the Earth's surface would be useful in demonstrating the KH instability's role in magnetospheric energy transport [1].

Ground Level and *in situ* Observations

The orbits of NASA's five THEMIS probes are ideal for *in situ* observations of KH waves [3]. The ion velocity observed by THEMIS was compared with magnetic field data from ground magnetometers (GMAGs) near the footprint of THEMIS to find corresponding waves in each dataset. The footprints were found by tracing the THEMIS position to the Earth along magnetic field lines predicted by the Tsyganenko 1996 magnetic field model.

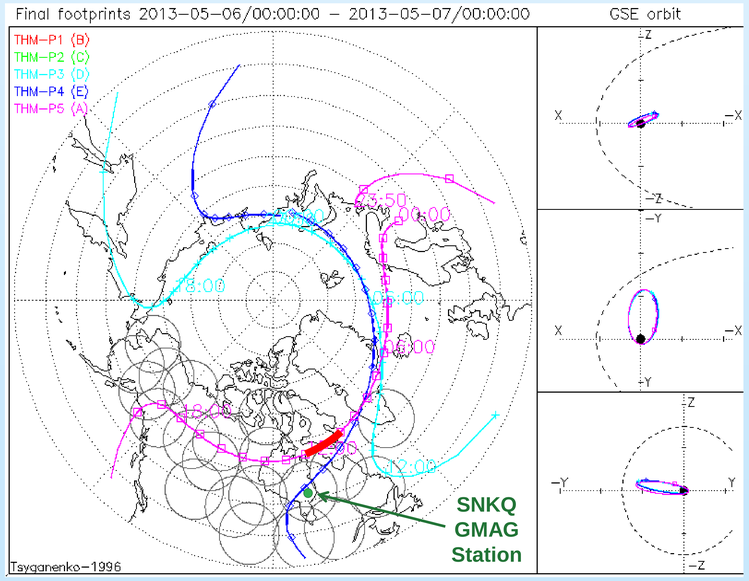

Figure 1: Footprints and orbits of the THEMIS probes on May 6, 2013. The footprint of THEMIS A (THA) while observing a KH event is highlighted in red.

Data Processing

- The period of KH waves is typically about 1-4 minutes, so the THEMIS and GMAG data were both band pass filtered to isolate the frequencies of interest.
- The KH events analyzed were 1-3 hours long so a wavelet transform was performed to identify periods of time where the wave frequencies in both data sets were similar.
- The waves observed by THEMIS have been predicted to take 1-10 minutes to travel to Earth [2], so once a region of interest had been identified from the wavelet transform, the THEMIS was data shifted forward in time to align waves observed by THEMIS with waves observed by GMAGs.

Results

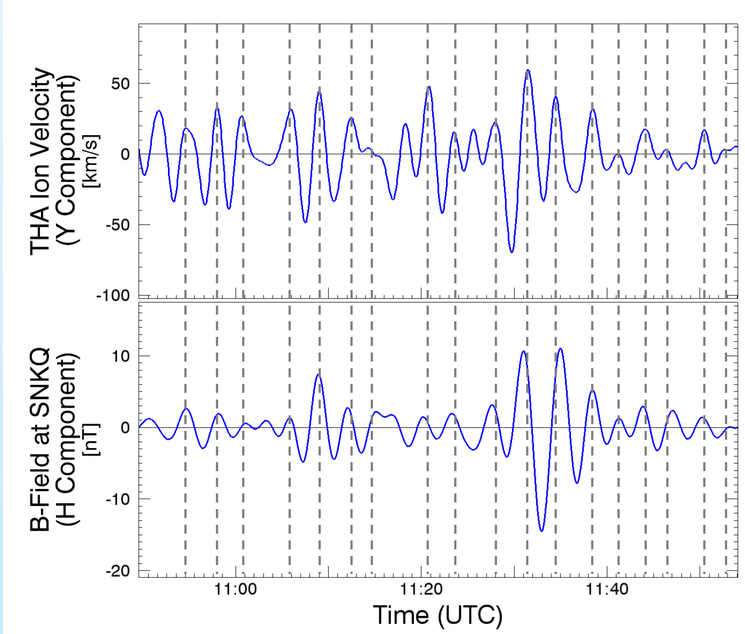

Figure 2: Time series of the THA ion velocity and the magnetic field at the SNKQ GMAG station (shown in green in Figure 1) during the KH event on May 6, 2013. THEMIS data is shifted forward in time by 140 seconds. There appears to be a strong correlation between the waves observed by THEMIS and the waves observed by the SNKQ station.

Other KH Events

Seven other KH events were analyzed, most of which yielded similar results. These are summarized in the table below. For a GMAG station to be listed, at least three consecutive periods had to match the THEMIS data.

Date	THEMIS Probe	Shift of THEMIS Data (sec)	GMAG Station
04/15/2008	C	+110	BRW
04/19/2008	C	+370	BRW/KIAN
10/06/2011	A	+165	FSIM/INUV/KAKO
02/10/2012	E	-	None Found
02/18/2012	A/D	+465	FSIM/SNAP/YKC
03/15/2013 (i)	D	+95	FSMI/GJOA
03/15/2013 (ii)	D/E	+170/+110	PG2/PG3
05/06/2013 (shown)	A	+140	SNKQ

Discussion and Conclusion

In nearly all of the events analyzed, waves observed by THEMIS could be matched with waves observed by GMAGs. We conclude that KW waves are capable of propagating through the magnetosphere to the ground. It remains to be seen in what percentage of the time these waves actually reach the ground, and over what area they are observable. However, this may be difficult, since to identify the waves, an arbitrary decision on the number of periods to match must be made. That decision could drastically affect the results of the study. Additionally, the relative scarcity of GMAGs may cause waves to be unobserved even when they are reaching the ground. Finally, though we have seen that KH waves are indeed capable of propagation through the magnetosphere, we must still determine the extent to which they facilitate energy transport.

References

[1] Hasegawa, Hiroshi. "Structure and Dynamics of the Magnetopause and Its Boundary Layers." Monographs on Environment, Earth and Planets Monogr. Environ. Earth Planets 1.2 (2012): 71-119.
[2] Hyatt, Emily. "Projected Ionospheric Location and Travel Time of Kelvin-Helmholtz Instabilities Occurring at the Low Latitude Boundary Layer." Embry-Riddle Aeronautical University, 2012.
[3] Kavosi, Shiva, and Joachim Raeder. "Ubiquity of Kelvin–Helmholtz Waves at Earth's Magnetopause." Nature Communications 6 (2015)