On the Causality of Chorus Wave Acceleration:

A Remarkable Correlation Between Storm-time ULF wave Power Profiles and the POES VLF Chorus Wave Proxy

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AGU Chapman, Cascais, 2018

Outline

Two main mechanisms for acceleration of electrons in radiation belt:

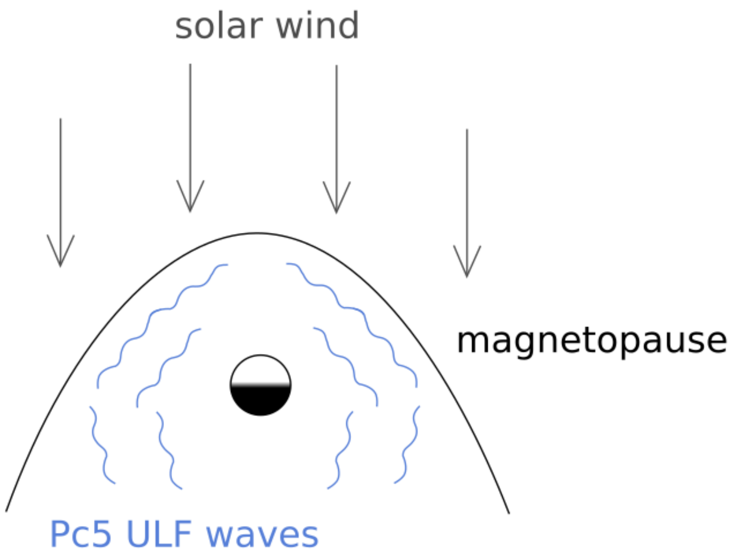
ULF waves VLF Chorus waves

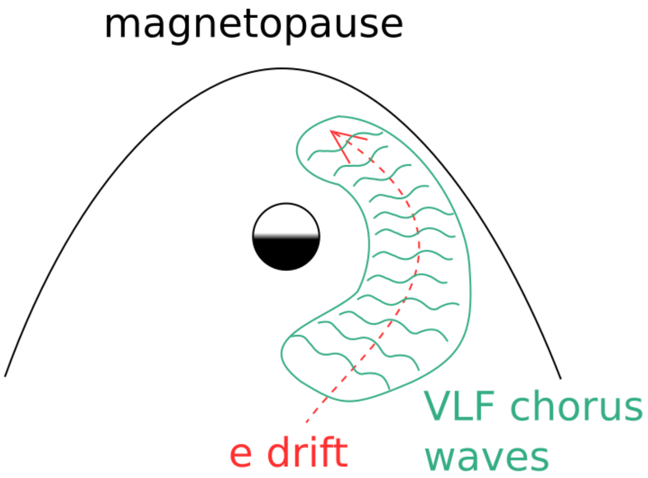
We measure ULF waves on the ground and compare them to previous VLF (proxy) study.

Striking similarities emerge.

Reasons are hypothesized.

ULF and Chorus waves in the magnetosphere





Targets

We will be revisiting two sets of acceleration events, from Li et al. [2015]*, analysed based on VLF wave proxy calculated using POES electron precipitation data.

16
Efficient acceleration events

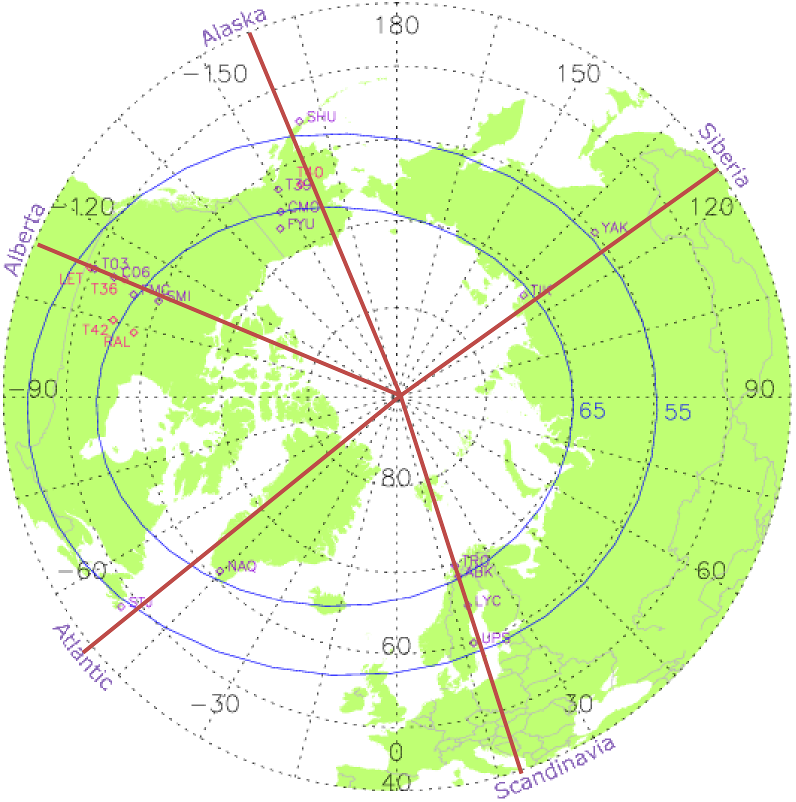
EA

17
Inefficient acceleration events

IA

* Li, W., R. M. Thorne, J. Bortnik, D. N. Baker, G. D. Reeves, S. G. Kanekal, H. E. Spence, and J. C. Green (2015), Solar wind conditions leading to efficient radiation belt electron acceleration: A superposed epoch analysis, *Geophys. Res. Lett.*, *42*, 6906

Magnetometers used

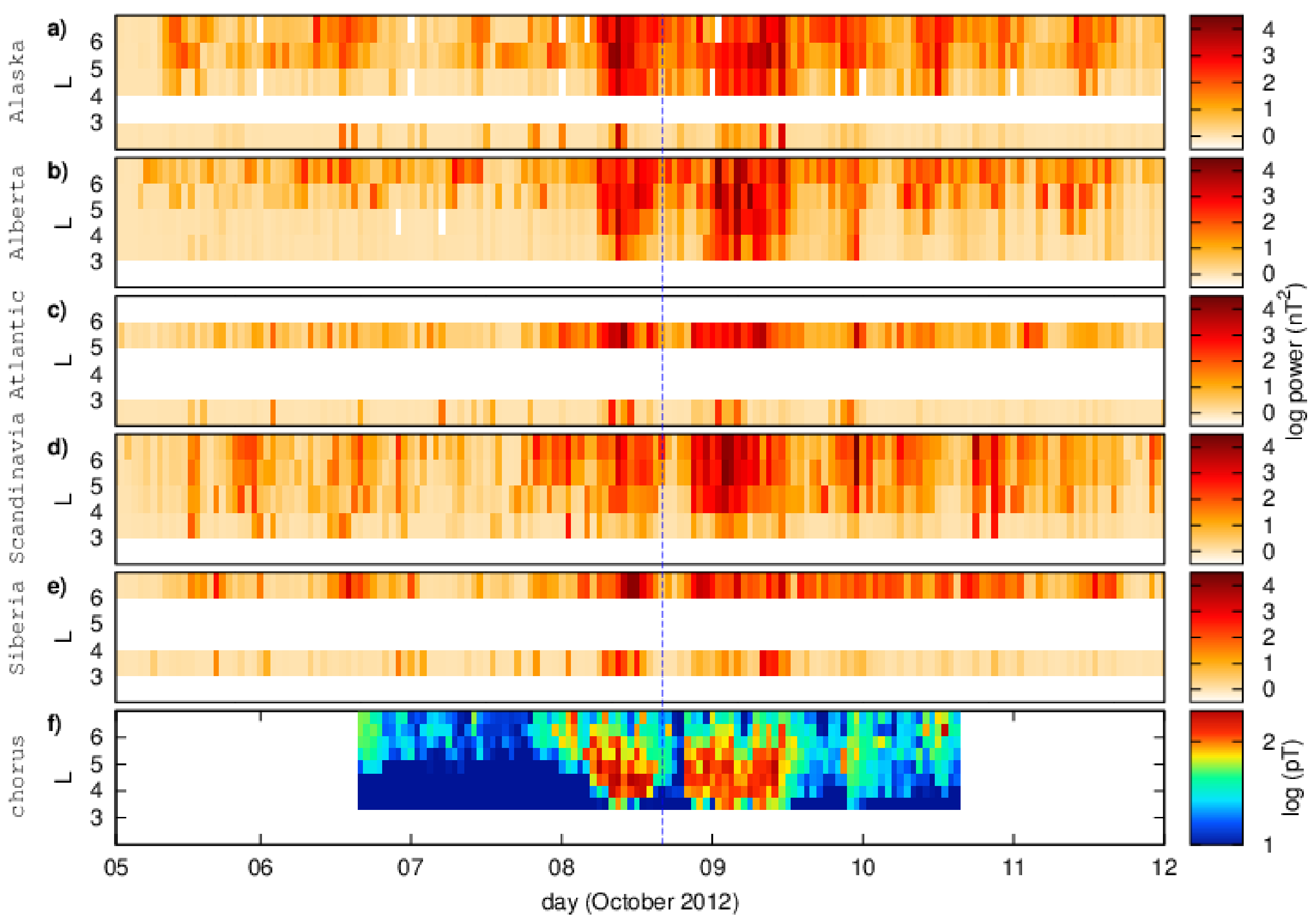


Code	Name	Geo. Lat.(°)N	Geo. Lon.(°)E	GCM Lat.(°)N	GCM Lon.(°)E	L-shell	primary operator
Alaska							
FYU	Fort Yukon	66.56	214.79	67.65	267.17	6.85	GIMA
CMO	College	64.87	212.14	65.45	266.18	5.77	GIMA
T39	Trapper Creek	62.30	209.80	62.37	265.76	4.65	THEMIS
SHU	Shumagin	55.38	199.54	53.29	260.26	2.83	INTERMAGNET
Alberta							
SMI	Fort Smith	60.03	248.07	67.47	307.71	6.74	CARISMA
FMC	Fort McMurray	56.66	248.79	64.28	309.98	5.3	CARISMA
C06	Ministik Lake	53.35	247.03	60.64	308.76	4.19	CARISMA
T03	Vulcan	50.37	247.02	57.60	309.60	3.53	CARISMA
Atlantic							
NAQ	Narssarssuaq	61.16	314.56	65.75	43.19	5.8	DTUSpace
STJ	St Johns	47.60	307.32	52.60	31.64	2.72	CANMOS
Scandinavia							
TRO	Tromso	69.66	18.94	67.07	102.77	6.56	IMAGE
ABK	Abisko	68.35	18.82	65.74	101.70	5.9	IMAGE
LYC	Lycksele	64.61	18.75	61.87	99.33	4.49	IMAGE
UPS	Uppsala	59.90	17.35	56.88	95.95	3.35	IMAGE
Siberia							
TIK	Tixie	71.59	128.78	66.70	198.71	6.4	RAPIDMAG
YAK	Yakutsk	60.02	129.72	54.88	202.60	3.05	GFZ
Additional stations							
T40	McGrath	63.00	204.40	62.16	260.84	4.59	THEMIS
RAL	Rabbit Lake	58.22	256.32	67.00	319.92	6.46	CARISMA
T42	La Ronge	55.15	254.84	63.76	318.65	5.1	THEMIS
T36	Athabasca	54.71	246.69	61.95	307.91	4.54	THEMIS
LET	Lethbridge	49.64	247.13	56.88	309.93	3.39	AUTUMN

One EA Event

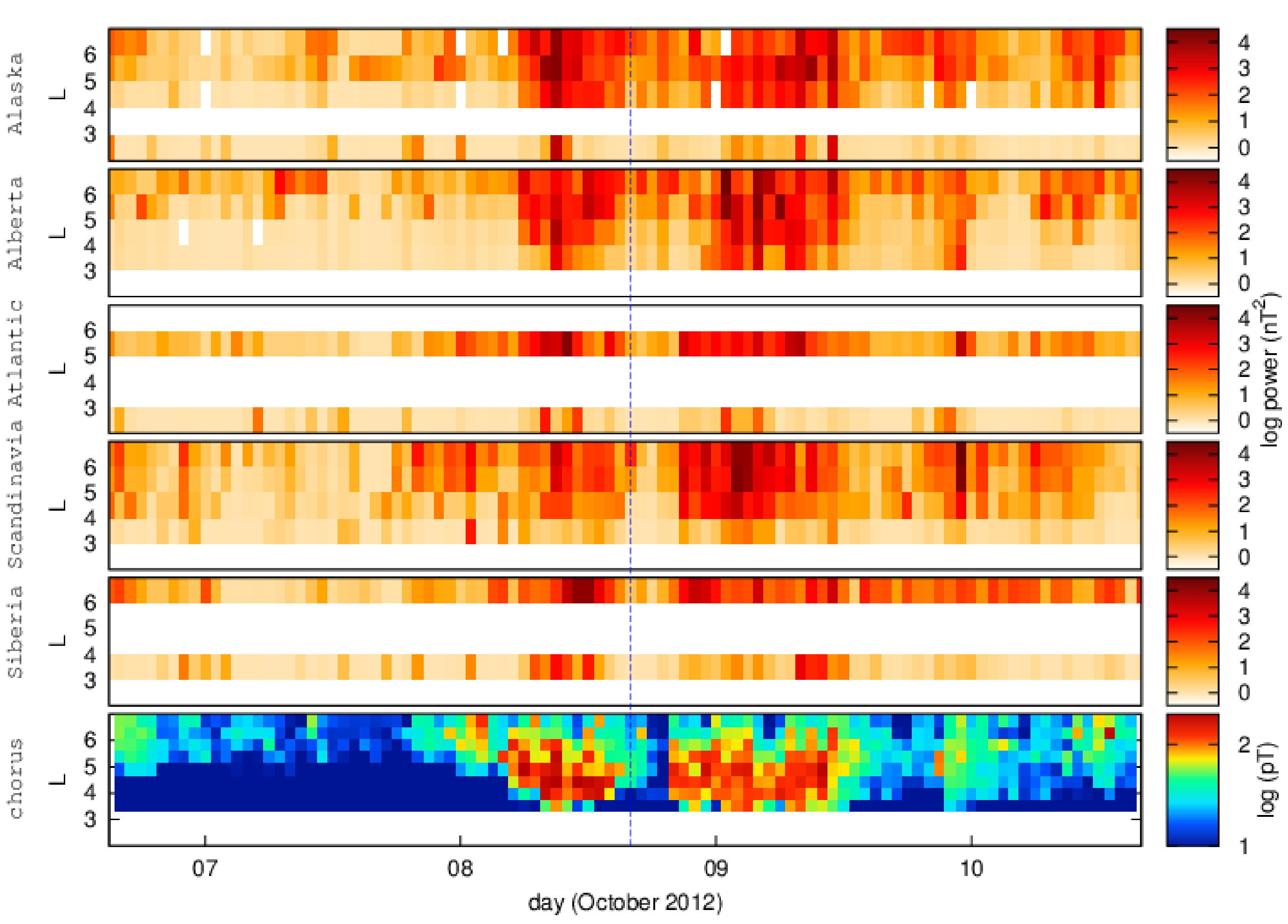
8-9 October 2012 storm.

ULF Pc5 wave power and VLF Chorus wave amplitudes, averaged over all MLT sectors.



Same EA Event

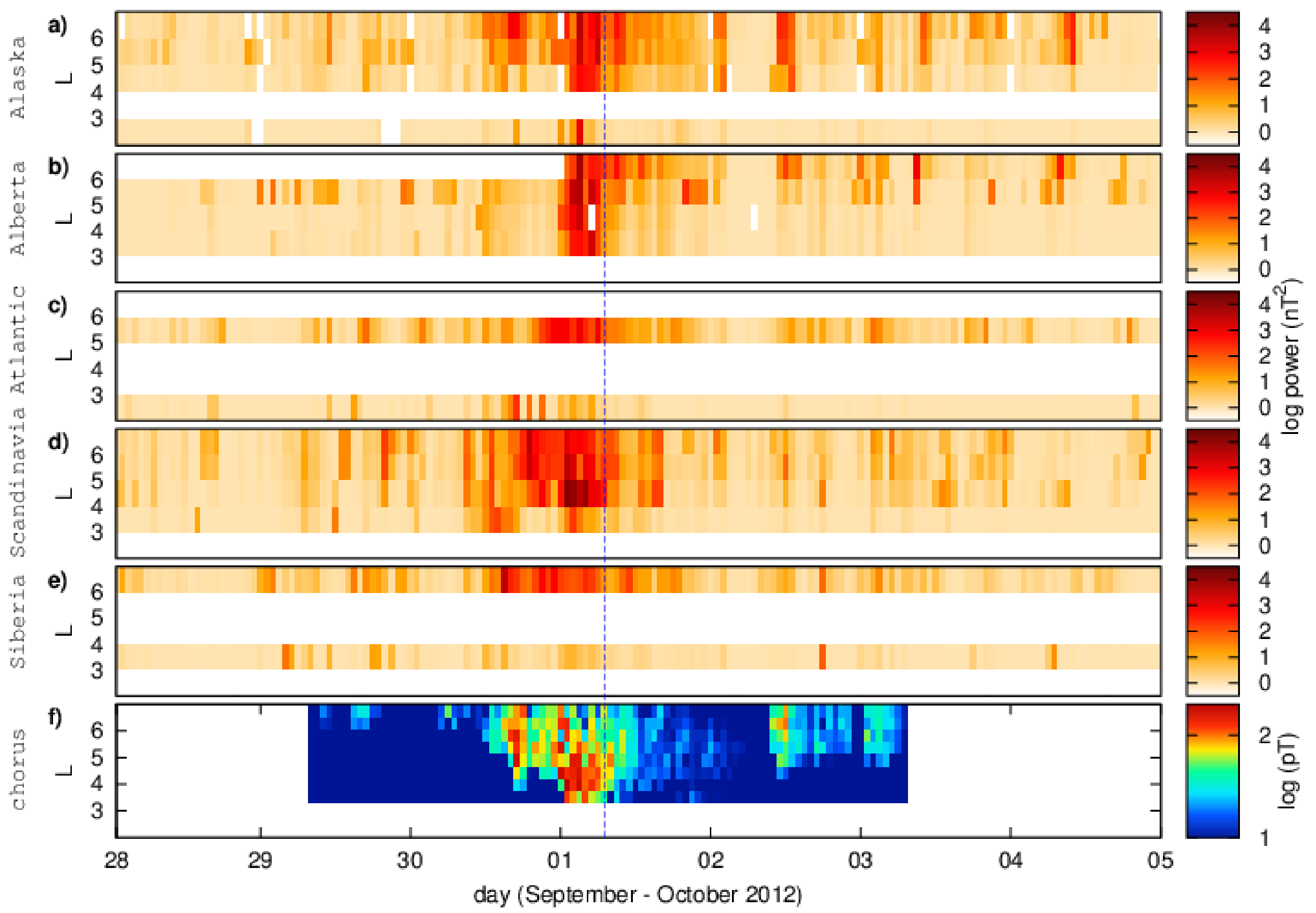
Zoomed in



One IA Event

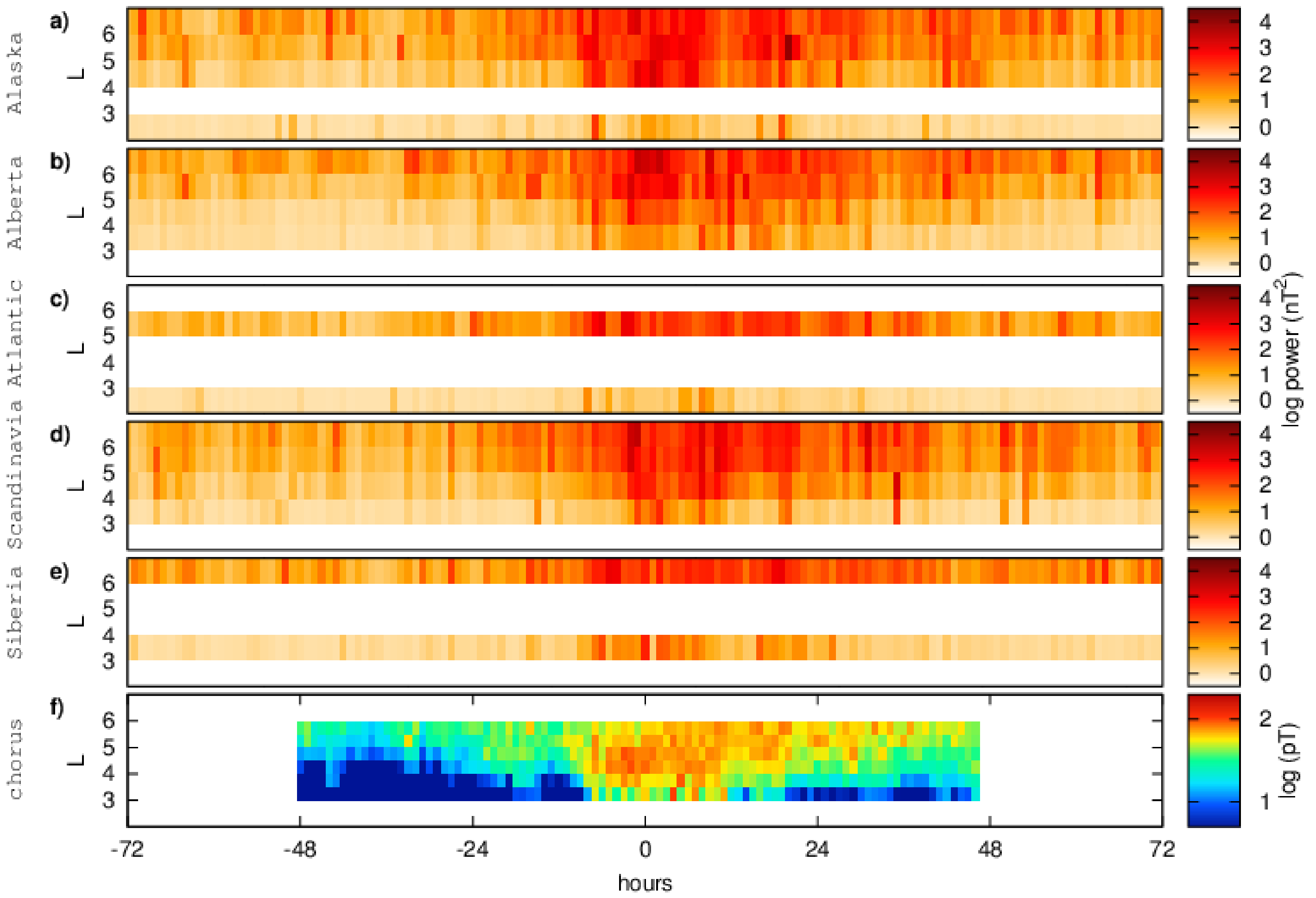
1 October 2012 storm.

ULF Pc5 wave power and VLF Chorus wave amplitudes, averaged over all MLT sectors.



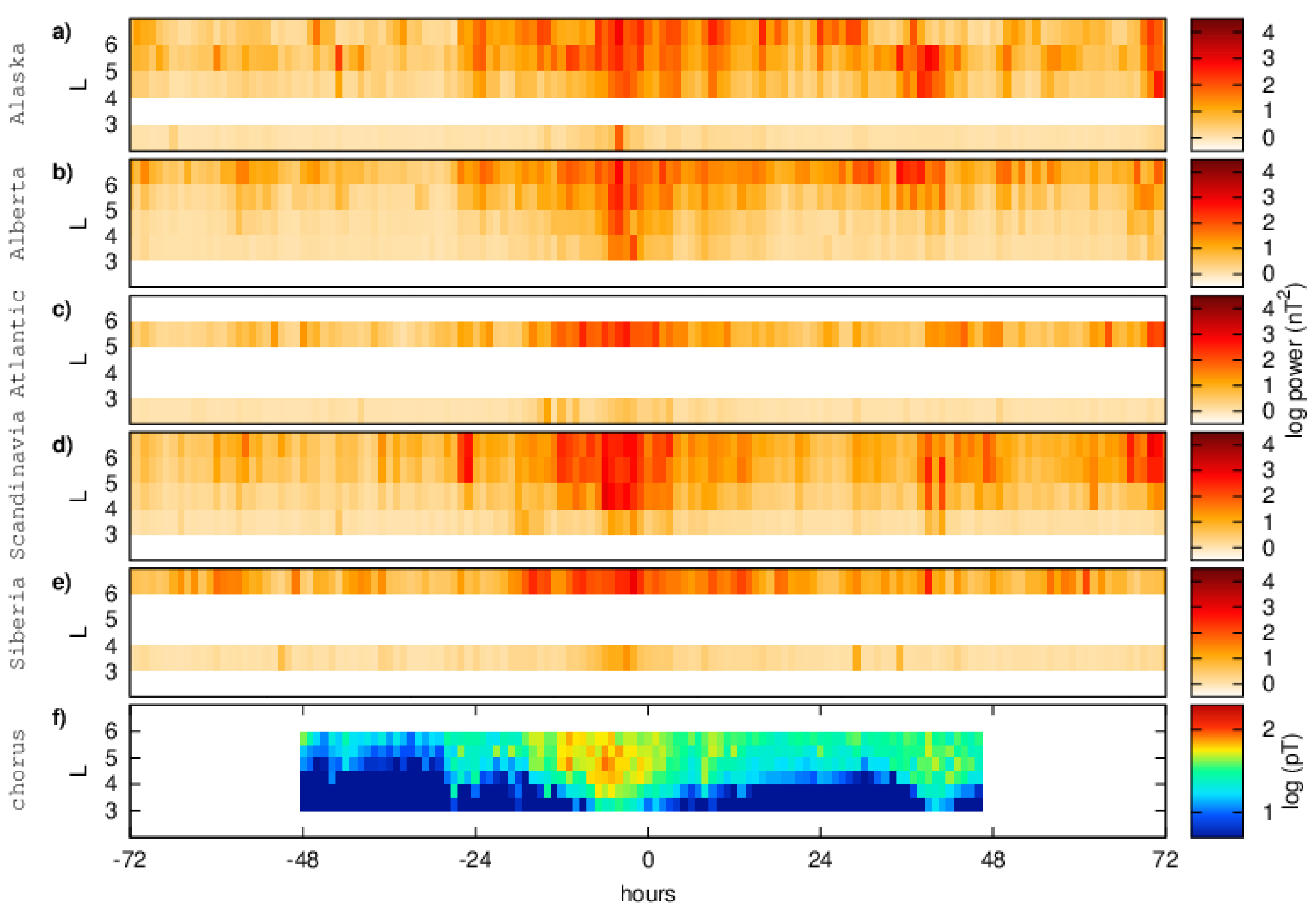
Superposed EA

Superposition of efficient acceleration events, with the x-axis centered on their zero epochs.



Superposed IA

Superposition of inefficient acceleration events, with the x-axis centered on their zero epochs.



Possible explanations

1. Chorus waves emerge first and cause a growth of ULF waves
2. ULF waves emerge first and cause a growth of chorus waves
3. Both ULF and chorus waves are caused by some solar wind or magnetosphere/ionosphere coupling driver in the same place at the same time
4. ULF waves affect precipitation, which is used as a proxy to determine the presence of Chorus waves

1. Chorus cause ULF

Energetically implausible.

2. ULF cause chorus

Plausible.

Compressional Pc4-5 pulsations have been found to produce conditions that encourage the production of chorus waves [e.g. Li et al 2011]*.

Jaynes et al. [2015]**, for example, while studying a substorm injection and its associated pulsating aurora, observed concurrent ULF and chorus waves with in situ measurements over Poker Flat, Alaska, with the ULF waves having twice the periodicity of the chorus waves.

* Li, W., R. M. Thorne, J. Bortnik, Y. Nishimura, and V. Angelopoulos (2011), Modulation of whistler mode chorus waves: 1. Role of compressional Pc4-5 pulsations, *Journal of Geophysical Research (Space Physics)*, *116*, A06205

** Jaynes, A. N., M. R. Lessard, K. Takahashi, A. F. Ali, D. M. Malaspina, R. G. Michell, E. L. Spanswick, D. N. Baker, J. B. Blake, C. Cully, E. F. Donovan, C. A. Kletzing, G. D. Reeves, M. Samara, H. E. Spence, and J. R. Wygant (2015), Correlated Pc4-5 ULF waves, whistler-mode chorus, and pulsating aurora observed by the Van Allen Probes and ground-based systems, *Journal of Geophysical Research (Space Physics)*, *120*, 8749-8761

3. Both emerge simultaneously

Plausible.

Both have been observed under similar geomagnetic conditions.

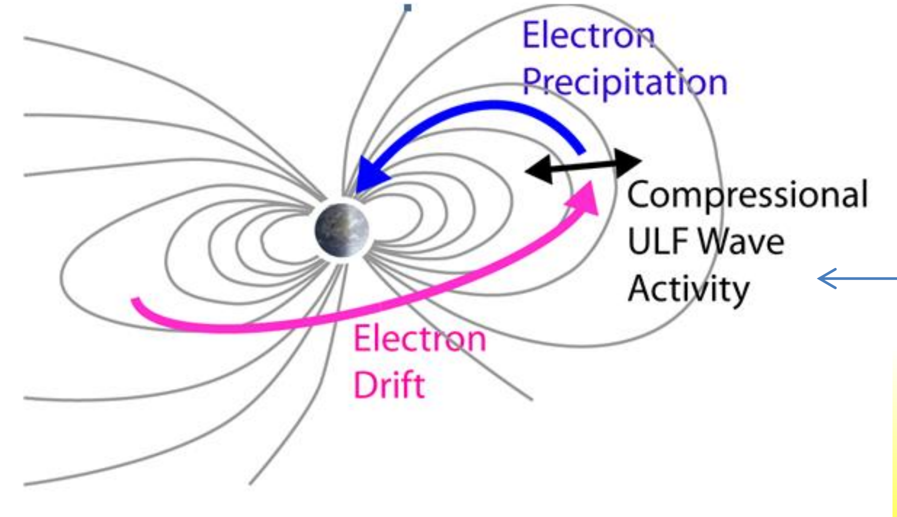
Further modeling is needed to ascertain whether certain drivers can produce near-identical ULF and VLF responses.

4. ULF contaminate chorus proxy

Theoretically plausible.

Requires mechanism with which ULF waves directly cause precipitation.

Such possible mechanism proposed by Rae et al. [2018]*

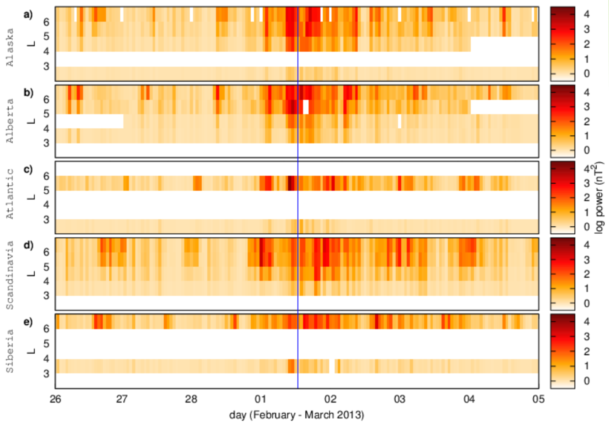


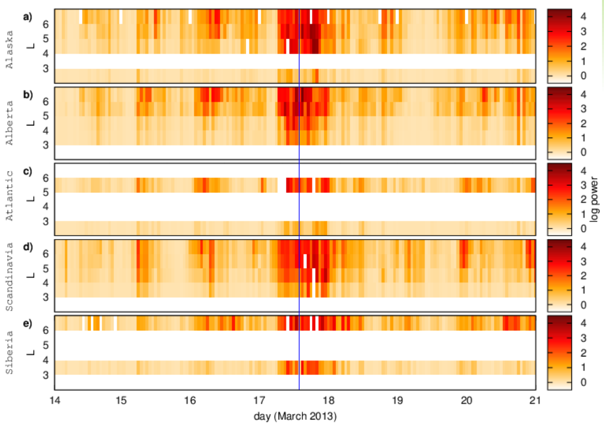
* Rae, I. J., K. R. Murphy, C. E. J.Watt, A. J. Halford, I. R. Mann, L. G. Ozeke, D. G. Sibeck, M. A. Clilverd, C. J. Rodger, A. W. Degeling, and H. J. Singer (2018), The role of compressional Ultra-Low Frequency waves in energetic electron precipitation, *Journal of Geophysical Research (Space Physics)*, *in press*.

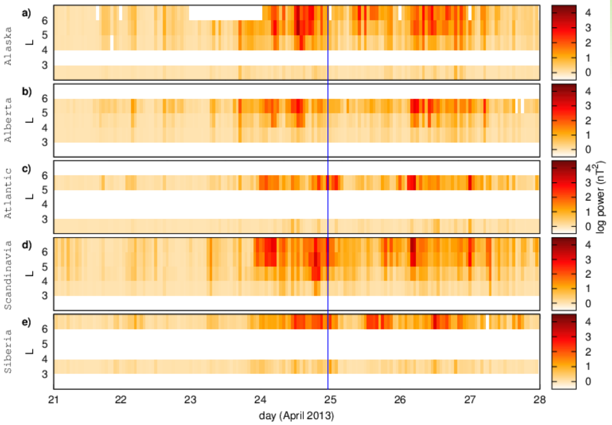
Summary / Conclusions

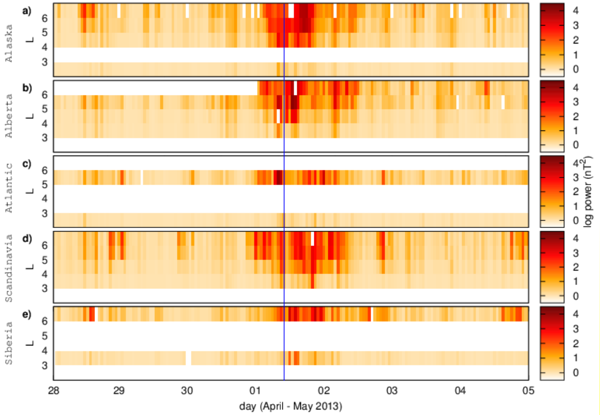
- Pc5 ULF power distributions almost identical to POES VLF proxy for all studied storms
- ULF waves are either:
  - responsible for the generation of concurrent VLF waves
  - produced by a common driver along with VLF waves
  - contaminating the VLF chorus wave proxy
- Further simulations needed to ascertain the relative importance of ULF and VLF waves on particle acceleration in the radiation belts.

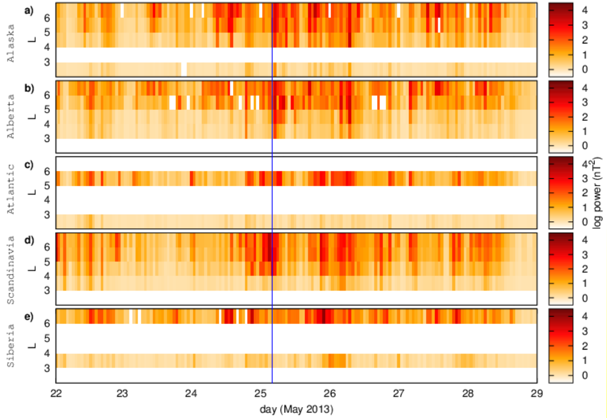
Extra Slides I: All EA events

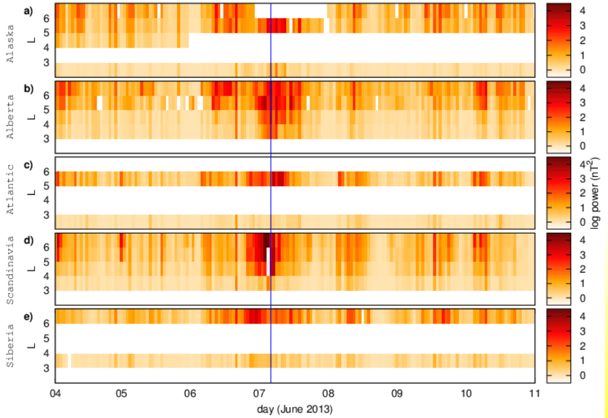




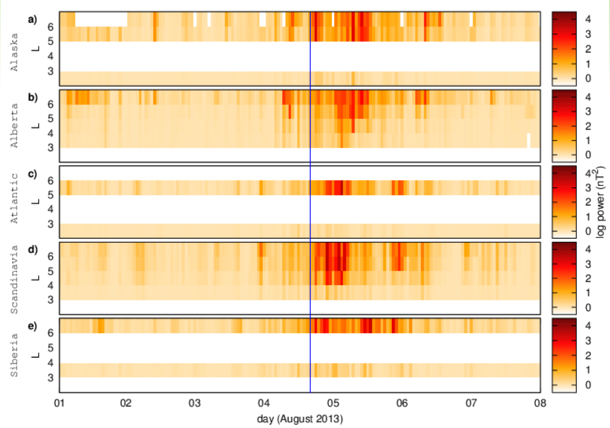


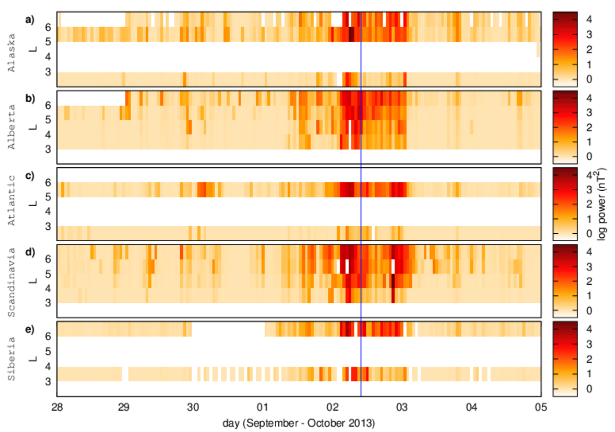


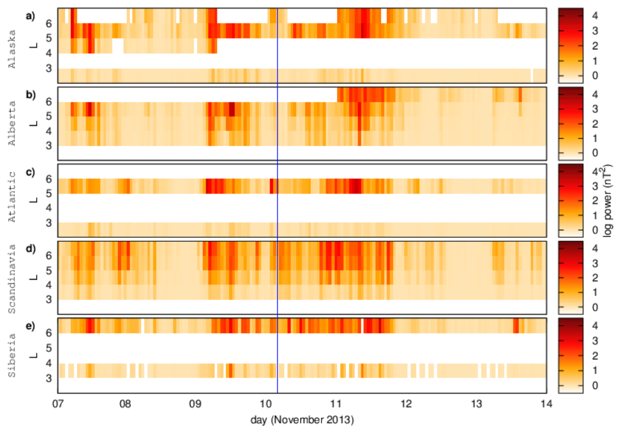


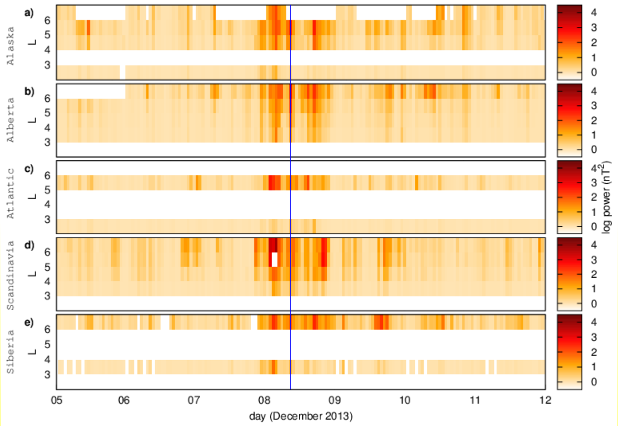


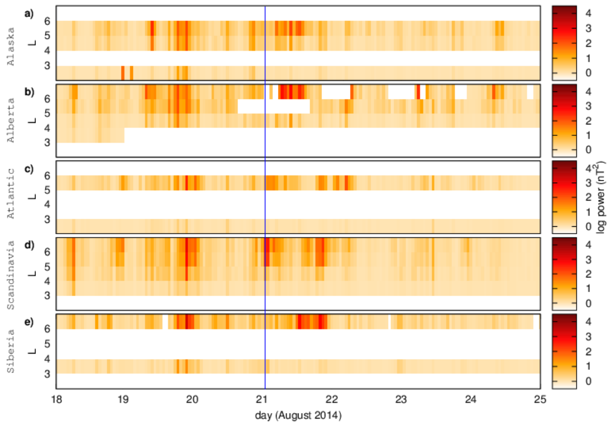
Extra Slides II: All EA events

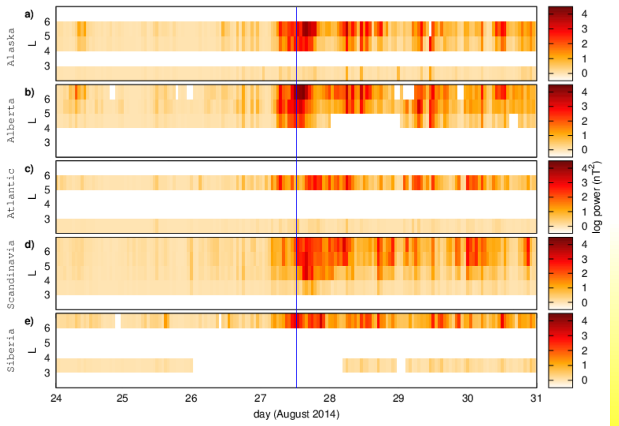




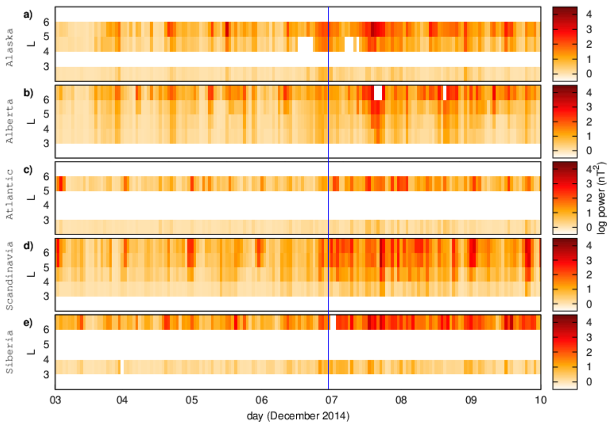


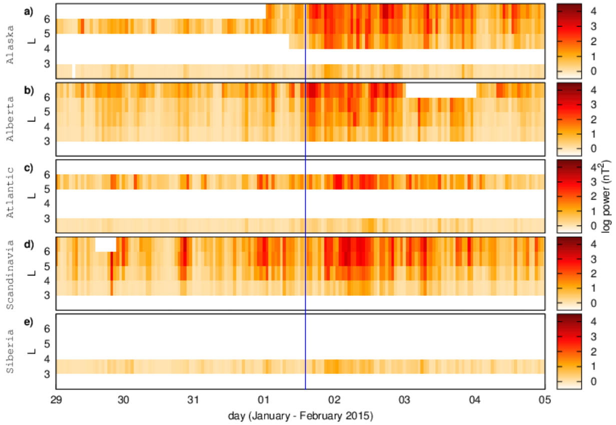


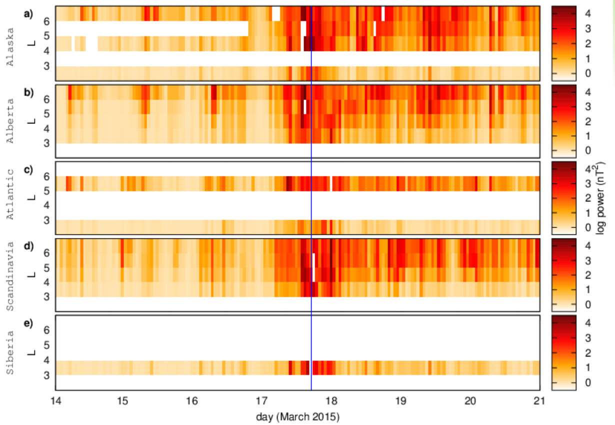


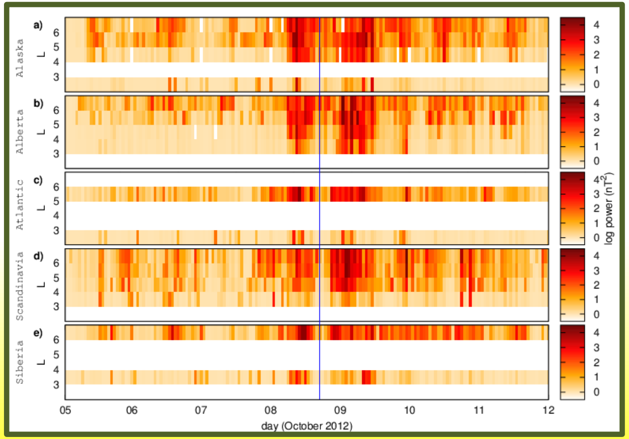


Extra Slides III: All EA events

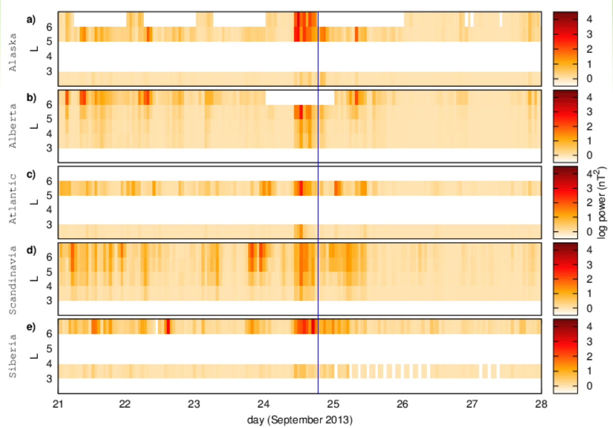


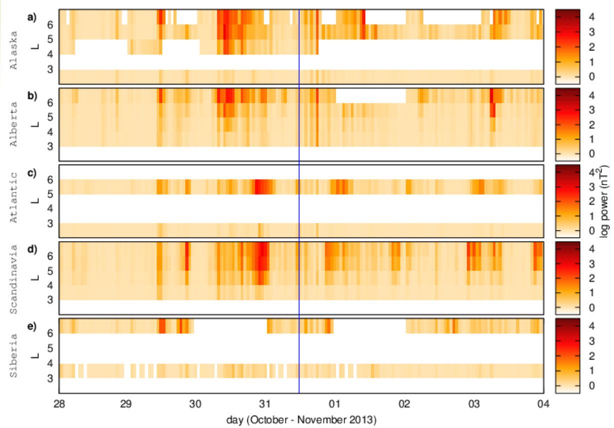


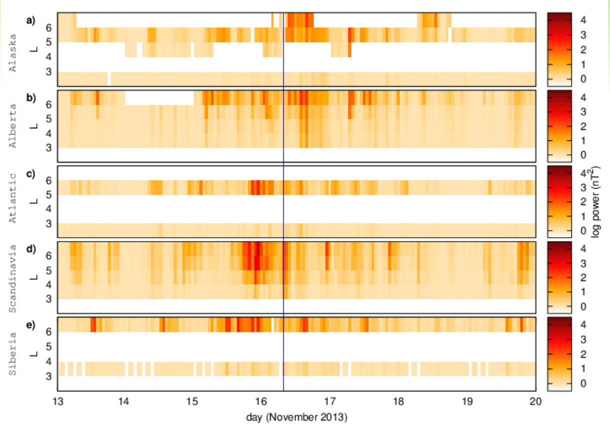


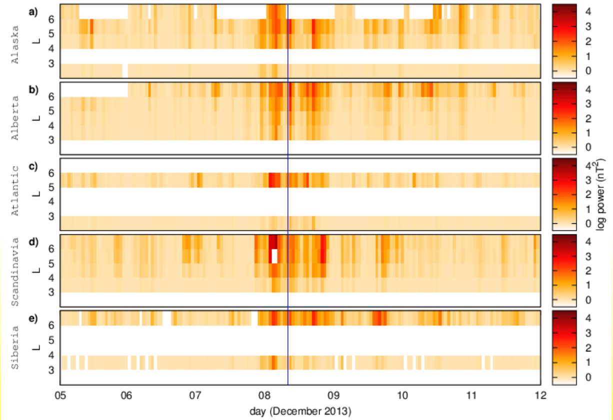


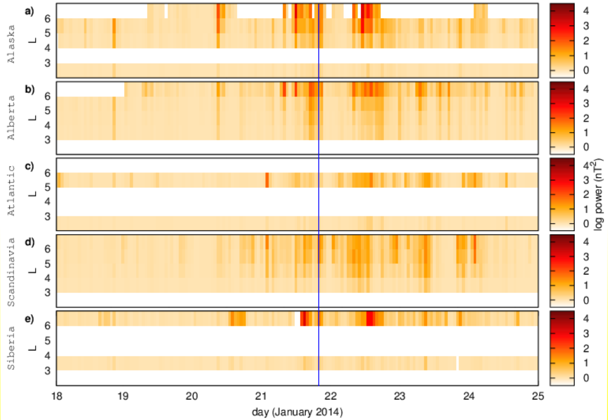
Extra Slides IV: All IA events

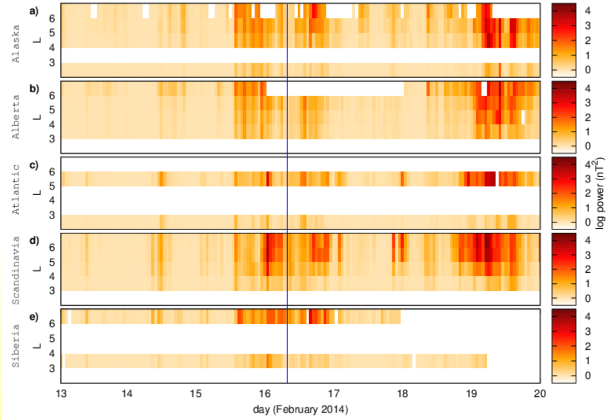




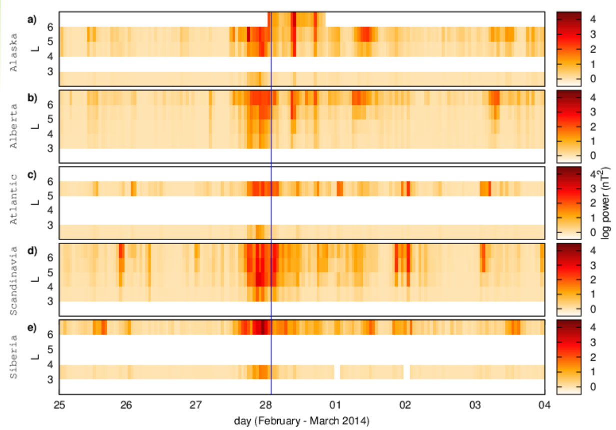


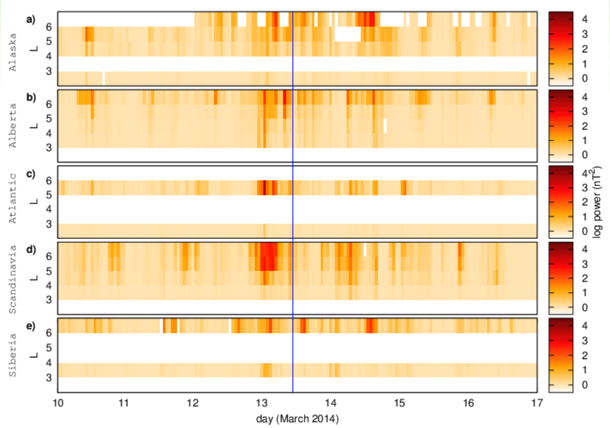


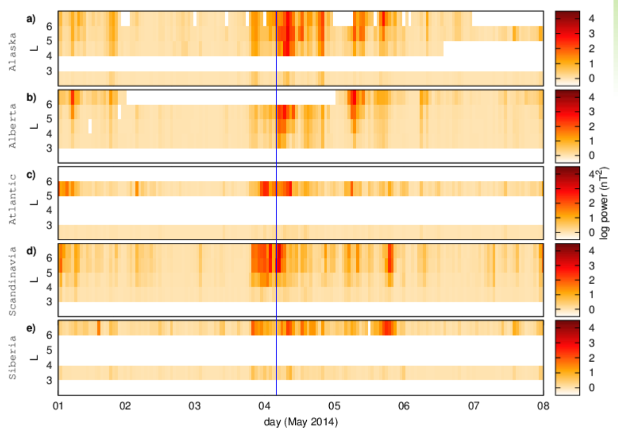


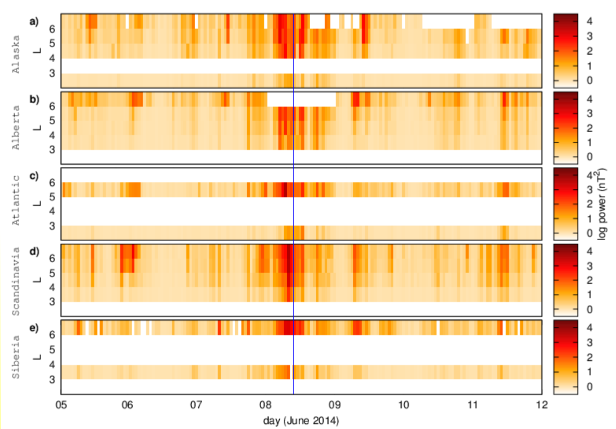


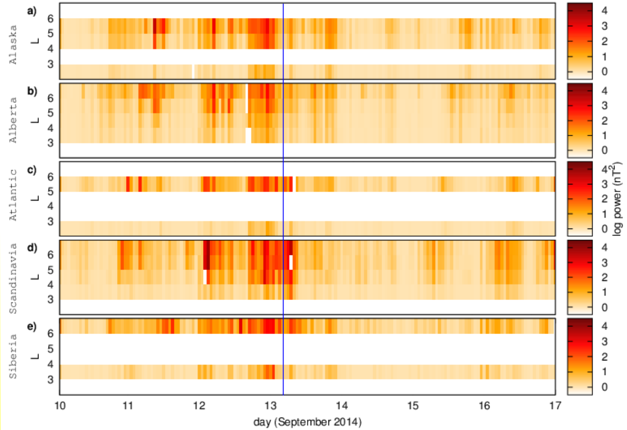
Extra Slides V: All IA events

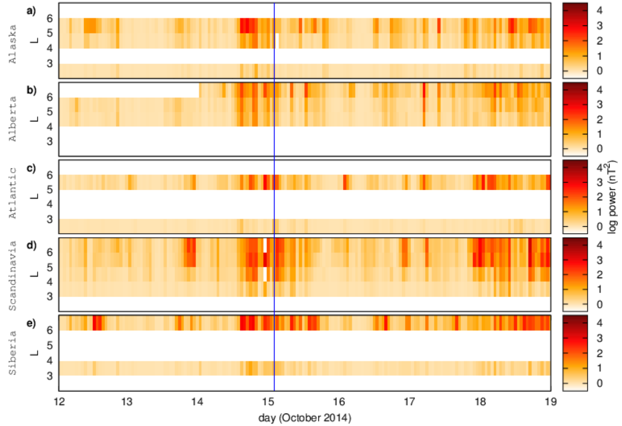












Extra Slides VI: All IA events