Intensity of Relativistic Electron Microbursts

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(3) British Antarctic Survey (NERC), Cambridge, UK

(4) The Aerospace Corporation, El Segundo CA, USA

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Unfortunately, Emma could not come to this meeting

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Introduction: Microbursts

- Short duration (< 1 s)
- Preferential occurrence in the dawn sector
- Contained to radiation belt (*L* = 3-8)
- Occur outside the plasmapause
- Can occur in trains of numerous bursts

A single large storm of microbursts can potentially empty the entire outer radiation belt relativistic electron population

For more detail see: Nakamura *et al.*, JGR, 2000; Lorentzen *et al.*, GRL, 2001; O'Brien *et al.,* JGR, 2003; Johnston and Anderson, JGR, 2010

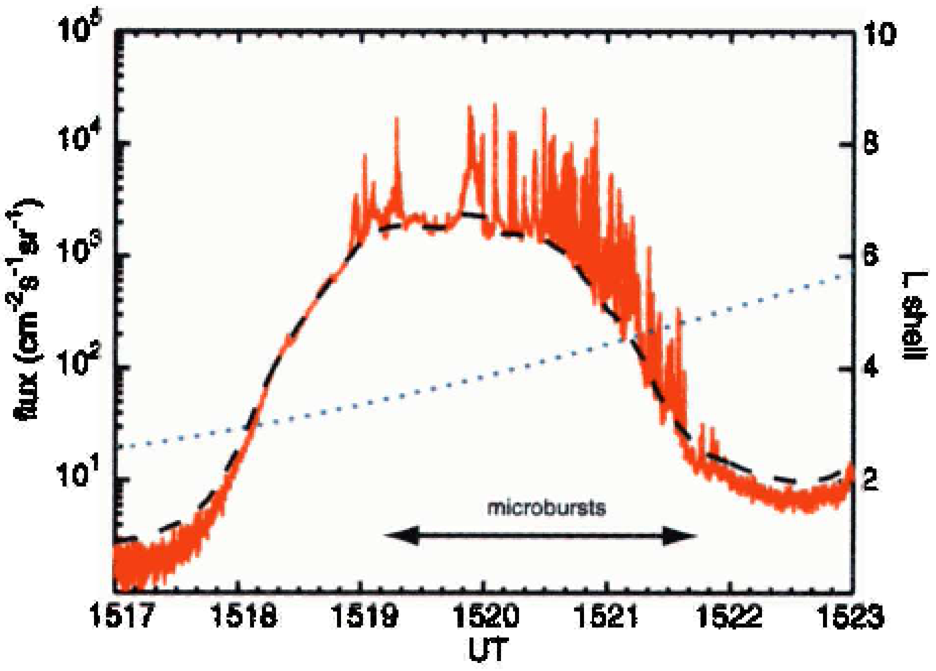

Figure 1. Electrons >1 MeV microbursts on October 19, 1998 (red). The satellite was in zenith-pointing mode at this time, so the instrument was looking approximately along the field lines at the microburst precipitation. The black dashed line shows our estimate of the locally trapped population and the blue dotted line shows the position in *L* shell.

Lorentzen *et al.,* GRL, 2001

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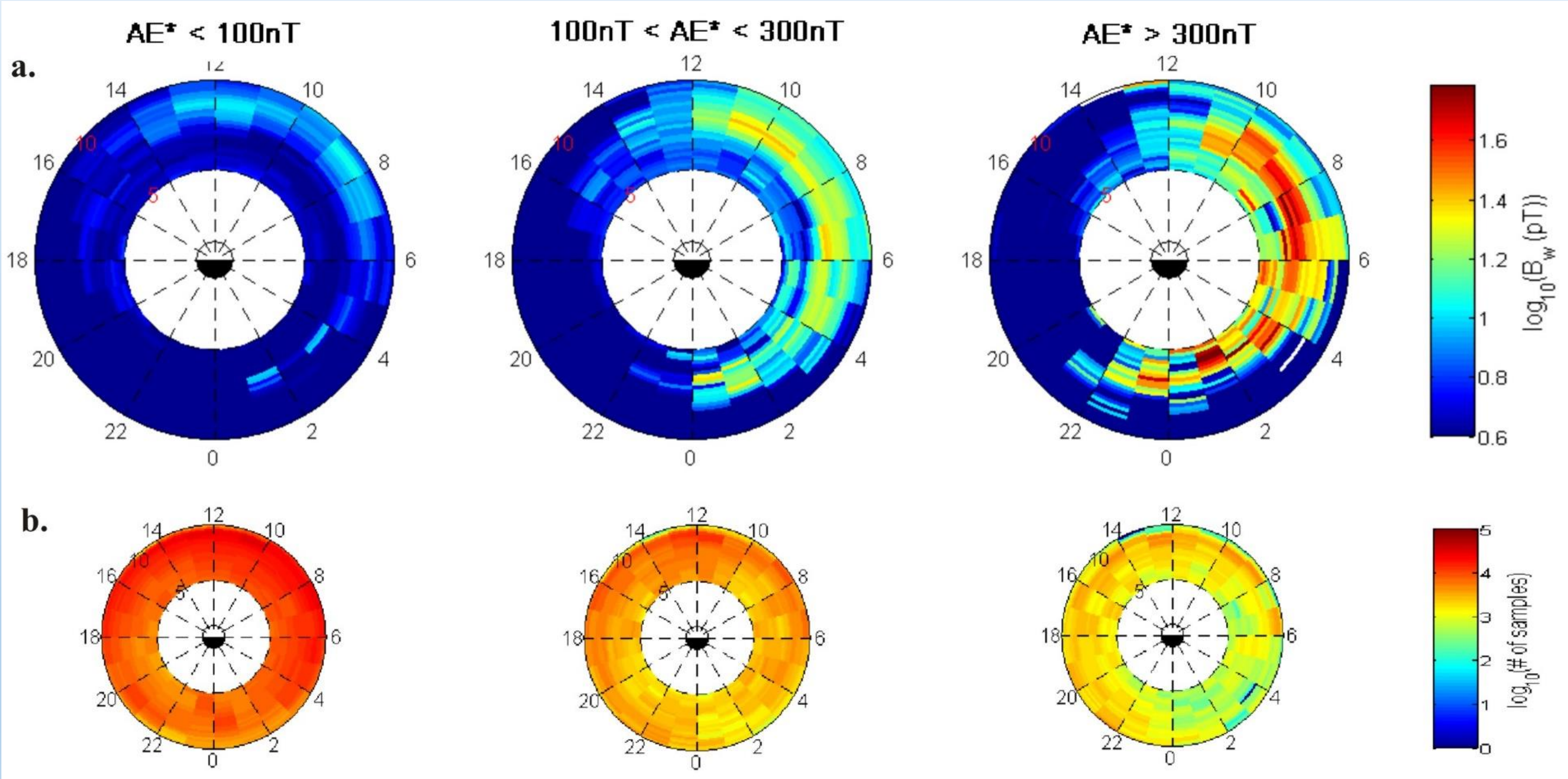
Introduction: Chorus waves

It is believed that relativistic microbursts are a result of whistler mode Chorus waves.

[e.g., Thorne *et al.*, JGR, 2005; Breneman *et al.*, GRL, 2017; Mozer *et al.*, GRL, 2018]

Chorus is usually found between 0.1 - 0.8 f_{ce} (electron gyrofrequency), with a gap at 0.5 f_{ce}.



Li *et al.,* GRL, 2009 (Figure 2 - modified)

Introduction: EMIC waves

Relativistic electron microbursts due to nonlinear pitch angle scattering by EMIC triggered emissions

Yoshiharu Omura[1] and Qinghua Zhao[1]

Received 17 May 2013; revised 5 July 2013; accepted 28 July 2013; published 13 August 2013.

[1] We show that the anomalous cyclotron resonance between relativistic electrons and electromagnetic ion cyclotron (EMIC) triggered emissions takes place very effectively near the magnetic equator because of the variation of the ambient magnetic field. Efficient precipitations are caused by nonlinear trapping of relativistic electrons by electromagnetic wave potentials formed by EMIC triggered emissions. We derive the necessary conditions of the wave amplitude, kinetic energies, and pitch angles that must be satisfied for the nonlinear wave trapping. We have conducted test particle simulations with a large number of relativistic electrons trapped by a parabolic magnetic field near the magnetic equator. In the presence of coherent EMIC-triggered emissions with increasing frequencies, a substantial amount of relativistic electrons is trapped by the wave, and the relativistic electrons at high pitch angles are guided to lower pitch angles within a short time scale much less than a second, resulting in rapid precipitation of relativistic electrons or relativistic electron microbursts.

Citation: Omura, Y., and Q. Zhao (2013), Relativistic electron microbursts due to nonlinear pitch angle scattering by EMIC triggered emissions, *J. Geophys. Res. Space Physics*, *118*, 5008–5020, doi:10.1002/jgra.50477.

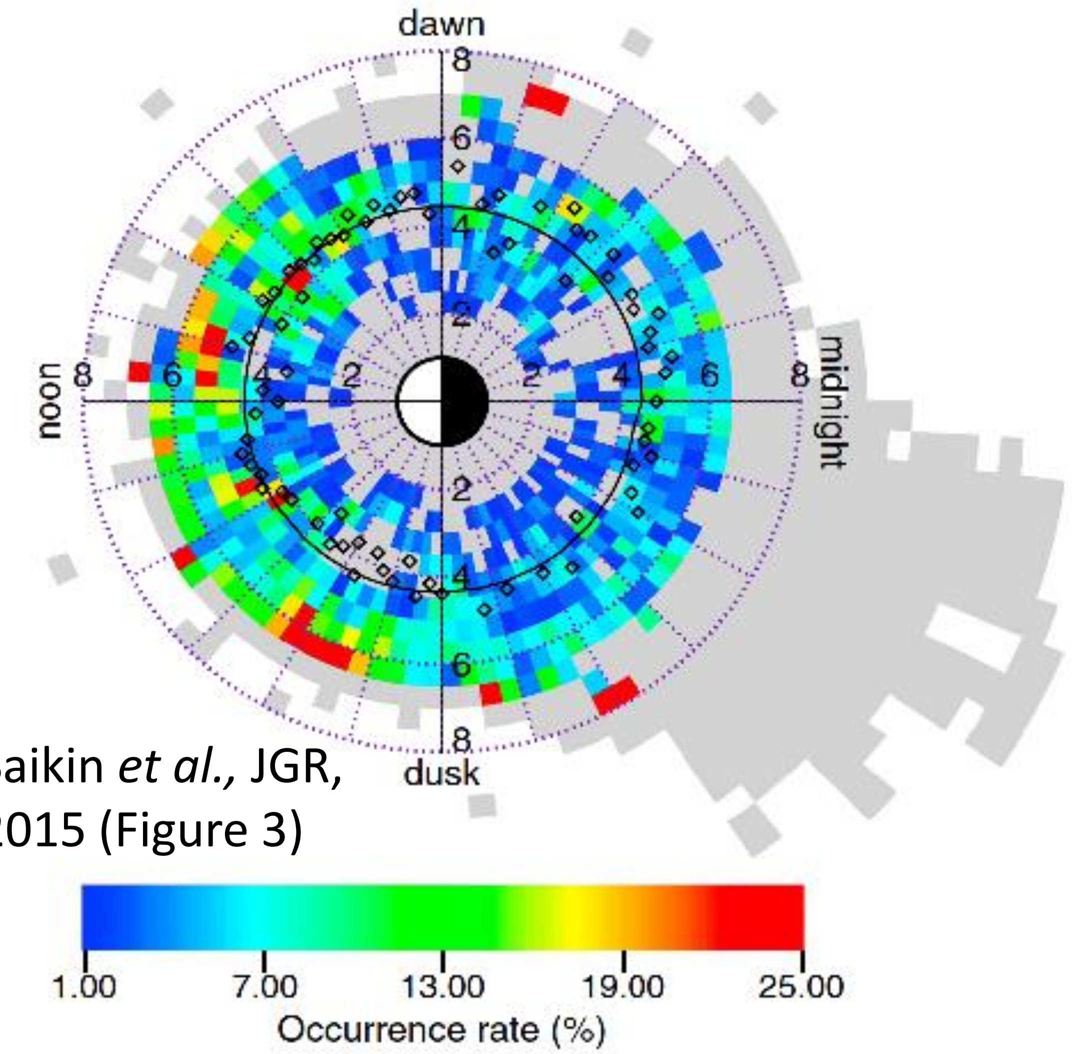
Omura and Zhao, JGR, 2013

Introduction: EMIC waves

- ElectroMagnetic Ion Cyclotron (EMIC) waves are in the Pc1 – Pc2 range (0.1 – 5 Hz).

- Previously thought to be restricted from noon to dusk regions. However, Saikin *et al.* [JGR, 2015] show a greater distribution in MLT from RBSP observations.

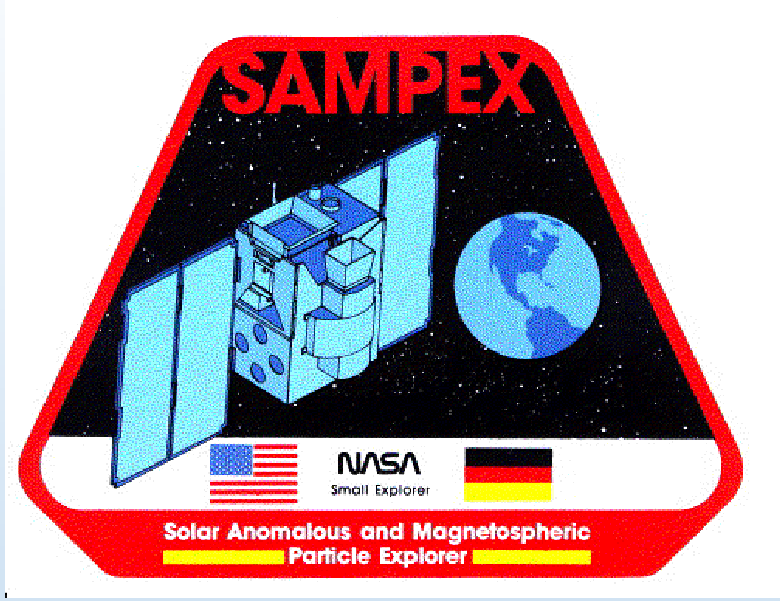
EMIC occurrence Sept. 2012 – June 2014



Saikin *et al.*, JGR, 2015 (Figure 3)

Introduction: SAMPEX

- The Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX)
- Launched in July 1992 into a **low altitude orbit** (520 – 670 km), with an inclination of 82°.
- Heavy Ion Large Telescope (HILT) instrument onboard, which can detect **> 1 MeV electrons**.



http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=1992-038A

Further material on the SAMPEX satellite can be found in Klecker *et al.*, 1993; Blake *et al.*, 1996

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Introduction: Microburst algorithm

We aim to investigate the distribution of relativistic electron microburst occurrence in the Earth's outer radiation belts.

- O'Brien *et al.*, JGR, 2003 algorithm is used to detect microbursts
  - Has been used by several others [e.g. Johnston and Anderson, JGR, 2010; Blum *et al.*, JGR, 2015].

$$\frac{N_{100} - A_{500}}{\sqrt{1 + A_{500}}} > 10 \, ,$$

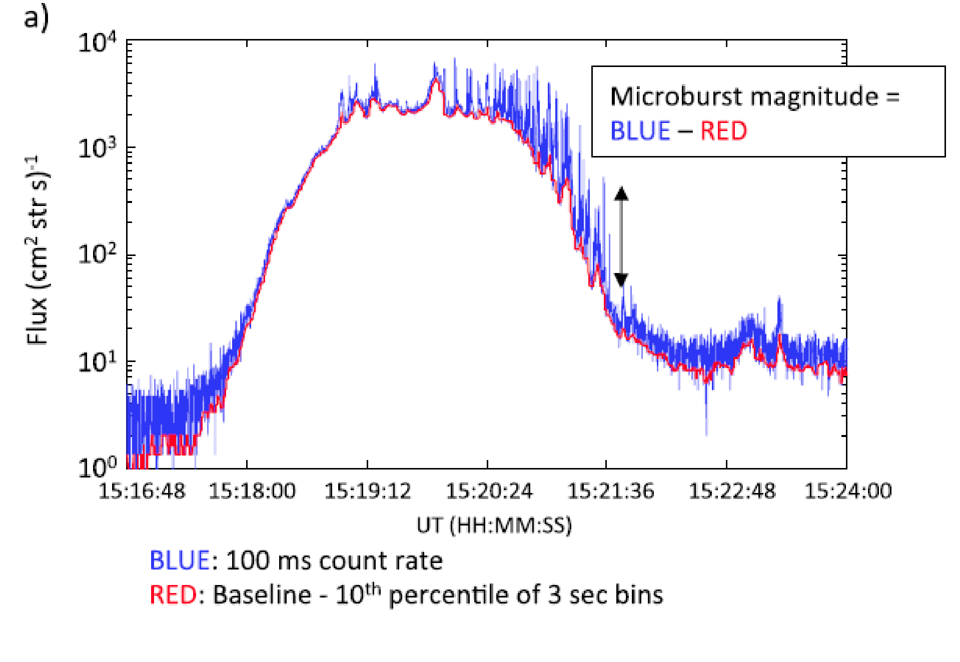
where the N_{100} is the number of counts in 100 ms and A_{500} is the centered running average of N_{100} over five 100 ms intervals (i.e., 0.5 s).

- Calculate baseline flux (10th percentile in 3 s bins) [Blum *et al.*, JGR, 2015]
- Intensity = flux – baseline
- Applied to the SAMPEX HILT >1MeV electron flux observations from 1996 – 2007

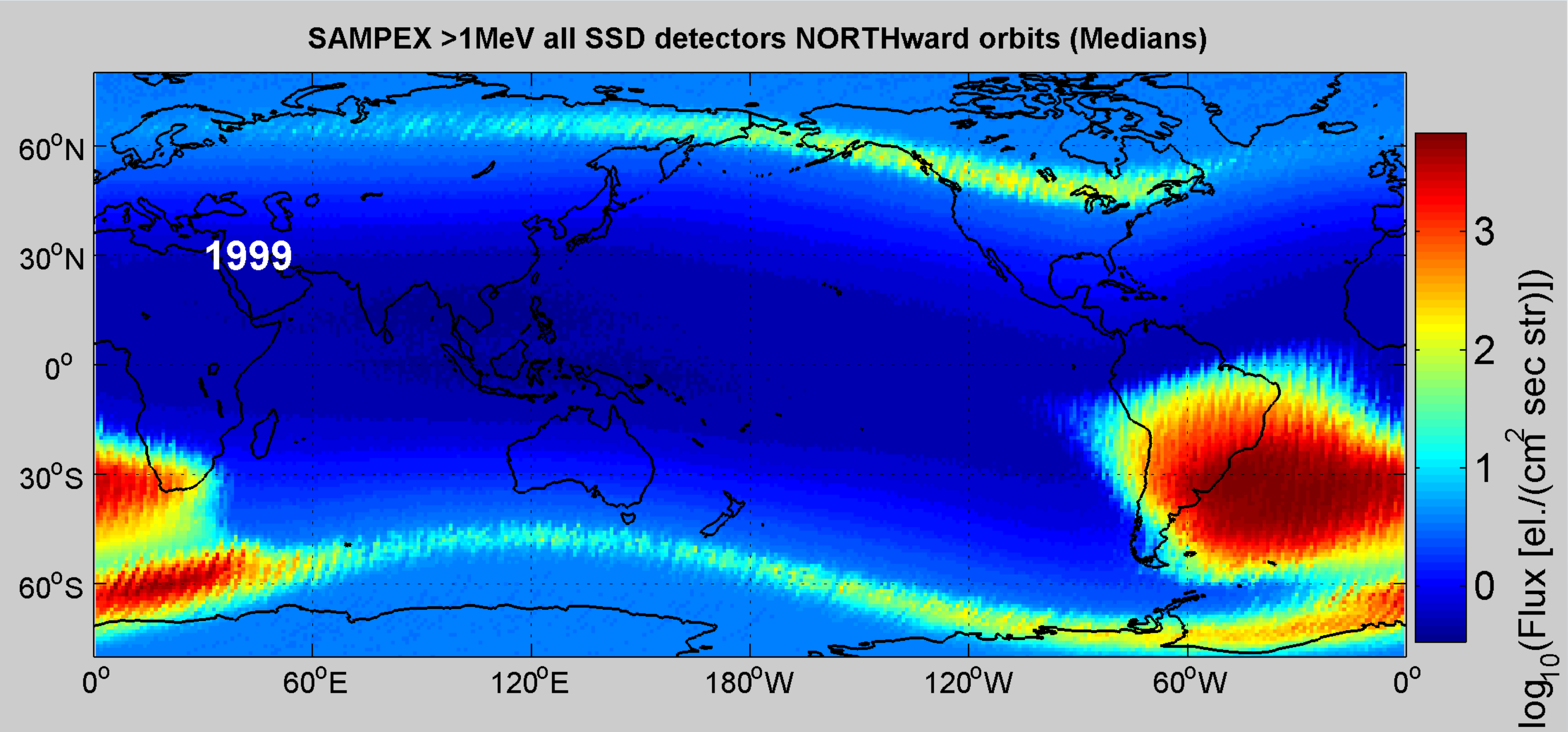
Microburst algorithm intensity magnitude

We aim to investigate the distribution of relativistic electron microburst occurrence in the Earth's outer radiation belts.

- Calculate baseline flux (10th percentile in 3 s bins) [Blum *et al.*, JGR, 2015]
- Intensity = flux – baseline



Introduction: SAMPEX HILT observations



Looking at a simple world map tells you a lot about the SAMPEX flux-observations. For example, it is clearly sampling the DLC in most of the world.

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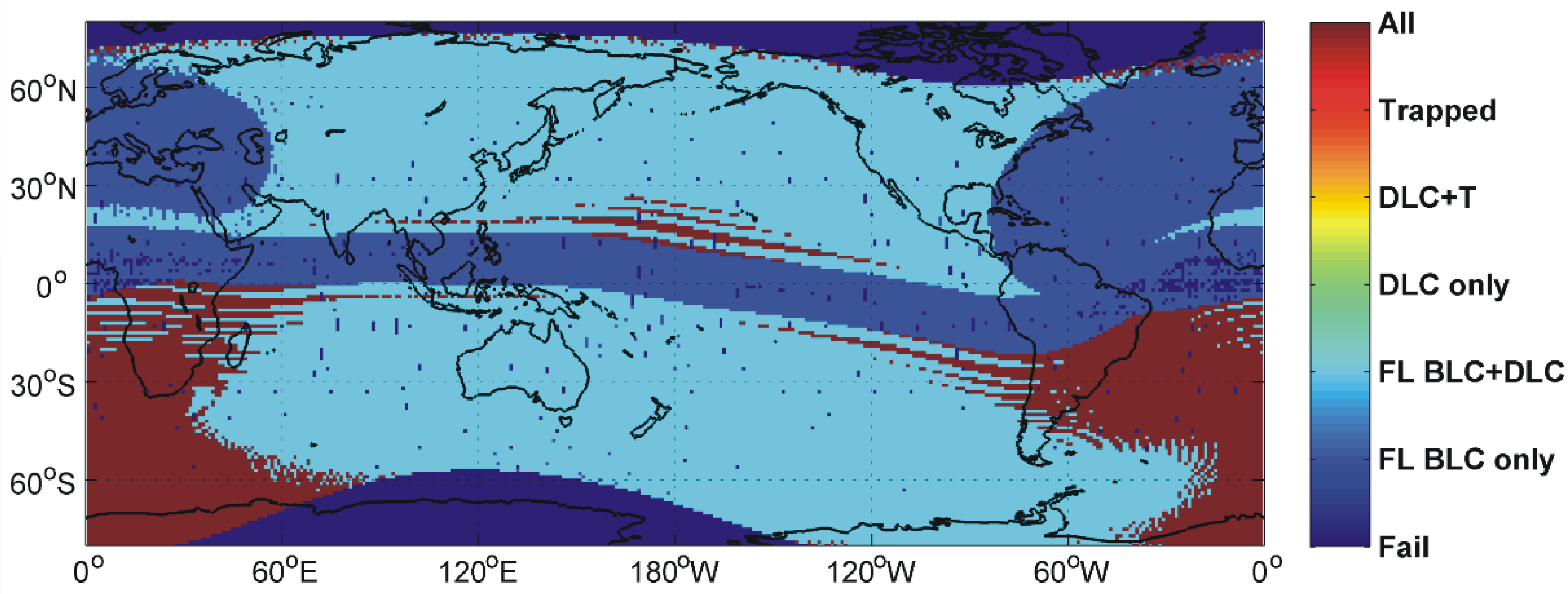
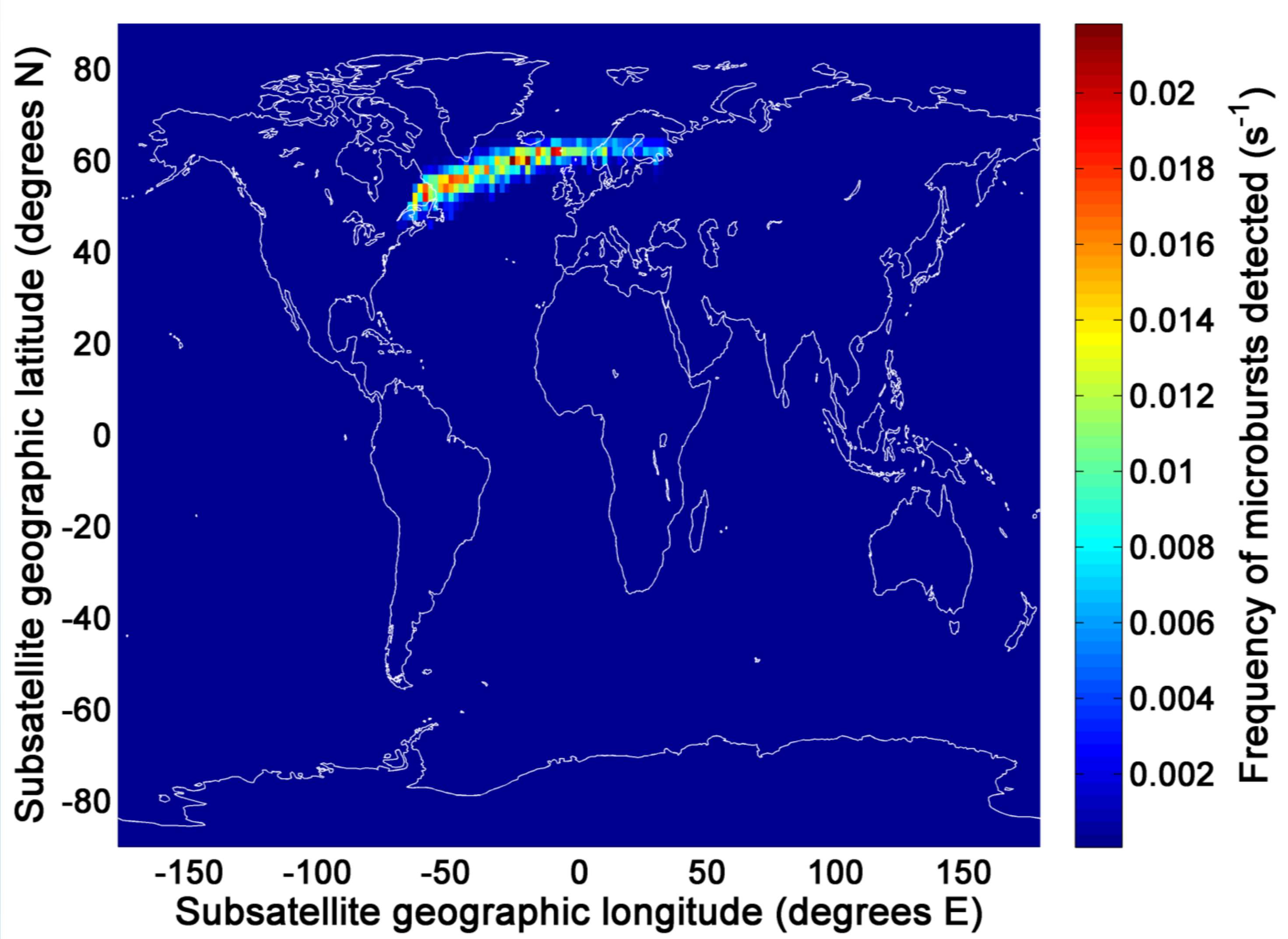
Introduction: SAMPEX



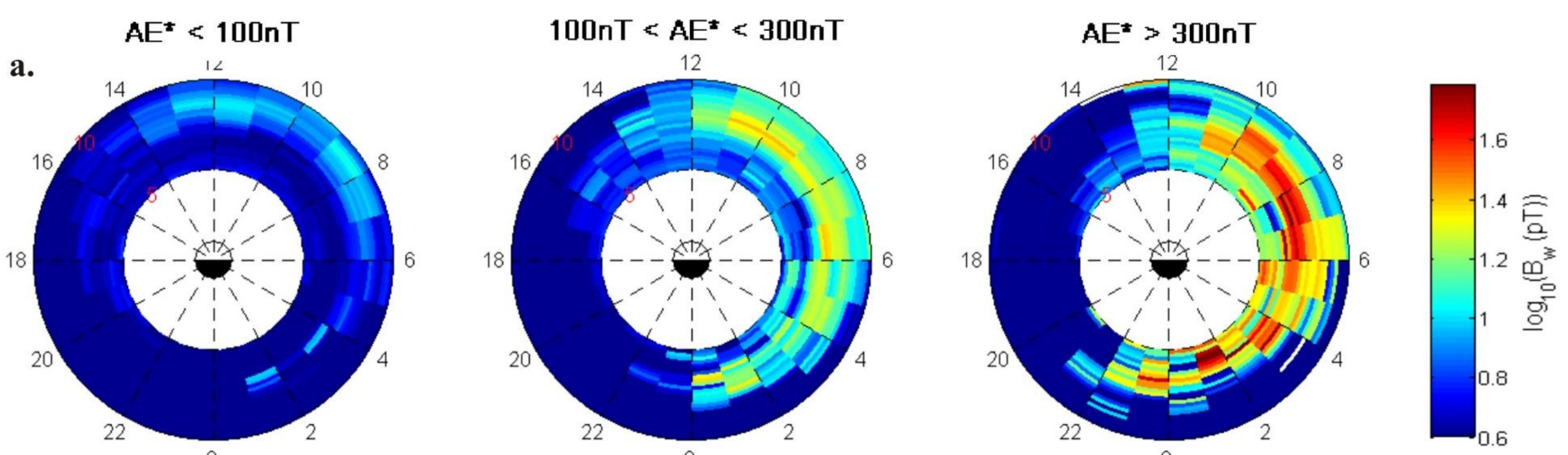
The HILT instrument samples different pitch angle distributions over different parts of the world [Dietrich *et al.*, JGR, 2010]

Occurrence of microbursts: World map

We detect 21,746 microbursts between 1996 and 2007 in the North Atlantic using the automated method described.



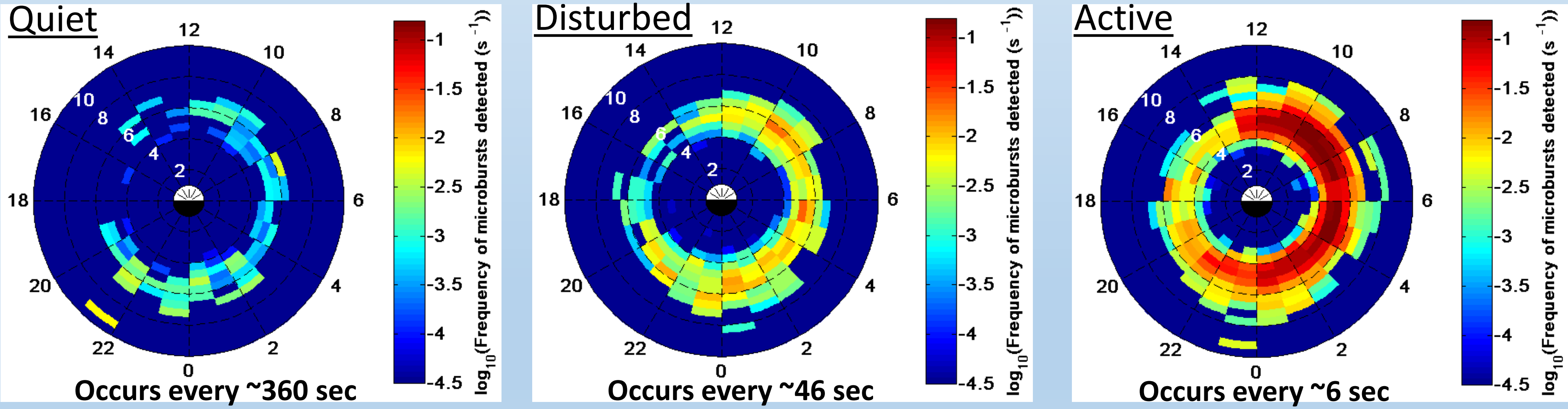
Comparison Occurrence and Chorus wave intensity



Li *et al.*, GRL, 2009 (Figure 2 - modified)

CHORUS amplitude

*AE** is mean *AE* value over previous 1 hour



MICROBURST activity

Quiet: *AE** ≤ 100 nT

Dist: *AE** > 100 nT & *AE** ≤ 300 nT

Active: *AE** > 300 nT

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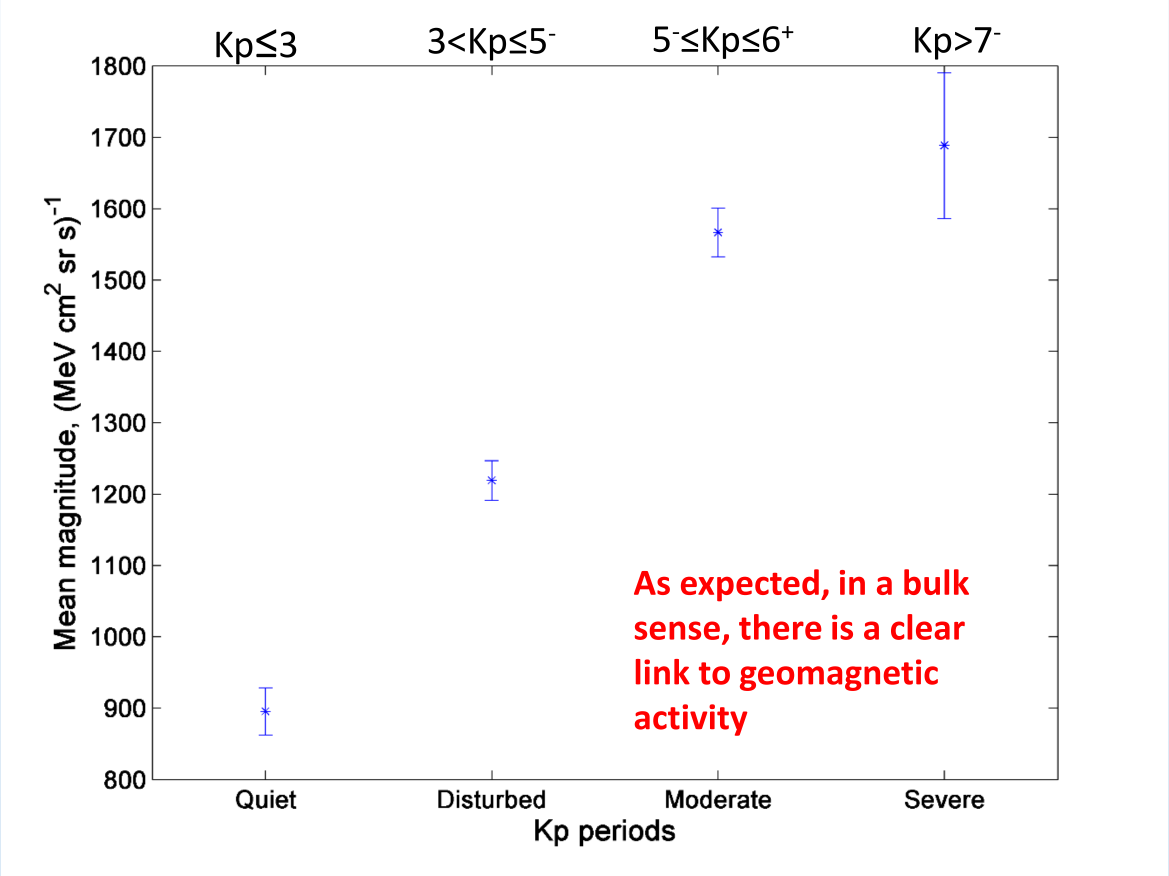
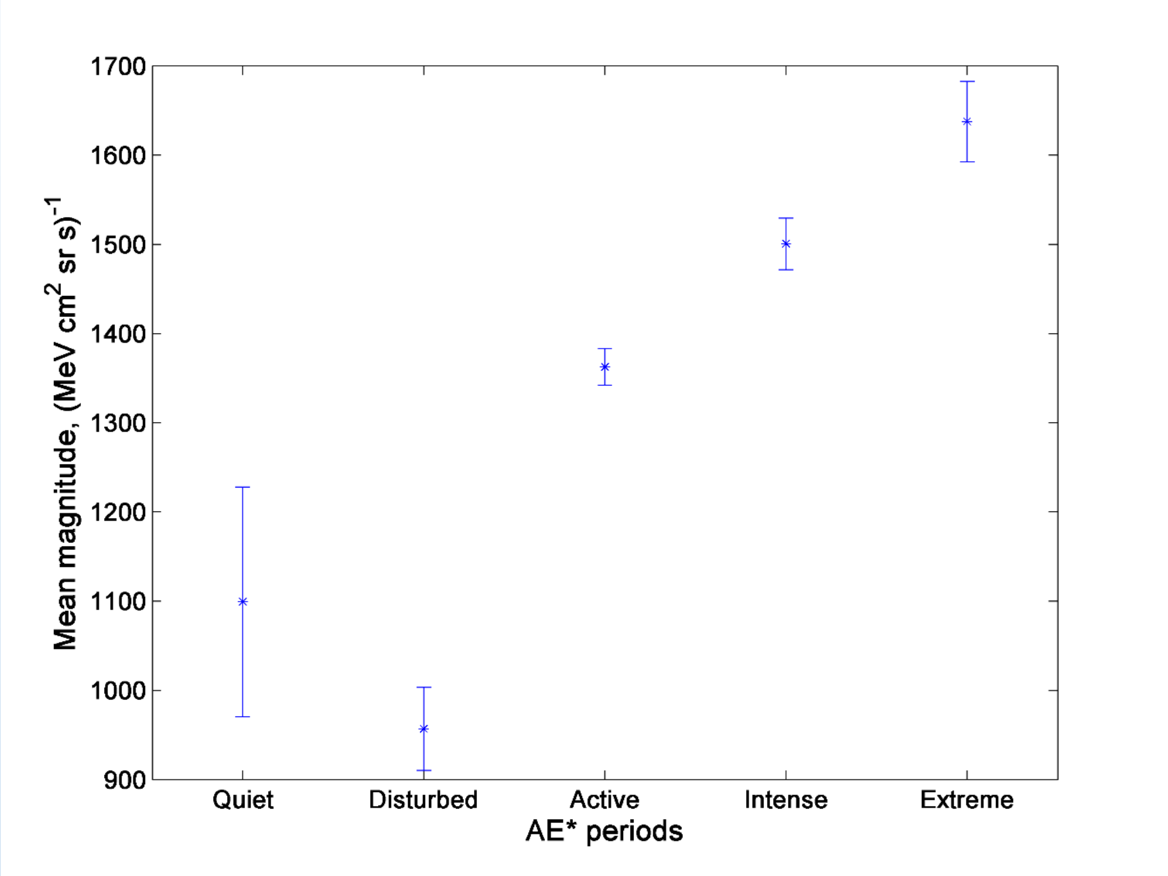
Similar to the distribution for the whole world [Douma *et al.*, JGR, 2017]

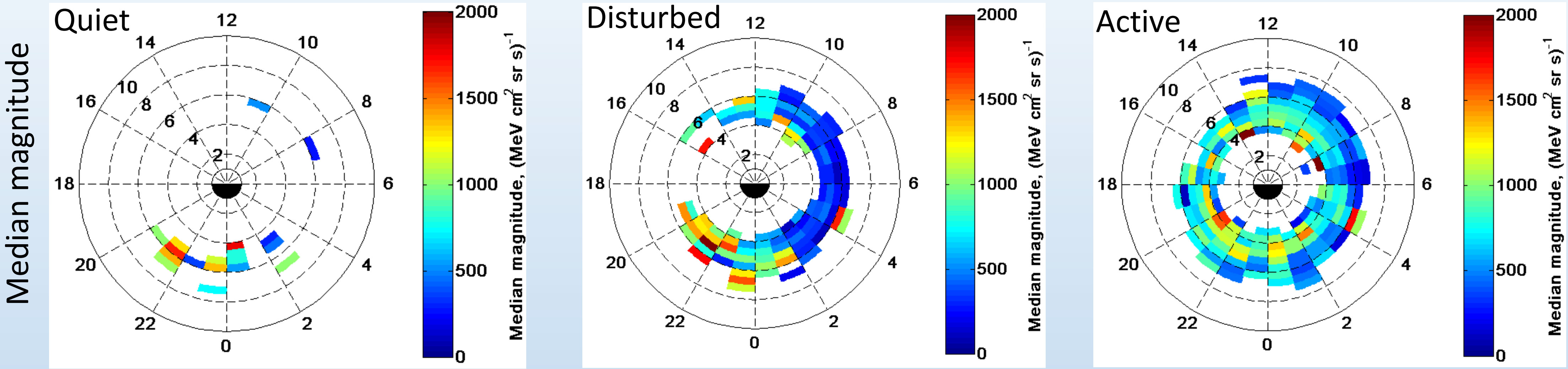
Variation in intensity with geomag. activity

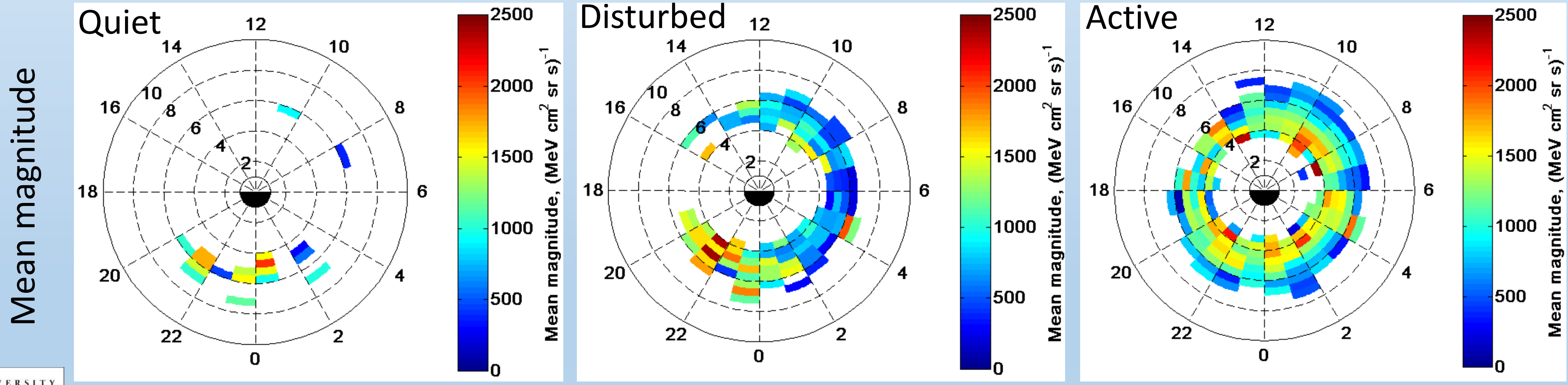




Quiet: *AE** ≤ 100 nT
Dist: *AE** > 100 nT ≤ 300 nT
Active: *AE** > 300 nT
Extreme: AE* > 550 nT
Extreme: *AE** > 750 nT

Intensity of microbursts: geomag. activity variation





MICROBURST flux

Quiet: *AE** ≤ 100 nT

Dist: *AE** > 100 nT & *AE** ≤ 300 nT

Active: *AE** > 300 nT

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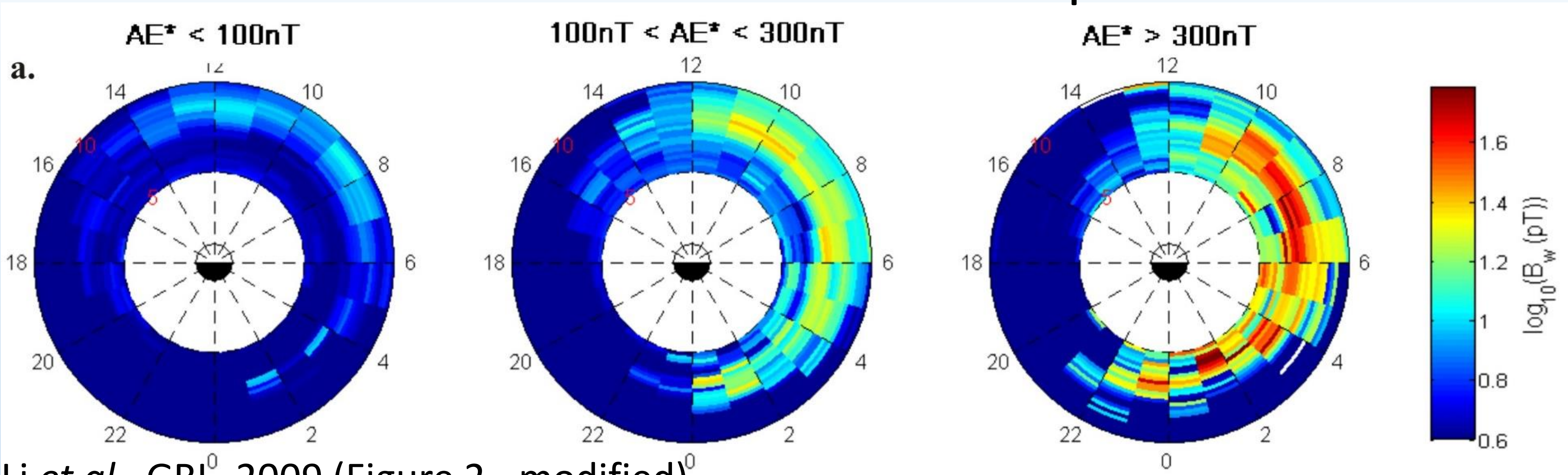
*AE** is mean *AE* value over previous 1 hour

Chorus Wave comparison

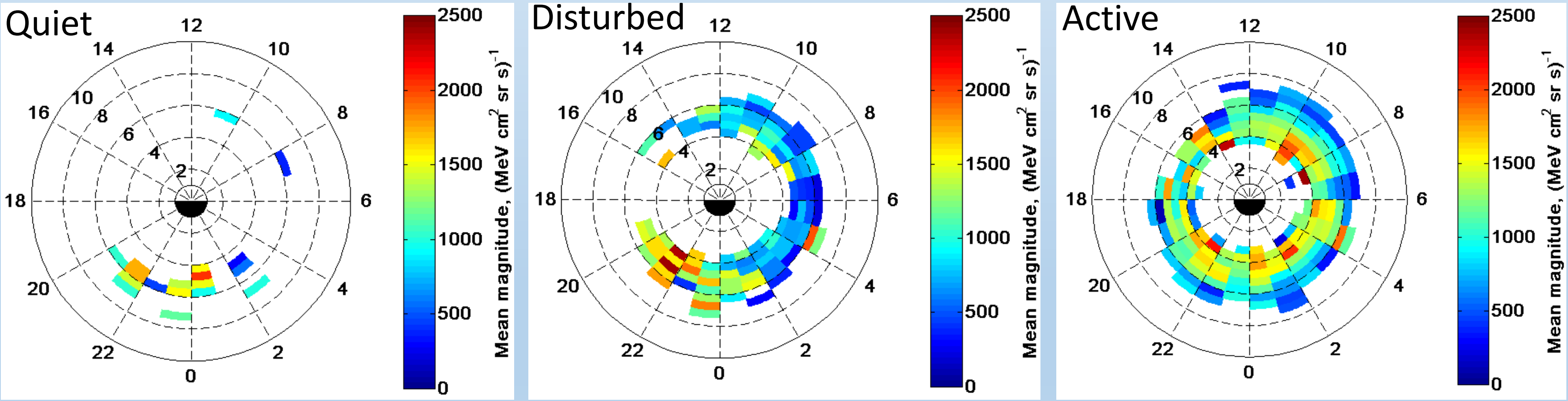


Li *et al.*, GRL, 2009 (Figure 2 - modified)

CHORUS amplitude

Root mean square wave amplitude

Mean magnitude



MICROBURST flux

Quiet: $AE^* \leq 100$ nT

Dist: $AE^* > 100$ nT & $AE^* \leq 300$ nT

Active: $AE^* > 300$ nT

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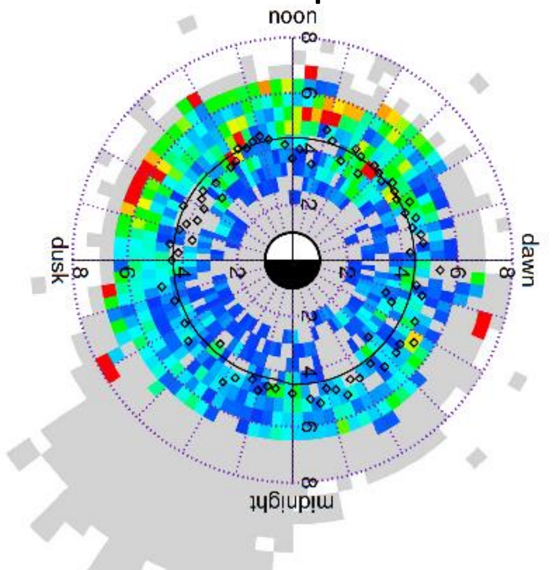
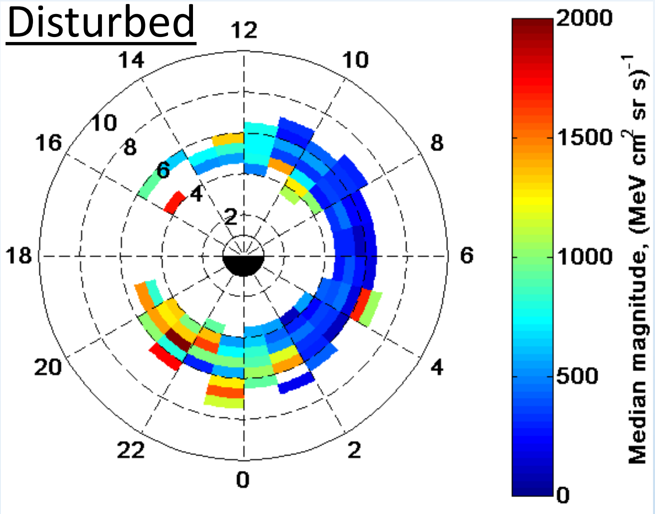
EMIC occurrence Sept. 2012 – June 2014

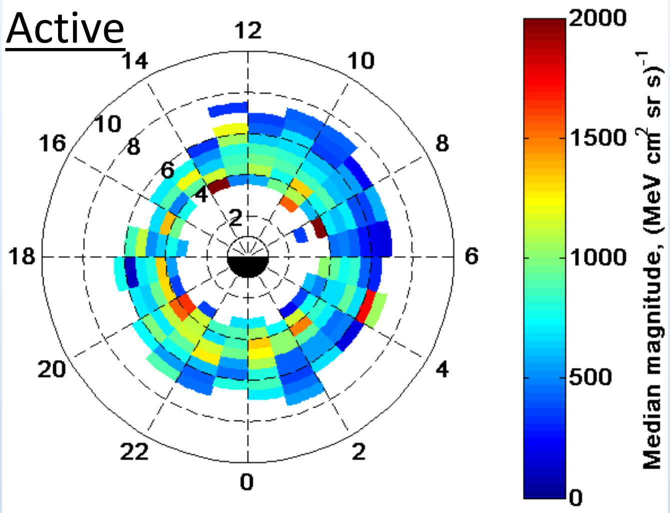
EMIC wave comparison



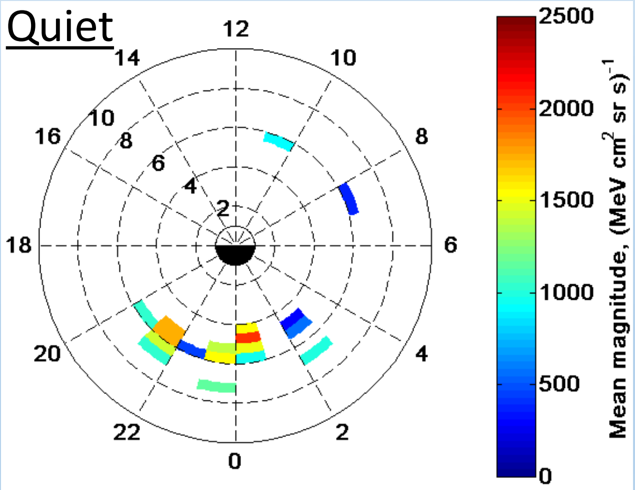
Saikin *et al.*, JGR, 2015
(Figure 3, rotated)

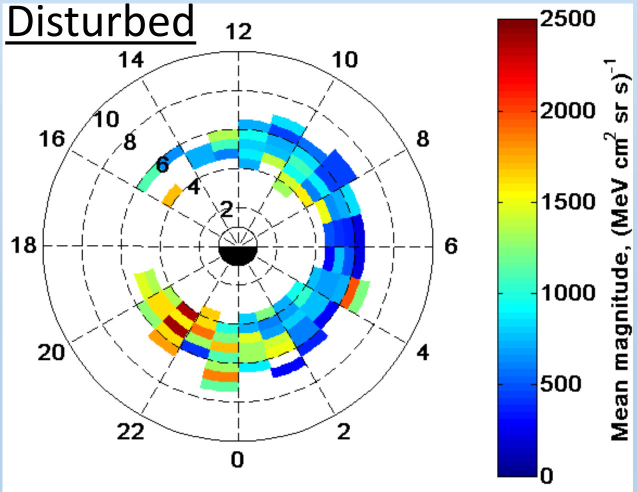
Median magnitude

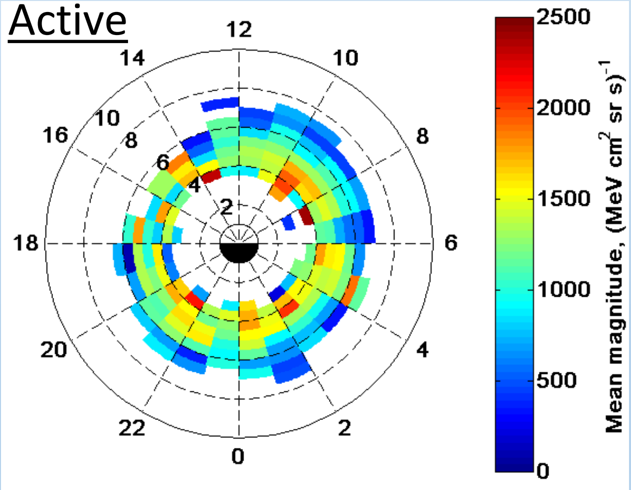




Mean magnitude







MICROBURST flux

Quiet: $AE^* \leq 100$ nT

Dist: $AE^* > 100$ nT & $AE^* \leq 300$ nT

Active: $AE^* > 300$ nT

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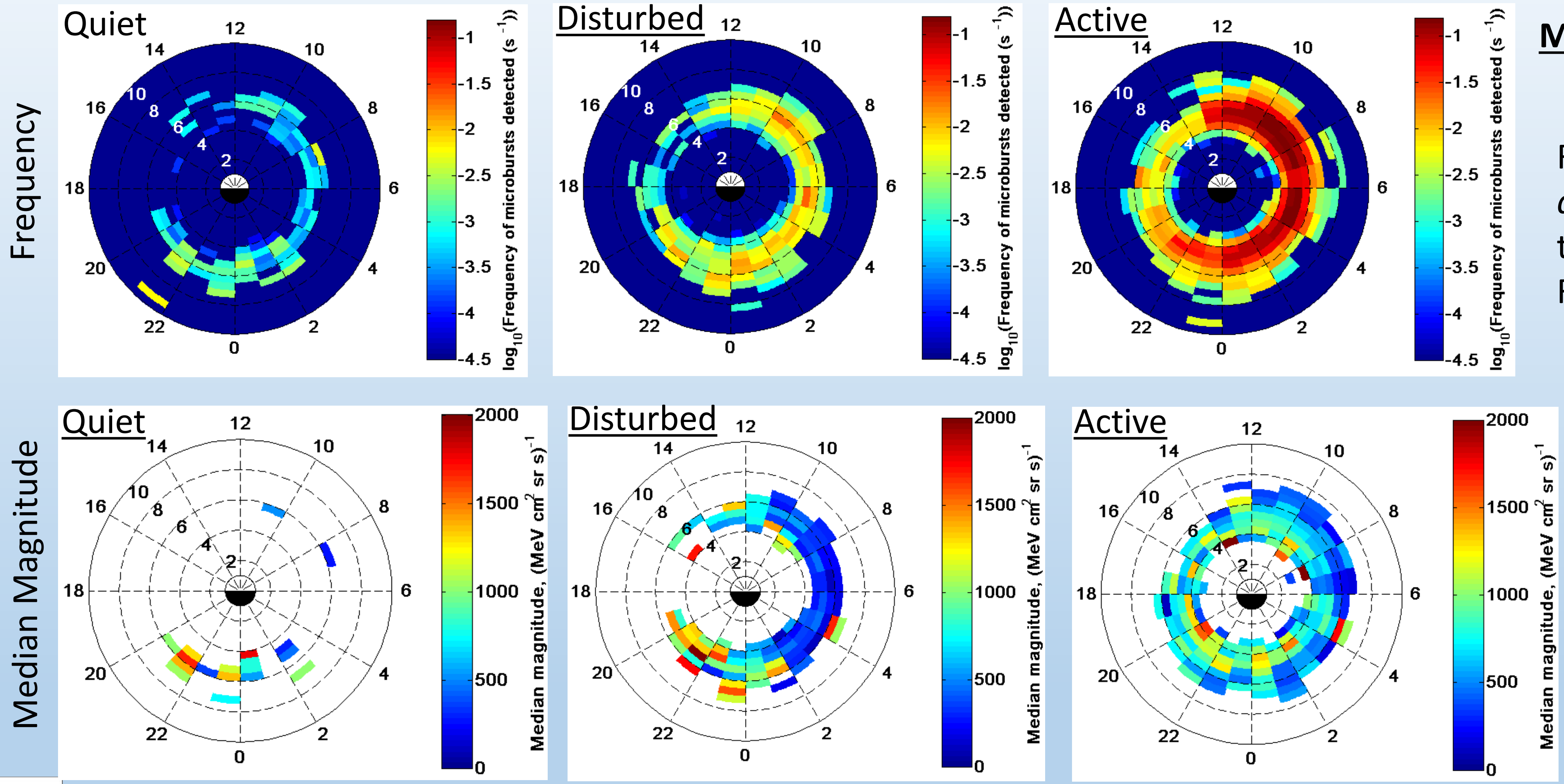
Comparison: Occurrence & Intensity



MICROBURST activity

Results from *Douma et al.*, [2017, JGR] limited to the North Atlantic Region

MICROBURST flux

Quiet: *AE** ≤ 100 nT

Dist: *AE** > 100 nT & *AE** ≤ 300 nT

Active: *AE** > 300 nT

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Introduction: HEO3

- Highly Elliptical Orbiter (HEO3), a.k.a. spacecraft 1997-068
- Launched in November 1997 into a **highly elliptical orbit,** with an inclination of 62°.
- Omnidirectional dosimeter onboard, which can detect **> 1.5 MeV electrons**.

Further material on the HEO3 satellite can be found in Blake *et al.* [GRL, 1997] and O'Brien *et al.* [Space Weather, 2007]

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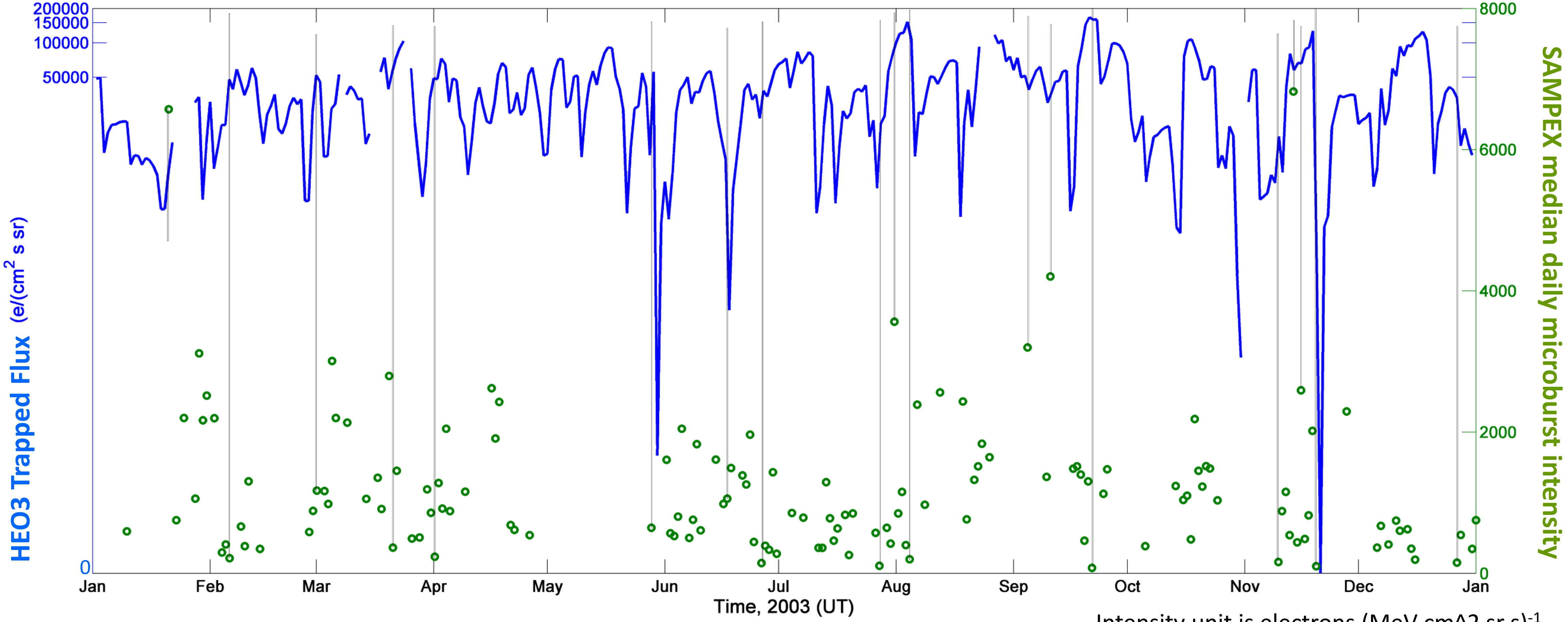
Trapped Flux Comparison



Intensity unit is electrons (MeV cm^2 sr s)$^{-1}$

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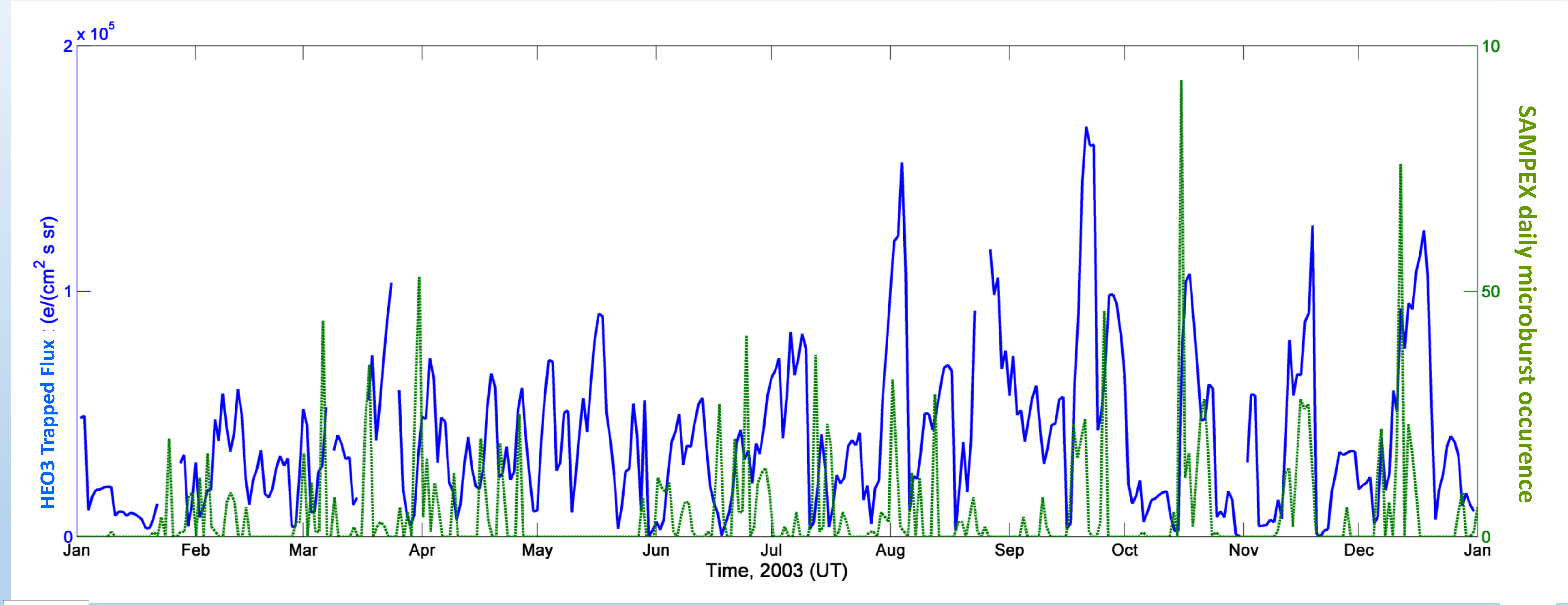
Does not seem to be a clear link between microburst magnitude and the trapped flux levels.

Trapped Flux Comparison



However, maybe microburst events tend to occur when fluxes are increasing (i.e., during acceleration events).

Conclusions

- The microburst occurrence distribution appears very similar to the chorus distributions (in *L* and MLT).
- Occurrence varies strongly with *L,* MLT, and geomagnetic activity.
- Intensity varies weakly with geomagnetic activity, *L,* and MLT.
- Overall, **there is much less variation in the intensity than in the occurrence** of relativistic microbursts.
- Occurrence distribution similar to chorus wave distribution
- Intensity distribution not similar to either chorus wave or EMIC wave distribution
- Occurrence increases with increased trapped flux. Intensity has no clear relationship with trapped flux.

Thank you!

Emma Douma and Craig Rodger standing inside the ruined medieval fortifications of Kaliakra on the northern Bulgarian Black Sea Coast. September 2016

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Outline

- Introduction
  - Microbursts
  - Chorus and EMIC waves
  - Solar Anomalous Magnetospheric Particle Explorer (SAMPEX)
  - Microburst algorithm
- Intensity of Microbursts
- Trapped Flux Correction – HEO3
- Conclusions & References