Effects of Electromagnetic Ion Cyclotron Waves on the Outer Electron Radiation Belt

R. B. Horne[1]
T. Kersten[1], S. A. Glauert[1], N. P. Meredith[1]
B. J. Fraser[2], and R. S. Grew[2]

[1]British Antarctic Survey, Cambridge, UK
[2]University of Newcastle, New South Wales, Australia

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Invited talk, Fall AGU, San Francisco, 17th December 2014

Goal

- To assess the importance of electron loss from the radiation belts caused by EMIC waves - on a global scale

- Approach
  - Analysis and fitting of wave data – from CRRES
  - Develop wave maps
  - Use the power spectra to calculate pitch angle and energy diffusion rates
  - Include the diffusion rates into the BAS Radiation Belt Model
  - Run the model for different scenarios to determine the importance of EMIC waves

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

BAS Radiation Belt Model

- Fokker-Planck Equation

$$\frac{\partial f}{\partial t} = L^2 \frac{\partial}{\partial L}\left(\frac{D_{LL}}{L^2}\frac{\partial f}{\partial L}\right)\bigg|_{\mu J} + \frac{1}{g(\alpha)}\frac{\partial}{\partial \alpha}\left(g(\alpha) D_{\alpha\alpha}\frac{\partial f}{\partial \alpha}\right)\bigg|_{EL} + \frac{1}{A(E)}\frac{\partial}{\partial E}\left(A(E) D_{EE}\frac{\partial f}{\partial E}\right)\bigg|_{\alpha L} - \frac{f}{\tau(\alpha, E)}$$

Radial transport | Pitch angle diffusion | Energy diffusion | Losses - inside loss cone

- Drift & bounce averaged diffusion coefficients D_{LL}, $D_{\alpha\alpha}$, D_{EE} are activity, location and energy dependent
- ULF waves contribute to D_{LL}
- VLF waves contribute to $D_{\alpha\alpha}$ and D_{EE}

- Details in: Glauert et al. JGR, [2014]

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Diffusion Coefficients - Requirements

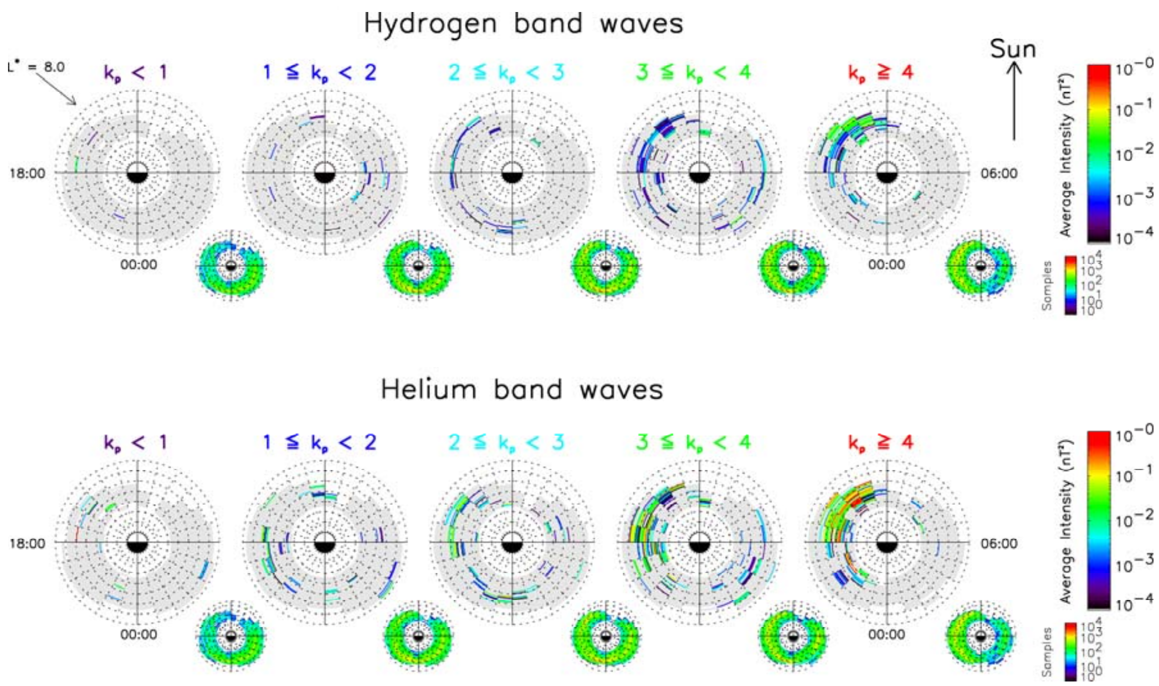
- Power spectrum of the waves – $nT^2 Hz^{-1}$ as a function of frequency
- Distribution of waves in MLT
- Radial distribution – here in L*
- Data for different levels of geomagnetic activity – Kp, AE, Vsw
- Distribution of the waves in latitude
- Ion composition
- Wave normal angle distribution

- fpe/fce distribution – with MLT, L*, latitude, geomagnetic activity
  - Data on density and magnetic field

- Alternative method - using POES data to calculate <Daa> is powerful
  - but only gives <Daa> at selected energies near the edge of the loss cone
  - Assumptions are required to obtain the full set of diffusion rates
- Future - combine both approaches

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

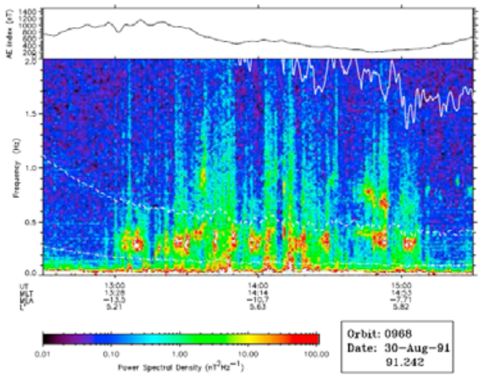
EMIC waves from CRRES

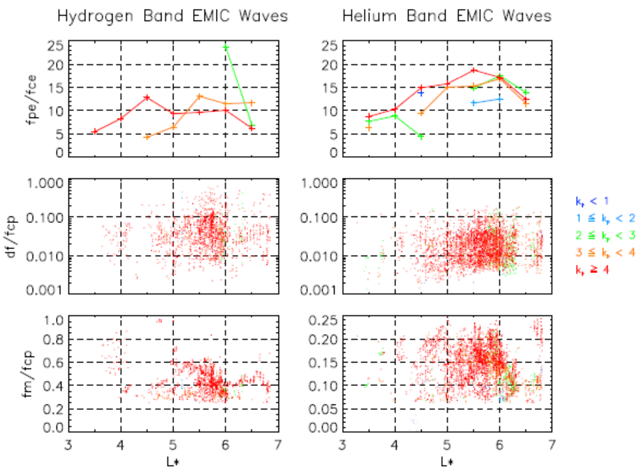


British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Meredith et al, [2014]

Wave Scatter Plot



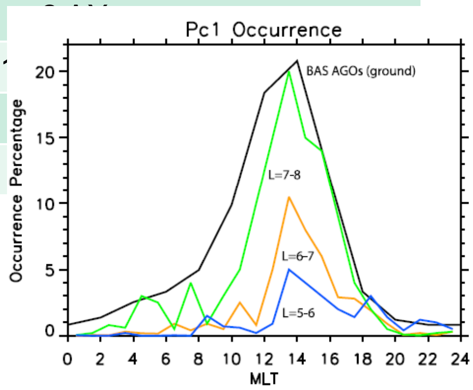


- Bursty
- Frequency variable

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Wave Parameters

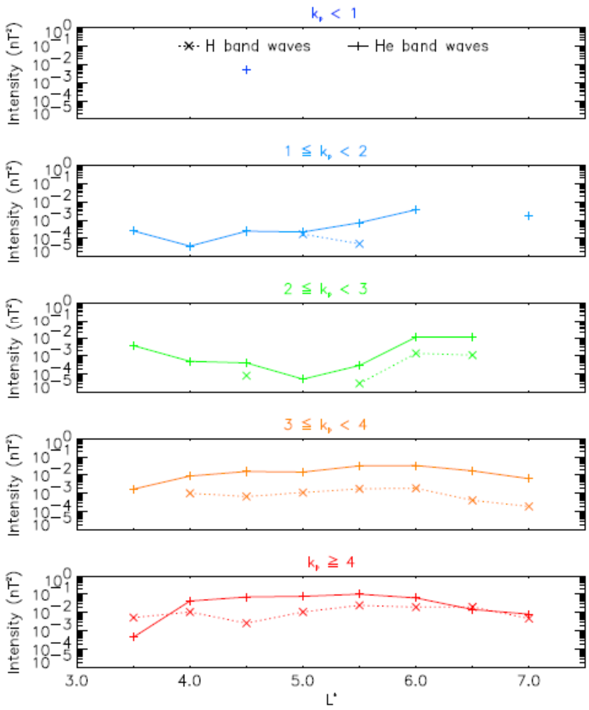
Parameter	Hydrogen band waves	Helium band waves
f_m/f_{cH}	0.4	0.15
df/f_{cH}	0.02	0.02
f_{lc}/f_{cH}	0.36	0.11
f_{uc}/f_{cH}	0.44	0.19
X_m	0.0	
ΔX	tan 15°	
X_{cut}	[illegible]	
Resonances	-1 [illegible]	
f_{pe}/f_{ce}		
Ion composition	94% H^+	



Posh et al. [2010]

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

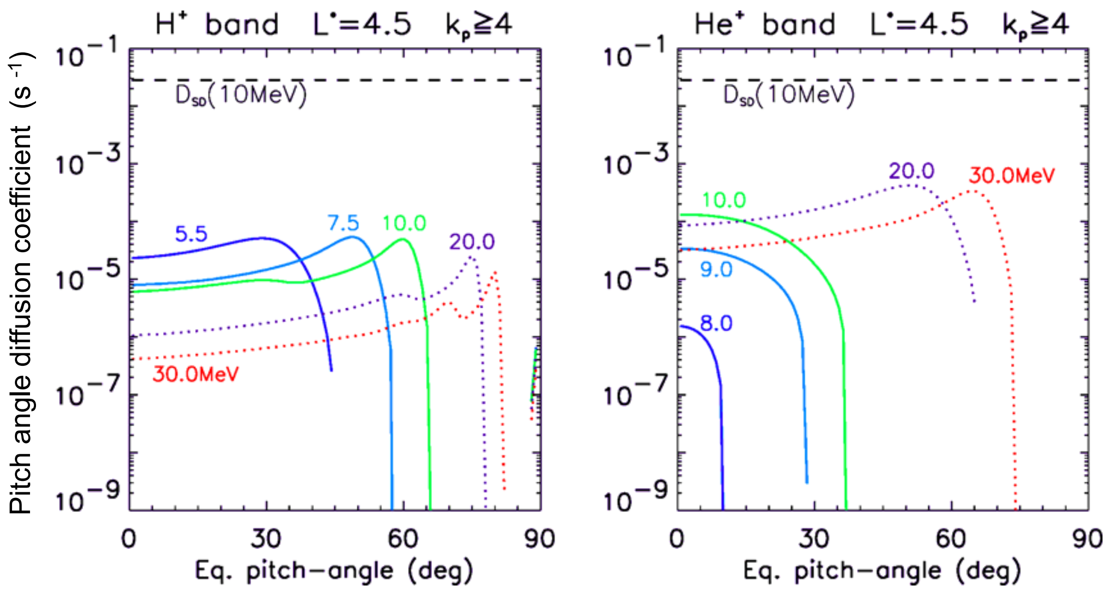
Wave Intensities



- He^+ band waves tend to be stronger

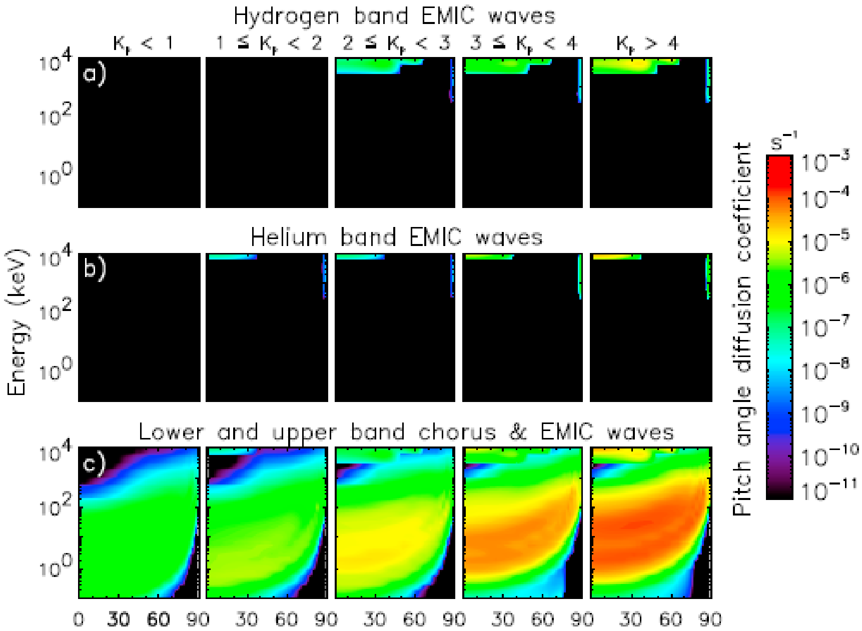
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

EMIC diffusion rates



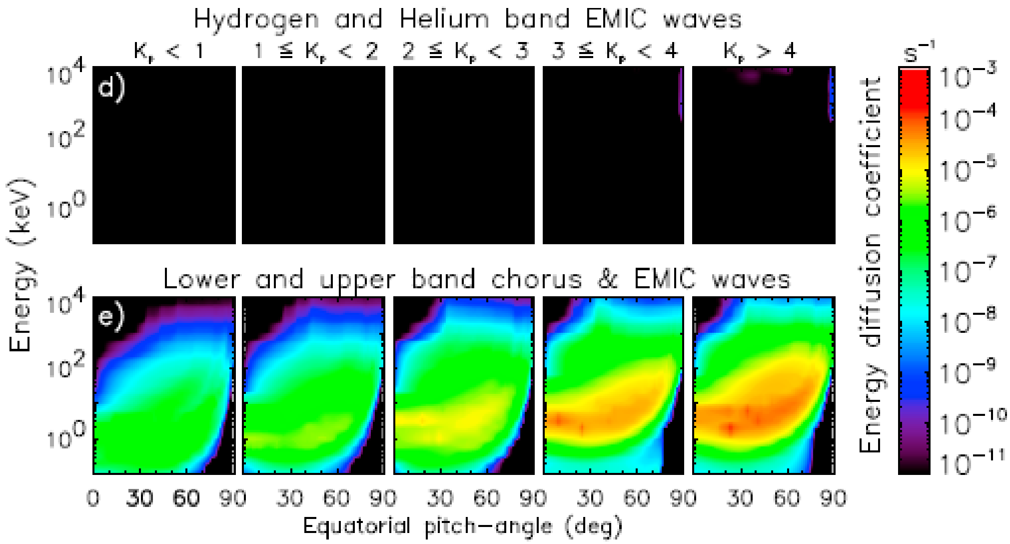
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

EMIC and EMIC + Chorus Diffusion



British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Energy Diffusion



British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Physical processes in the BAS model

- Radial transport [*Brautigam & Albert, JGR, 2000*]
- Upper & lower band whistler mode chorus waves *[Horne et al., JGR, 2013]*
- Plasmaspheric hiss & lightning-generated whistlers *[Glauert et al., JGR, 2013]*
- EMIC waves
- Plasmapause model *[O'Brian and Moldwin,2003]*
- Collisions with atmosphere [*Abel & Thorne, JGR,1998*]

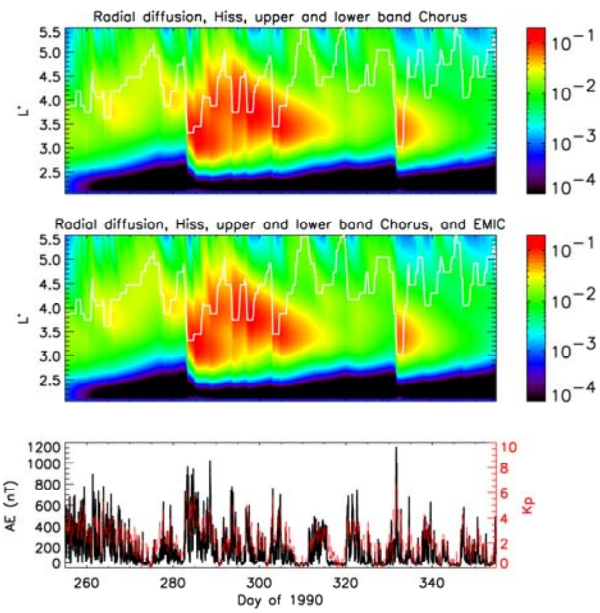
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Electron flux: 100 day simulation – 90°

45° flux ($cm^{-2}sr^{-1}s^{-1}keV^{-1}$) for 6MeV electrons

Without EMIC

With EMIC



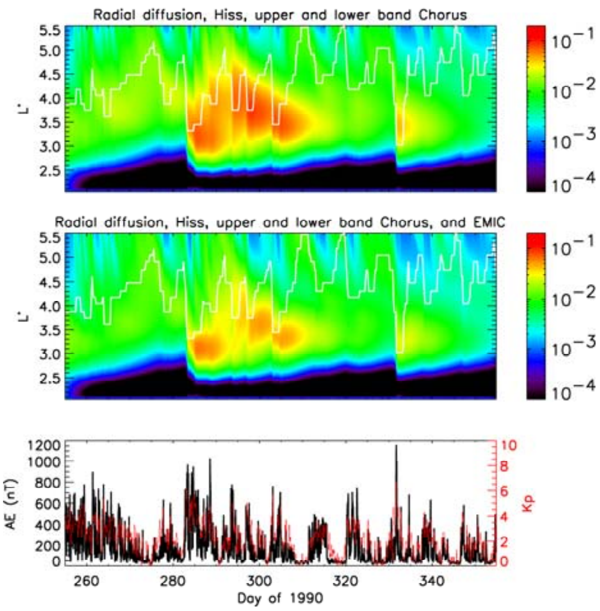
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Electron flux: 100 day simulation – 45°

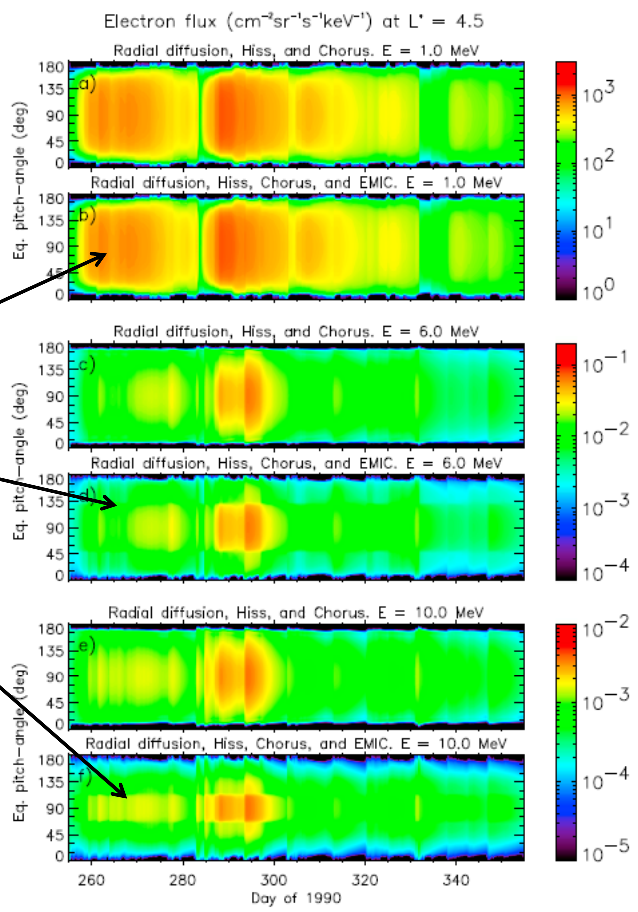
45° flux ($cm^{-2}sr^{-1}s^{-1}keV^{-1}$) for 6MeV electrons

Without EMIC

With EMIC



British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL



1 MeV

6 MeV

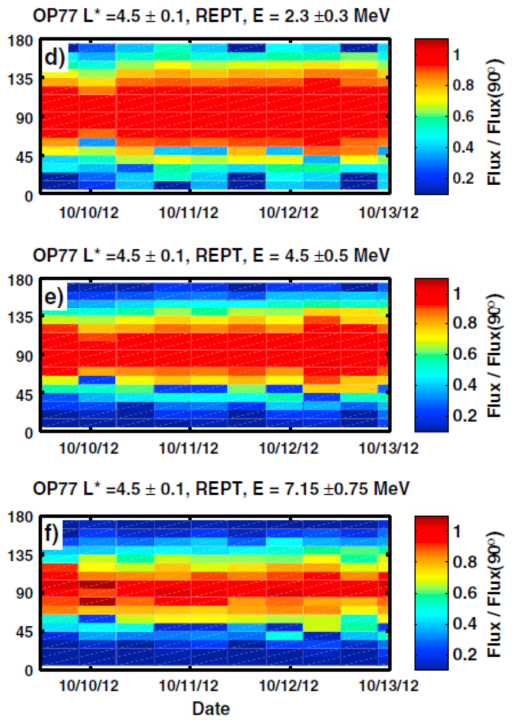
10 MeV

- EMIC waves:
- Electron distribution becomes narrower for higher energies

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNC

Van Allen Probes Observations

- Usanova et al [2014]
- REPT
- Electron distribution narrower at higher energies



British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Conclusions

- EMIC waves are effective at scattering electrons for E > 2MeV
- Variable frequency – could be effective at lower energies
- No significant energy diffusion
- EMIC waves lead to significant losses at pitch-angles < 60° (for L* > 3.5)
- EMIC waves result in an electron distribution peaked between 70° - 90°
- Narrower at higher energies

- Similar distrbutions observed by REPT [Usanova et al., 2014]

- Even at 30 MeV – do not remove all electrons up to 90°
  - Unlikely to set an upper energy limit on the flux

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Acknowledgements

- The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) grant number 262468 (SPACECAST) and 284520 (MAARBLE)

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL