Summary of precipitation events observed by BARREL during storms

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Key Points:

1) A single instrument on an array of balloons can help answer many questions about radiation belt dynamics as well as other heliospheric science.

2) Remote sensing and in situ instruments working together provide a more complete understanding.

3) Geomagnetic storms exhibit many different types of Radiation belt loss processes.
BARREL: Balloon Array for Radiation belt Relativistic Electron Losses

Float Altitude of BARREL balloon ~22 - 40 km

B-field

Bremsstrahlung x-ray

Precipitating Electrons

Ionospheric/Atmospheric Particles

Atmospheric Absorption of x-rays

~27 km
Type of events observed by BARREL

1) Microbursts
2) Precipitation due to lightning induced whistlers?
3) GRBs
4) Solar Flare
5) Relativistic Electron Precipitation
6) Precipitation due to substorm injection
7) Precipitation due to whistler mode waves
8) ULF time scale modulations
9) Drift echo time scale modulations
10) Solar Energetic Proton events

Here we cover numbered topics 1, 5-9 in detail
The storm that (almost) had it all - Jan 25 - 28 2013

**BARREL Payload 1T**
- 32 second
- 256 energy channel spectra

**BARREL Payload 1H**
- 32 second
- 256 energy channel spectra

**Sym-H [nT]**
- period discussed in poster

**Energy [keV]**
- 10
- 2
- 10
- 0

**cnts keV⁻¹ s⁻¹**
- 10²
- 10¹
- 10⁻¹
- 10⁻²

**January 25 2013**
- 12:00
- 00:00

**January 26 2013**
- 12:00
- 00:00

**January 27 2013**
- 12:00
- 00:00

**January 28 2013**
- 12:00
- 00:00
5) Relativistic Electron Precipitation:
BARREL observed REPS in the dusk sector at an L-value and MLT similar to that where Van Allen Probe B saw EMIC waves.

Although Van Allen Probe A was close in L to the two BARREL payloads, it was on the dawn side of the magnetosphere and did not see an EMIC wave.

Zhang, Halford et al in prep.
Spectral analysis with BARREL

Ionospheric/Atmospheric Particles

Precipitating Electron

Ionospheric/Atmospheric Particles

Atmospheric Absorption of x-rays ~22 - 27 km

Bremsstrahlung x-ray

Woodger et al 2015

Spectral analysis with BARREL

Modeled electron population

GEANT model through Atmosphere

GEANT model through BARREL detector

Modeled expected x-ray response

X-ray Counts vs. energy

Counts vs. electron energy
5) **Relativistic Electron Precipitation**: Using the approx. min resonant energy and an upper limit of observed electrons at MagEIS/REPT we can see that EMIC waves may have precipitated the inferred particle population generating the observed X-rays.

Zhang, Halford et al in prep.
6) Substorm injection:
Payload 1H saw X-rays upwards of 450 keV and was conjugate to observations from the CARISMA array in Canada as well as GOES and LANL satellites.

Mann et al in prep.
6) Substorm injection:
The differing structures seen in FSPC1 (<180 keV) and FSPC2 (180 - 550 keV) X-rays indicate two separate precipitating electron populations.

Mann et al in prep.
1) Microbursts: Microbursts were observed during and after the substorm event. As RBSP-A came out of perigee, it observed chorus waves and time domain structures.

1) Microbursts: Because RBSP-A was not directly conjugate to payload 1H, one-to-one correlations were not observed. Halford et al in prep.
9) **Drift echo time scales**: BARREL and other balloon missions have observed structures comparable to drift time scales (5 - 30 minutes). During this interval both microbursts and ULF time scales were observed.

During this event, the Van Allen probes were at a similar L-value and about 5 mins away for a 45 deg, 300 keV electron.

Halford et al in prep.
RBSP-A MagEIS Pitch Angle

35 keV

175 keV

317 keV at 172 deg.

Halford et al in prep.
9) Drift echo time scales: The best fit e-folding energy describing the observed X-ray response is 45 keV and the best fit mono-energetic value is 157 keV. By comparison, the expected X-ray response to either the MagEIS spectra, or the MagEIS energy bin with a drift time similar to that observed in the X-rays, are too hard.

Halford et al in prep.
ULF time scales: ULF period oscillations modulate the precipitation envelope, by changing in the size of the loss cone during the precipitation event. Although the ULF wave does not change the loss cone size much, very small increases/decreases will result in a large change in the precipitating population if the pitch angle distribution is very steep near the loss cone.
8) ULF time scales: ULF wave activity was also observed in ISLL riometer data, and GOES at similar frequencies, consistent with a spatially localized ULF wave modulation of BARREL precipitation.

Rae et al 2015 submitted JGR
Conclusions

Storms are often complicated with multiple mechanisms acting throughout causing radiation belt loss to the atmosphere. BARREL is able to examine the range of radiation belt loss from ms to days, and 10s keV - 10 MeV energies.

1/25/13 23:30 - 1/26/13 1:00 The Relativistic electron precipitation event observed by BARREL may be explained by the observed EMIC wave from the Van Allen Probe.

1/26/13 8:30 - 9:45 During the substorm, both microbursts and ULF time scales were observed. The precipitation follows the populations observed to be injected by in situ instruments.

1/26/13 10:00 - 10:08 Microbursts, rising tone chorus, and time domain structures were observed at similar times and locations.

1/26/13 10:00 - 12:00 Although drift echo times scales can be observed in the X-ray counts, the process remains unclear.

1/26/13 19:30 - 21:30 ULF periods are often observed in the data. One mechanism which may contribute to this is ULF waves modulating the size of the loss cone.