POES SEM-2 Observations of Radiation Belt Dynamics and Energetic Electron Precipitation in to the Atmosphere

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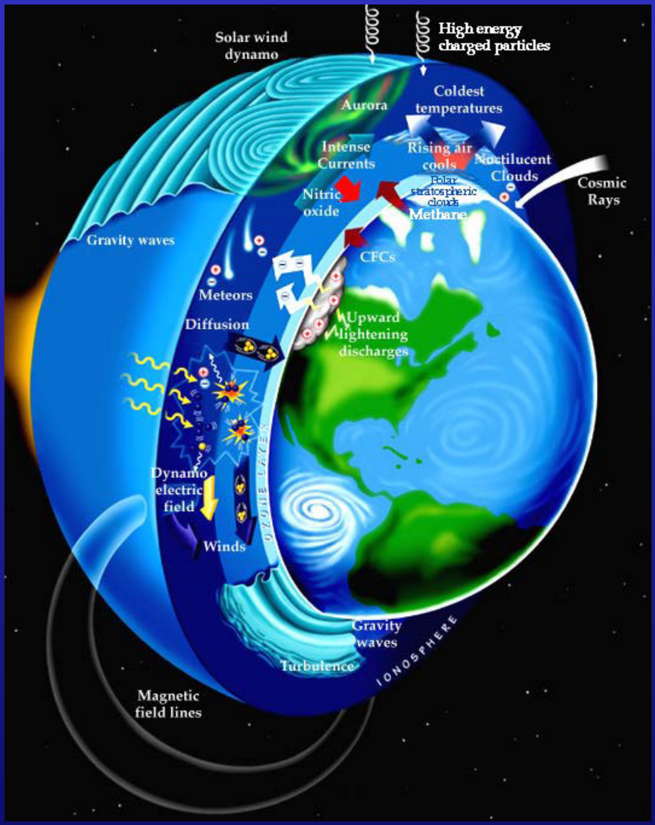
Energetic Particle Precipitation

<u>Losses:</u> overall response of the RB to geomagnetic storms are a "delicate and complicated balance between the effects of particle acceleration and loss" [*Reeves et al.*, GRL, 2003].

Thus while there has been a lot of focus on the acceleration of radiation belt particles, it is also necessary to understand the losses to understand the radiation belts.

<u>Space Weather links to the atmosphere (and beyond?).</u> In addition, particle precipitation is one way that changes at the Sun, and around the Earth, can couple into the atmosphere - and possibly into the climate.



There are multiple "important" questions which need to be answered to understand RB-losses & the significance of Energetic Particle Precipitation.

Losses: the POES database

TIROS-N (start of SEM-1)	1978-1981
(multiple missions with SEM-1)	1978-2004
POES NOAA-15 (start of SEM-2)	**1998-present**
POES NOAA-16	**2001-present**
POES NOAA-17	**2002-present**
POES NOAA-18	

All of the Space Environment Monitor (SEM-2) data is available for download from the NOAA website, as text files with 16-second resolution.

Data Channel	Energy Passband	Directionality	Contaminant
e1	>30 keV	0°, 90°	210-2700 keV protons
e2	>100 keV	0°, 90°	280-2700 keV protons
e3	>300 keV	0°, 90°	440-2700 keV protons
P1	30-80 keV	0°, 90°	none
P2	80-240 keV	0°, 90°	none
P3	240-800 keV	0°, 90°	none
P6	>6.9 MeV	0°, 90°	electrons above 700 keV
$P6_{omni}$	>16 MeV	0°	electrons above 800 keV
$P7_{omni}$	>36 MeV	0°	none

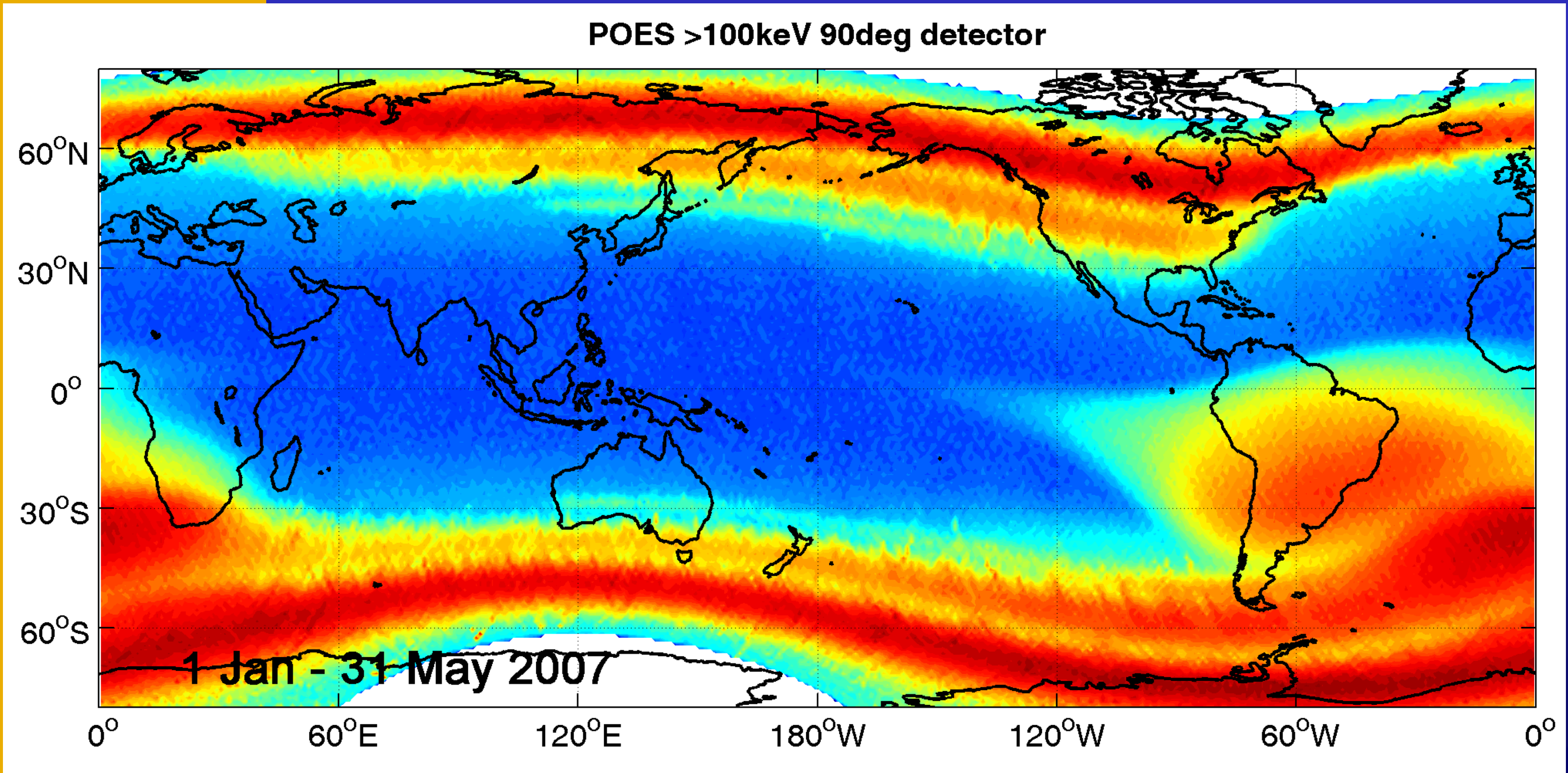
Contamination information from Robyn Millan

Contamination information from Sandagner et al. [2007].

So we can remove the solar proton events seen with the $P7_{omni}$ channel, and hence use the P6 and $P6_{omni}$ as REP detectors.

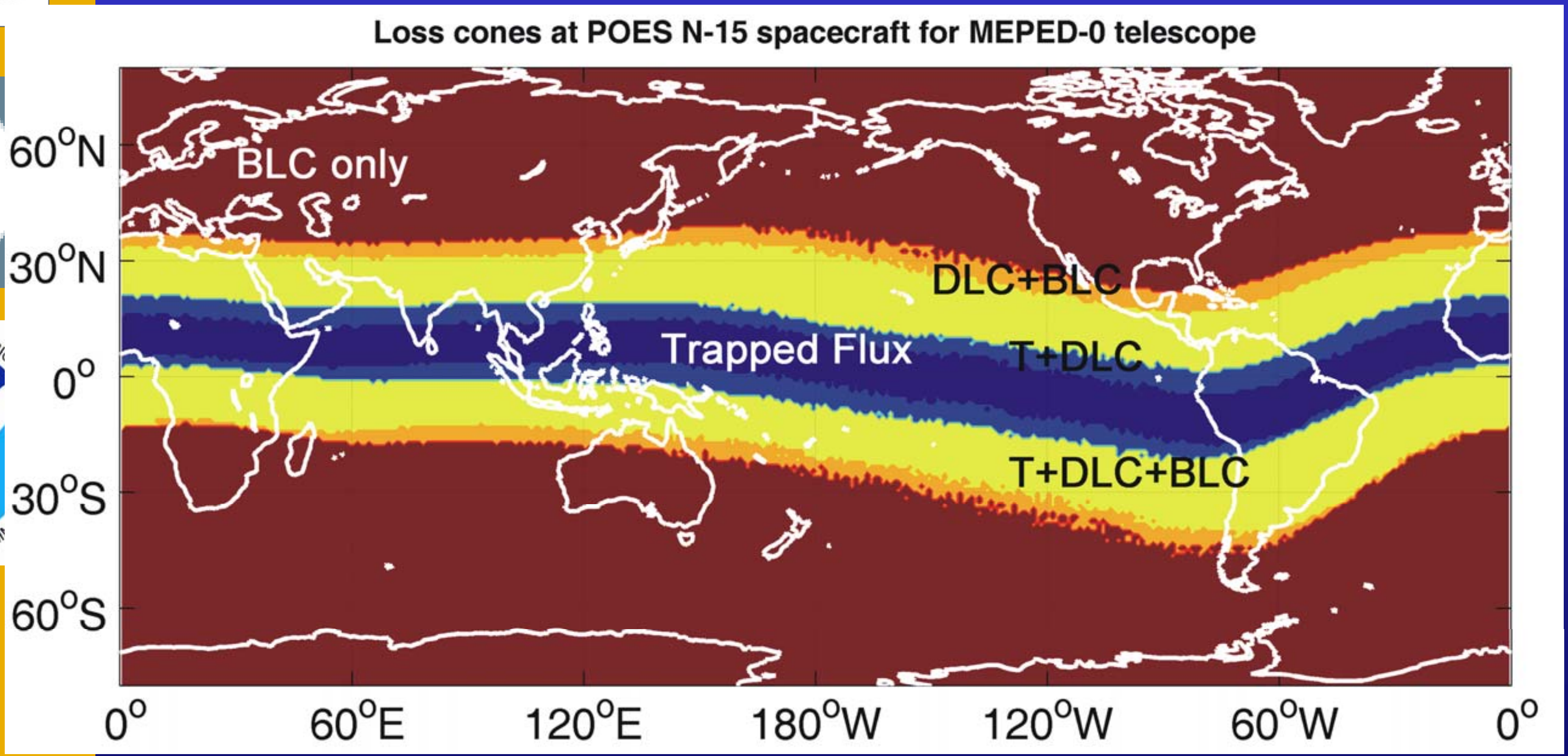
POES 90º detector is DLC and trapped

Combination of 5 months of >100keV 90º detector observations from the 4 NOAA POES spacecraft (N-15,-16,-17, & -18).



MEPED-0° BLC detector

By combining the central pitch angle measured at the spacecraft (which is in the datafiles), with the IGRF geomagnetic field model, we show that above about L=1.4, this instrument is measuring some part of the bounce loss cone.



In contrast, the $P6_{omni}$ detector, which responds to relativistic electrons (like the P6 telescopes), measures a combination of trapped, DLC and BLC at essentially all locations. Note that the "trapped" contribution is just above the loss cones!

Contamination of e1,e2,e3

It turns out that the "medium" energy electron channels of the POES SEM-2 package (the MEPED instrument) can be contaminated by lowish energy protons.

Data Channel	Energy Passband	Directionality	Contaminant
e1	>30 keV	0°, 90°	210-2700 keV protons
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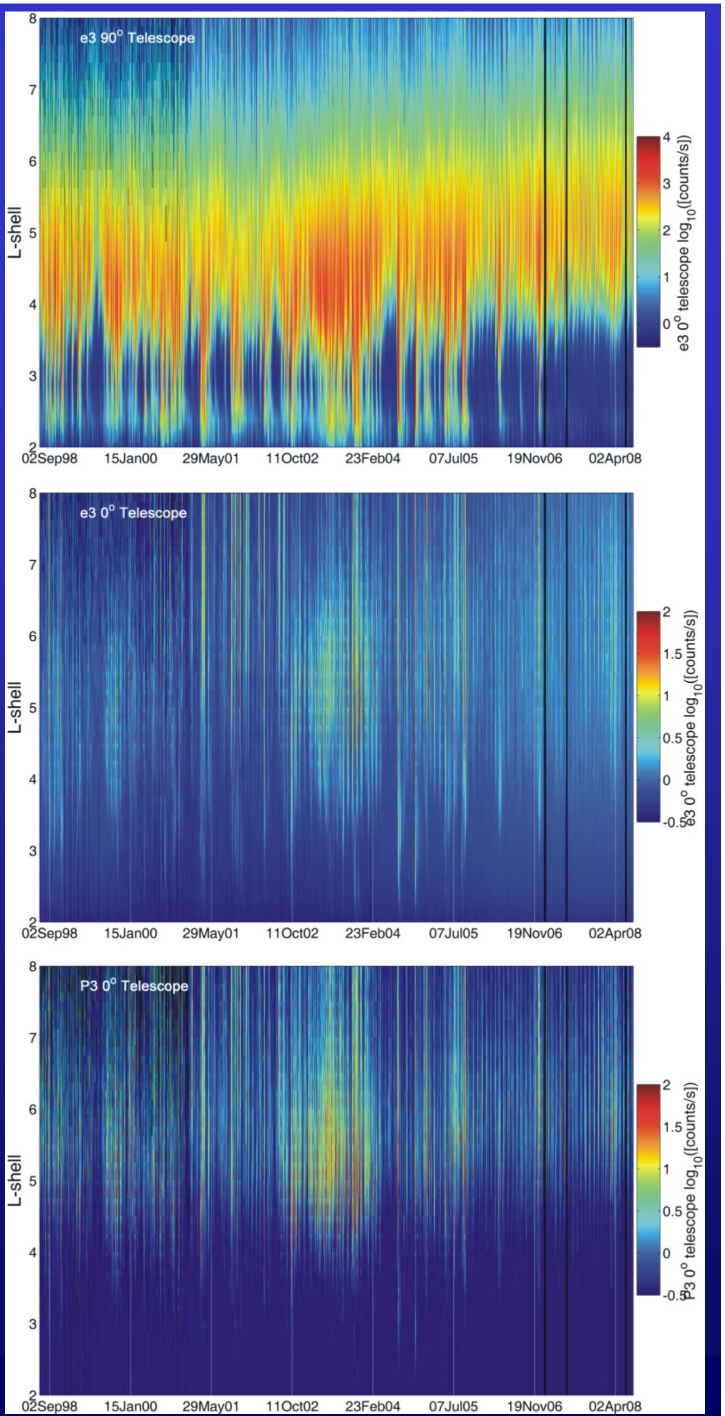
The SEM-1, while a different instrumental design, has a similar contamination problem for these channels (similar energy protons). Studies which have used SEM-1 (TIROS) and SEM-2 (POES) data to produce precipitation climatologies do not mention this issue. Oh dear!

Contamination – how bad?

This plot shows how strongly the e3 0º telescope (>300 keV BLC) resembles the P3 0º telescope (240-800 keV BLC). It is troubling that the channel which is thought to be measuring BLC electrons does not show the basic structure of the RB.

There is also a gross resemblance between the e3 90º telescope (>300 keV trapped) and the P3 plot. The question is, is this just "geophysics", or have those pesky protons stuffed most of the data?

The upper panel looks like a sensible plot of long-term radiation belt fluxes, after all.



Contamination of e1,e2,e3

In discussion with Janet Green (NOAA), I was provided with some simple "rules" for establishing that the reported flux was primarily electrons and not protons.

$$e1 > 2 \times P2$$

$$e2 > 2 \times P3$$

$$e3 > 2 \times P3$$

These are slightly conservative, but that suits my nature. Janet has also developed a technique to correct the fluxes too, and that data is now available through ViRBO.

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Contamination of e1,e2,e3

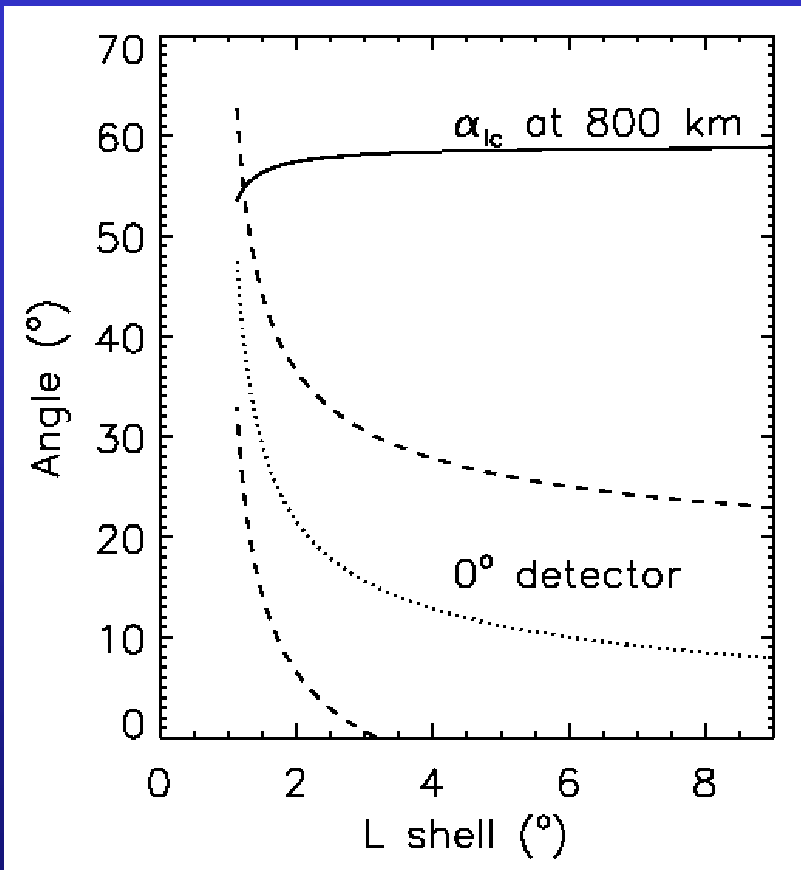
Generally, we are most interested in precipitation from the outer radiation belt, due to the high fluxes, and the link into the polar atmosphere. We will therefore restrict ourselves to the zone where *L*=4-7 and 1 December 1998-31 December 2007 (due to AE availability from the Kyoto WDC).

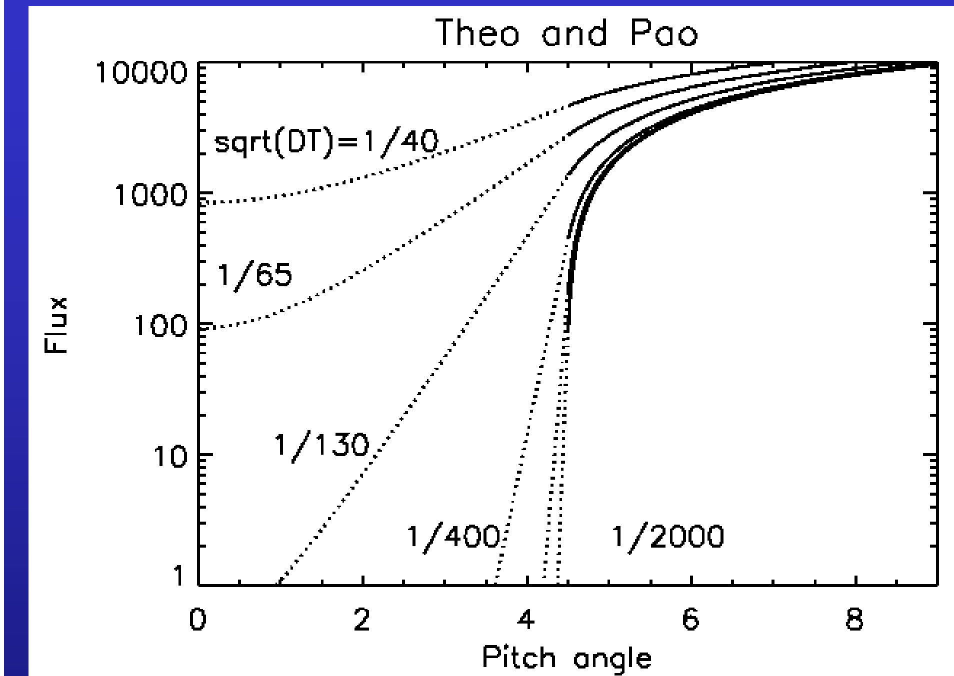
What percentage of the POES/SEM-2 medium electron observations are untrustworthy? How does this vary with geomagnetic activity?

Data Channel	Directionality	All	Quiet (AE≤150 nT)	Disturbed (AE>150 nT)
e1 (>30 keV)	90° (trapped)	1.3%	0.5%	2.0%
e2 (>100 keV)	90° (trapped)	0.4%	0.3%	0.6%
e3 (>300 keV)	90° (trapped)	3.5%	0.7%	6.4%
e1 (>30 keV)	0° (BLC)	22.7%	24.7%	20.6%
e2 (>100 keV)	0° (BLC)	10.2%	8.91%	11.6%
e3 (>300 keV)	0° (BLC)	41.7%	29.1%	55.0%

Trapped are mostly OK, while precipitating is badly affected, particularly when disturbed. This has worrying implications for the existing (and operational) climatologies. But it can be corrected for.

Measures PART of the BLC



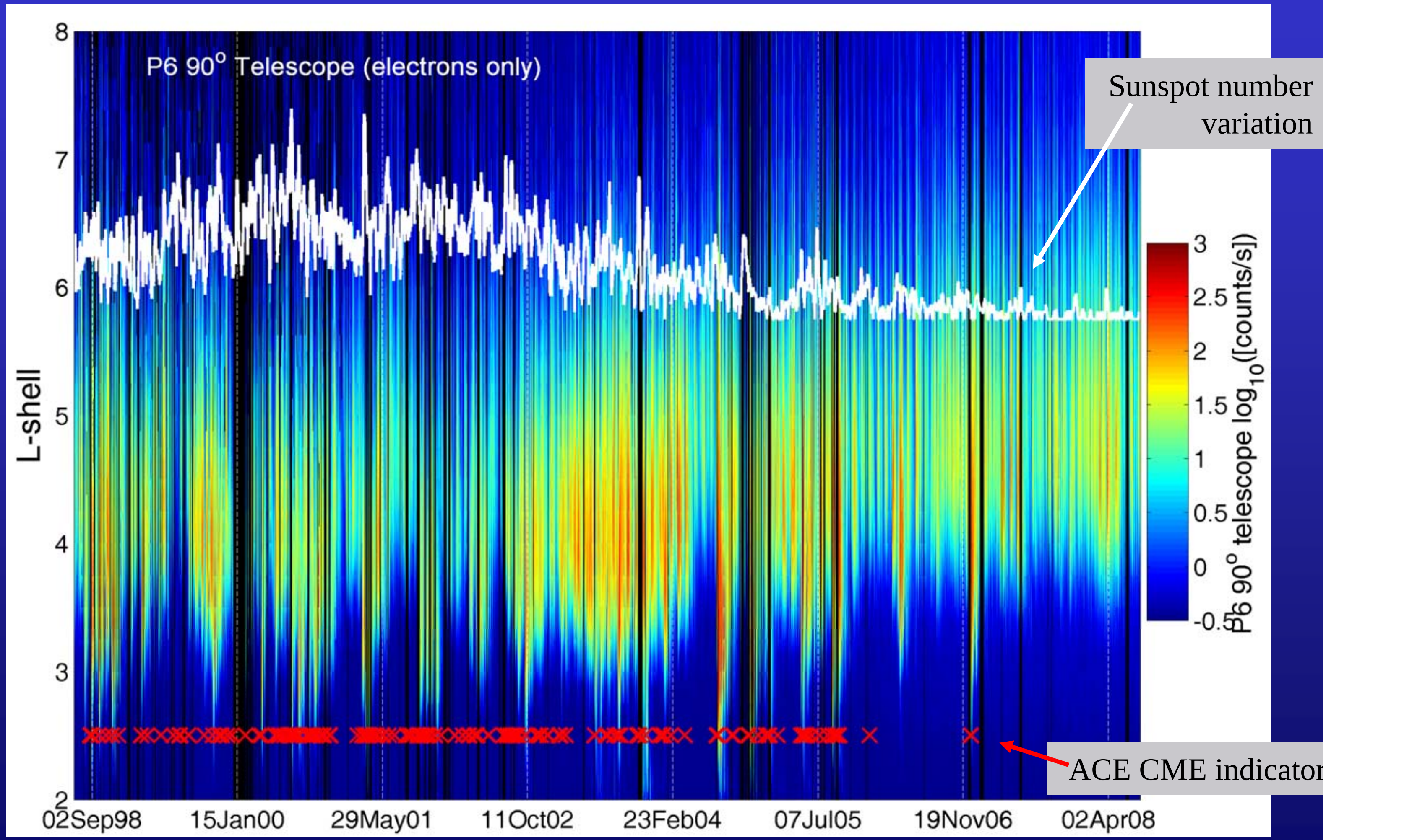


- NOAA POES may underestimate electron precipitation by <u>order of magnitude or more</u>

Estimate courtesy of Richard Horne (British Antarctic Survey)

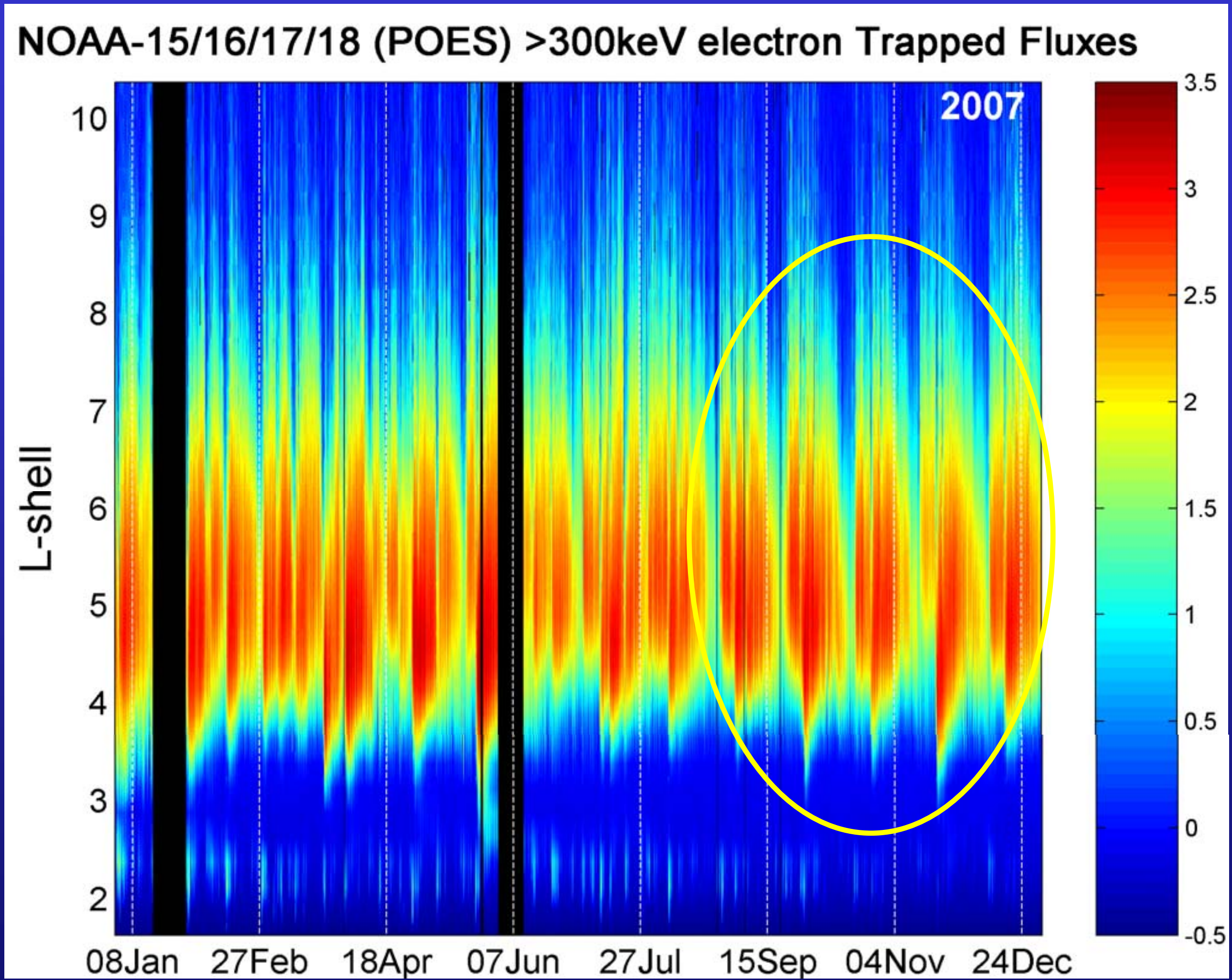
Trapped relativistic electrons

Lets look at the P6 “contamination” electrons which have energies above 700keV. What can we learn from these?



Observations primarily in the outer radiation belt, strong enhancement in the declining solar phase, occasional brief impulses through the slot. SPE do not obscure so much we can’t use these!

Periodic RB enhancements



It is well known that high-speed solar wind streams can produce enhancements in radiation belt fluxes. As these can come from long-lived coronal holes, they can reoccur over significant time scales showing a ~27 day periodicity.

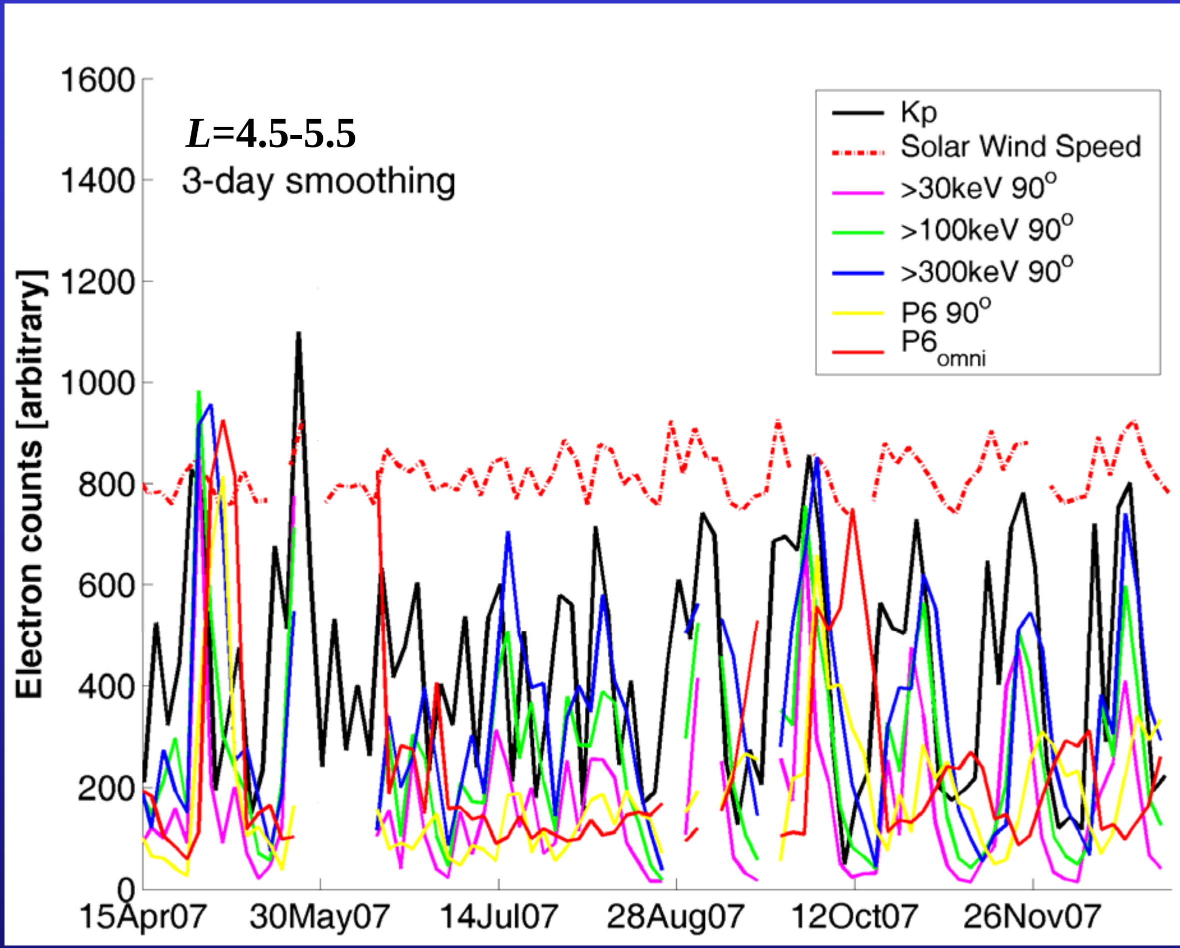
Periodic RB enhancements

Solar wind driver

(ACE solar wind speed)

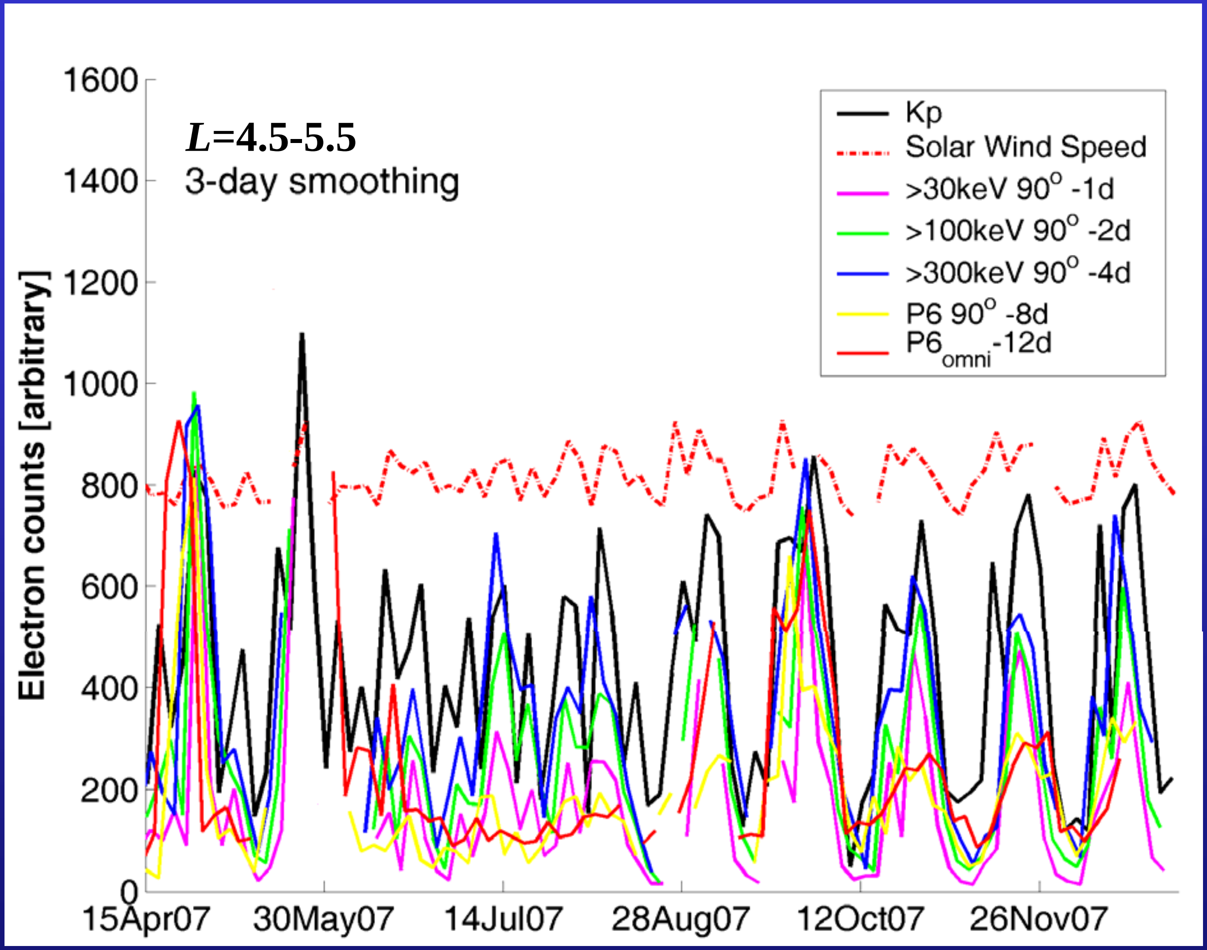
Looking at the relativistic electrons from the P6 90º (trapped) instrument, which responds to electrons with energies larger than about 700keV, we noted that the electron signature seemed to be offset from the solar wind driver.

Delays from solar wind to P6 90° e⁻



We noted that there seemed to be a slight time delay between the solar wind driver and the relativistic trapped fluxes reported by the P6 telescope detector. When one plots the various energy channels, they appear somewhat "jumbled".

Delays from solar wind to electrons



We have some other examples, but not as clear, and with some varying time delays.

It turns out that once the solar-wind driver starts causing strong period enhancements in the electron fluxes, there is an **energy dependent delay**, which brings the solar wind and Kp driver and all the fluxes into line. Signature of the acceleration process?

Time delays in enhanced electron fluxes

POES (low-altitudes), i.e., about to be lost

	inside Plasmapause				
Time Period	**>30 keV**	**>100 keV**	**>300 keV**	**P6 90°**	**P6$_{omni}$**
mid-August to late October 1999	1	2	3	4	5
mid-August 2003 to mid-March 2004	1	1	2	5	6
April 2006	0	1	1	3	3
mid-March to late May 2007	0	1	2	5	8
mid-August to end-December 2007	1	2	3	9	12
average delay in days	**1**	**1**	**2**	**5**	7

Taking a series of periods in which periodic RB enhancements are seen, we looked at the delays (and confirmed them by cross correlation).

The values above are also representative of those outside the plasmapause (described through a statistically determined PP model [*Moldwin et al.*, 2002]).

Time delays in enhanced electron fluxes

GOES-12 (geomagnetic equator), i.e., mostly trapped

Time Period	>600 keV	>2 MeV
mid-August to late October 1999	1	2
mid-August 2003 to mid-March 2004	2	3
April 2006	2	3
mid-March to late May 2007	2	5
mid-August to end-December 2007	3	7
average delay in days	**2**	**4**

Observations of trapped relativistic electron fluxes near the geomagnetic equator by GOES show similar delays, indicating a "coherency" to the radiation belts at high and low orbits, and also a strong link between trapped and precipitating particle fluxes.

Such large delays should have consequences for the timing of the atmospheric impact of geomagnetic storms.

Time delays in all processes

Periodic enhancements in relativistic electron fluxes associated with the 27-day solar rotation period have previously been reported at geostationary orbits [e.g., *Blake et al.*, 1997], and linked to high speed streams.

In addition, time delays between the beginning of the acceleration driver and the appearance of energetic electron flux enhancements in the RB are expected from a theoretical perspective, irrespective of whether the process is a VLF wave driven local heating or ULF-wave driven transport. **This means precipitation into the atmosphere will last a long time from low-ish energy through to MeV stuff!**

Our study has shown much longer delays than commonly expected, such that the relativistic enhancement (and precipitation) might even be interpreted as being de-coupled from the storm itself.

This was possible to see due to the long sequence of periodic high speed solar wind periods. Thus it really stands out. NOT NEW NEWS, but should emphasise how the precipitation will go on and on!

While we have heard at HEPPA that lower energy (<30keV) might be the “dominant” source of NO_x in the middle atmosphere, some case-studies would disagree.

For example, in mid February 2004, a highly energetic electron precipitation event (REP of >1 MeV electrons) doubled the NO_x population (early Feb compared with late Feb).

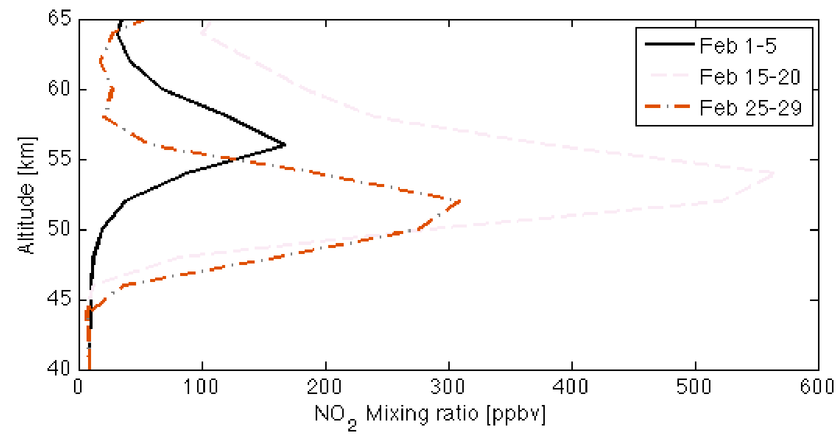
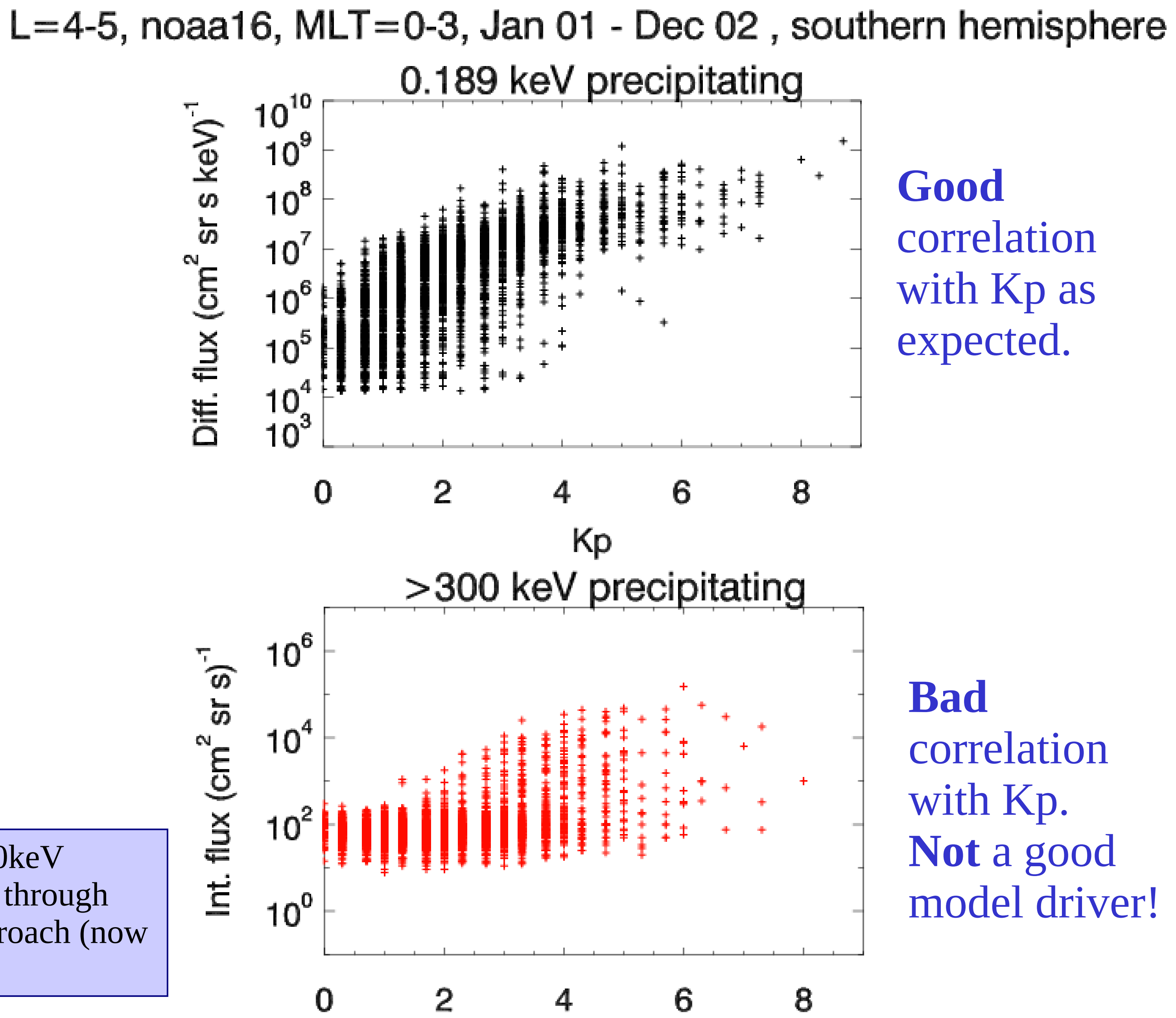


Figure 5. (top) Showing the variation in the latitude range 65–75°N of the NO_2 mixing ratio with altitude during three selected periods during February 2004. The blue line represents observations made before the onset of the geomagnetic storm period, the green line is during the geomagnetic storm, and the red line is after the end of the storm. (bottom) The 2-day average mixing ratio (circles) at the peak of the descending NO_x feature (squares represent the altitude of the peak), measured during January and February. There was a gradual increase in mixing ratio from low levels at the start of January, leveling off at ~150 ppbv between 22 January and 5 February, then increasing from 14 February, leveling off again at ~300 ppbv by the end of the month, consistent with Figure 5 (top).

Measurements from Envisat/ GOMOS!

Clilverd, M A, A Seppälä, C J Rodger, M G Mlynczak, and J U Kozyra, Additional stratospheric NOx production by relativistic electron precipitation during the 2004 spring NOx descent event, J. Geophys. Res., 114, A04305, doi:10.1029/2008JA013472, 2009.

Issue for Kp-driven EPP climatology



Good correlation with Kp as expected.

Bad correlation with Kp. **Not** a good model driver!

Note, these >300keV fluxes corrected through Janet Green approach (now in VirBO).

Summary

- Better quality understanding is needed to describe the precipitation of electrons with energies >20keV (for RB and atmosphere)
- The POES SEM-2 observations could well be useful for this, although one needs to be aware of the very significant amounts of contamination in the electron telescopes.
- Fortuitously, the POES SEM-2 proton channels can provide valuable insight into the behaviour of relativistic electrons.
- there is an energy-dependent time delay observed in the POES/SEM-2 observations, with the relativistic electron enhancement (electrons above 800 keV) delayed by ~1-week relative to the >30 keV electron enhancement, possible due to the timescales of the acceleration processes.
- Enhancements driven by high speed solar wind streams show these time delays, but it is not clear that RB enhancements from CME-shocks have such delays.

It's Over! Craig attempting to sleep in a snow "coffin" several meters under the ground, during Antarctic Field Training on the Ross Sea Ice Shelf [December 2008].

Thankyou!

Are there any questions?