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What the Swarm mission may tell us about the South Atlantic Anomaly

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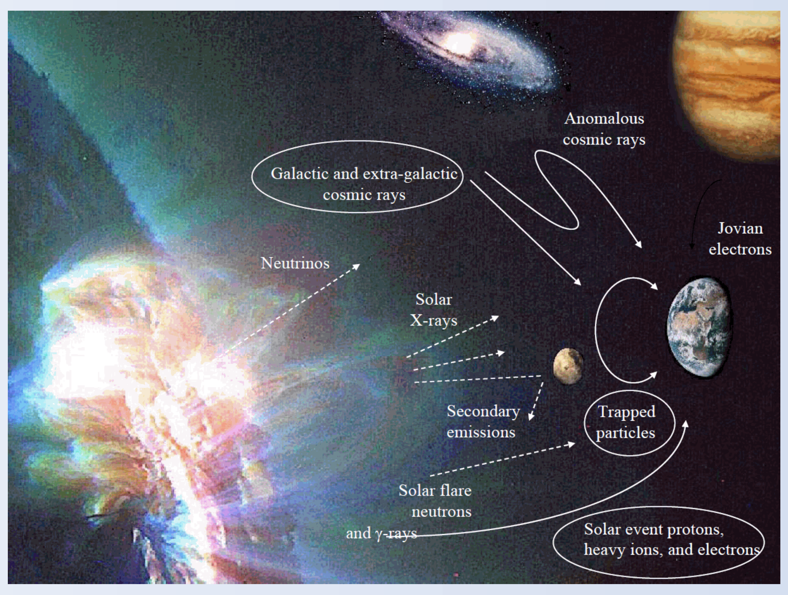
The South Atlantic Anomaly (SAA) is often simply mapped using total intensity values taken from spherical harmonic models of the Earth's magnetic field. These models are derived from magnetic field observations taken by satellites and observatories and it is expected that data from the forthcoming Swarm mission will make a significant contribution to them. However, the location of the SAA as it affects Low Earth Orbiting (LEO) satellites is more completely determined by considering charged particle trajectories in the Earth's magnetic field. To include the effects of solar wind variations and magnetic storms, dynamic radiation belt models are used, and they generally assume that the Earth's magnetic field is dipolar. In order to quantify the effect of the omission of the non-dipolar terms and how it is changing with time, we calculate loss cones for trapped particles in the SAA region at typical LEO altitudes using a full spherical harmonic model and a simplified dipolar model. We also compare the results with SAA peak locations through time as derived from the along-track scanning radiometer series of instruments on board the ERS-1, ERS-2 and ENVISAT satellites.

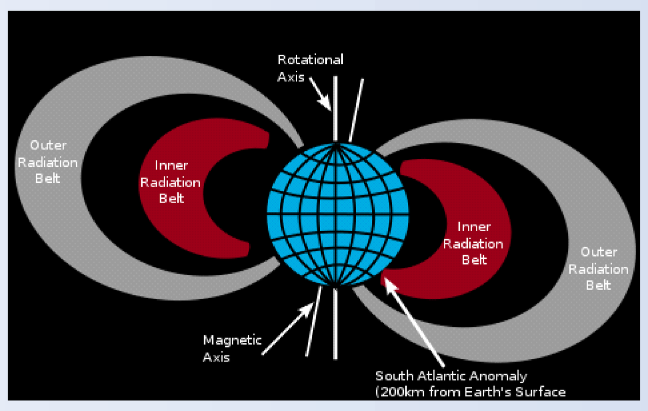
What is the SAA?

The South Atlantic Anomaly (SAA) is a region spanning the southern Atlantic and South America where the Earth's magnetic field is at its weakest. In the SAA the field is about 1/3 the strength of the field near the magnetic poles and this affects how close to the Earth energetic charged particles can reach. What's more, the SAA is deepening - the minimum strength now is 6% lower than it was at the start of the space age 50 years ago.

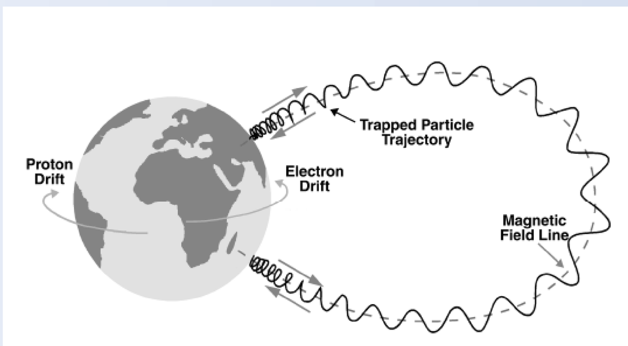
The particles have 2 main sources: (1) trapped radiation which originates from the Sun with the protons being the most hazardous to satellites and (2) galactic cosmic rays which are extremely energetic. The trapped radiation is in two belts:



• inner belt dominated by energetic protons up to ~400 MeV energy range
– product of cosmic ray neutron decay
– inner edge is encountered as the SAA
– affects Space Station and Low Earth Orbiting (LEO) satellites (altitude < 2000 km)



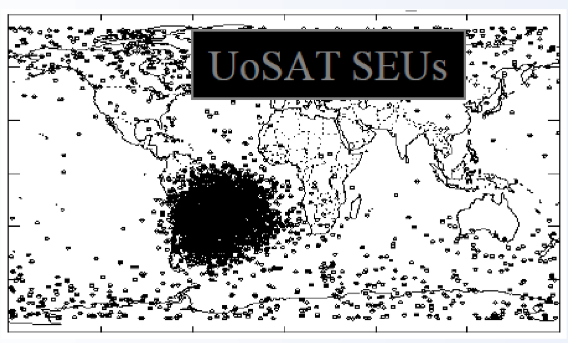
• outer belt dominated by energetic electrons up to 7 MeV
– frequent injections and drop-outs associated with storms and solar material interacting with the magnetosphere
– affects geostationary orbit environment (mostly telecom) and navigation (Galileo, GPS) orbits (20000 - 36000 km), as well as science missions in highly elliptic orbits



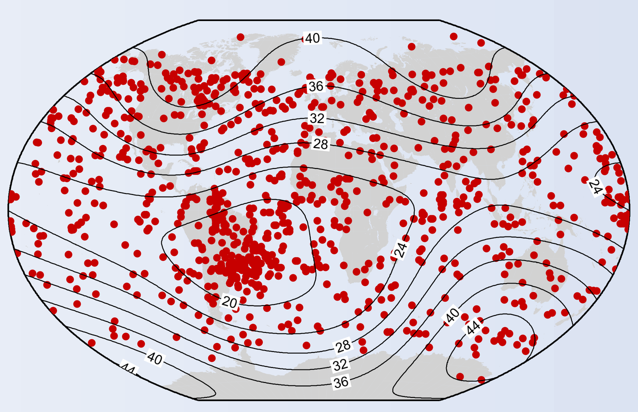
For satellites radiation affects electronic, optical and computer systems and can also cause surface charging. These problems are worse for satellites over the polar regions and for LEO satellites over the SAA.

Locating the SAA

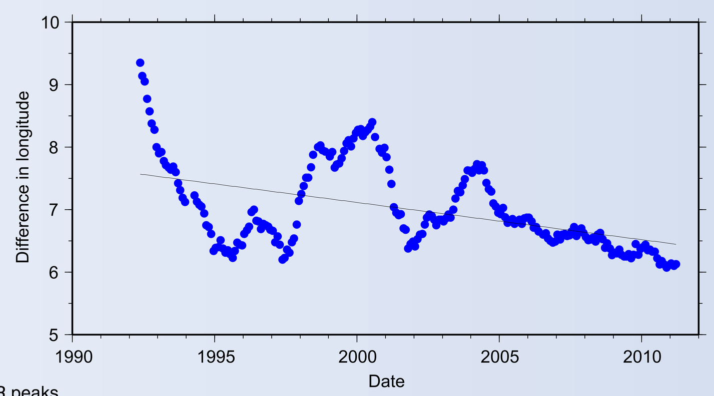
Below are examples of satellite anomalies clustering in SAA. Shown are locations of University of Surrey satellite single event upsets (left) and satellite anomaly dataset anom5j.xls from www.ngdc.noaa.gov/stp/satellite/anomaly/doc/ with contours of strength of the magnetic field (right).



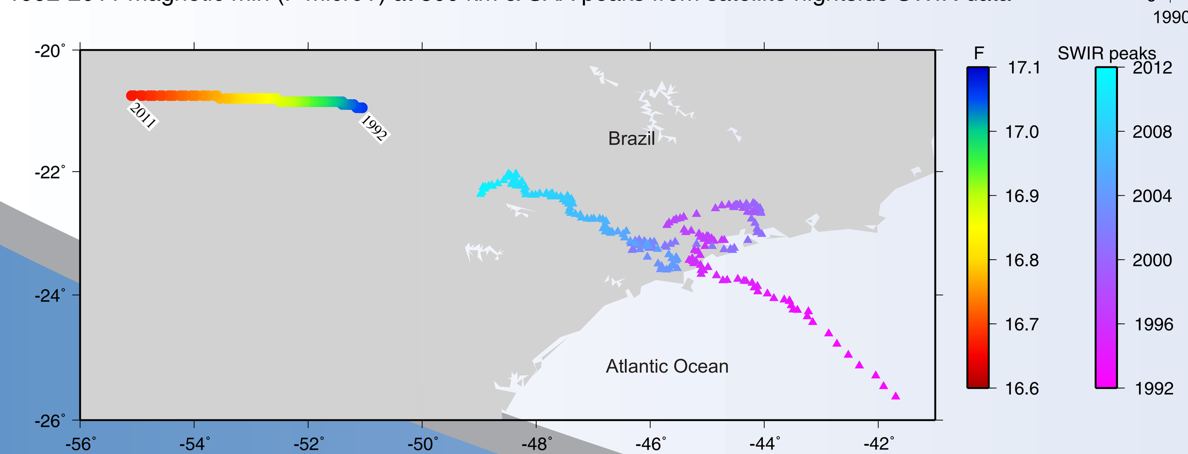
IGRF total intensity at 1990 at 800 km and NGDC satellite anomalies 1986-1992



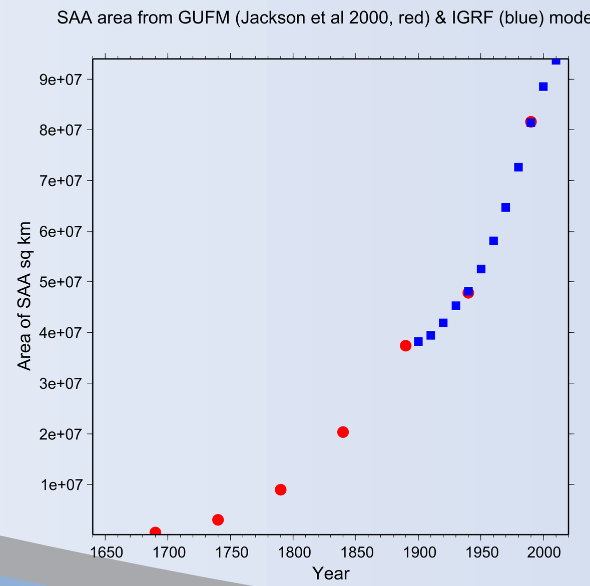
The plot (below left) shows the recent westward movement and deepening of the SAA from a magnetic field model (updated from Thomson *et al*, 2010) and from analysis of noise in nightside short-wavelength infrared (SWIR) radiometer data from ERS-1, ERS-2 and ENVISAT satellites (Casadio & Arino, 2011, Casadio, 2011). The offset between loci of magnetic field minima and SAA peaks as derived from SWIR data shows us that the SAA, as it affects satellites, is not necessarily where we expect it from models. The offset varies with time (right) in a manner that is not obviously linked with solar activity.



1992-2011 magnetic min (F microT) at 800 km & SAA peaks from satellite nightside SWIR data



SAA area from GUFM (Jackson et al 2000, red) & IGRF (blue) models



The area of the SAA has increased since 1600 and the rate of increase is highest during the space age (above).

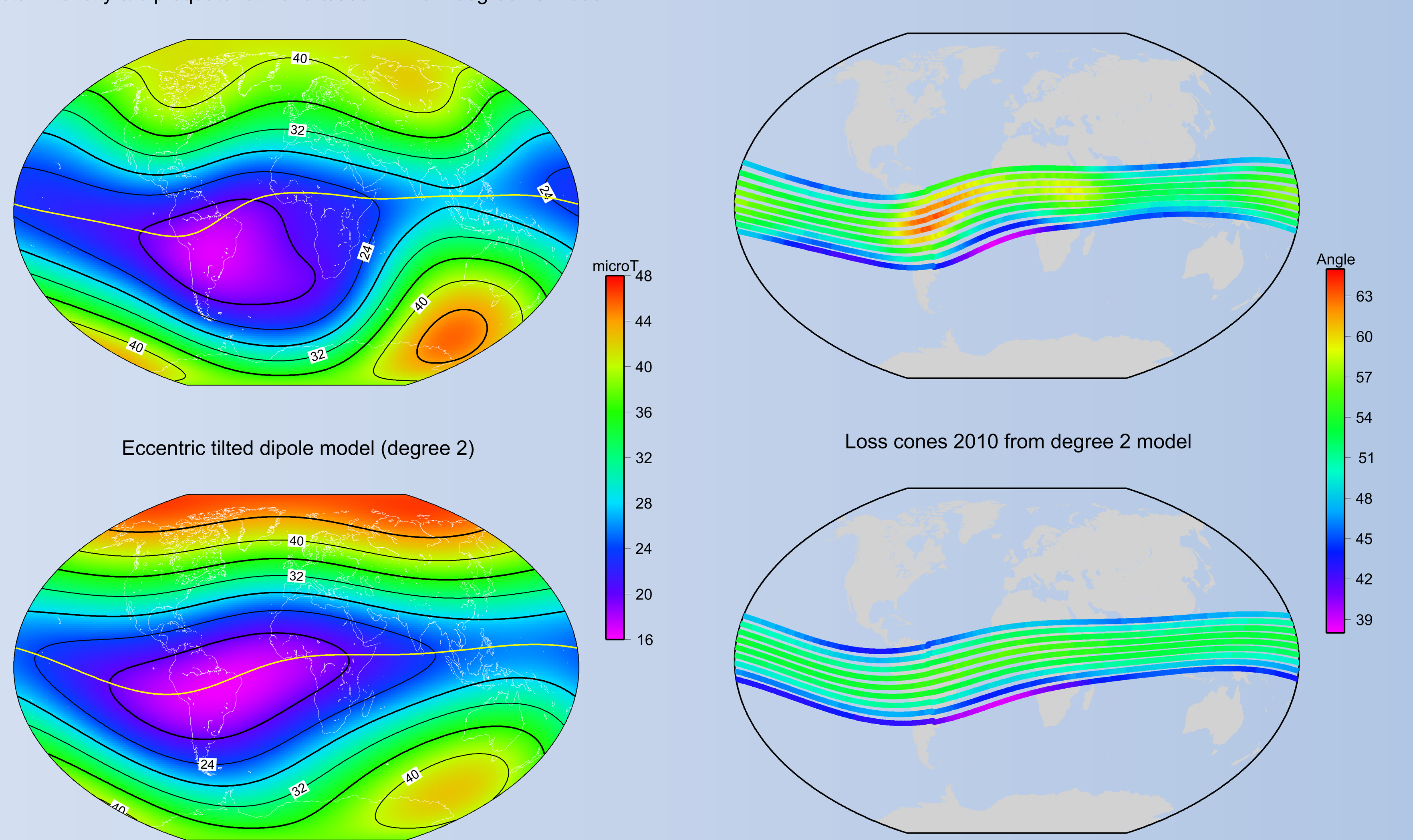
Dipolar or multipolar magnetic field?

The difference between the SAA as mapped by all spherical harmonics of a core field model and by a truncated eccentric dipole version of same model is quite marked (below left). In dynamic radiation belt models simple magnetic field models are generally used.

To assess the impact on charged particle trajectories and life expectancies we have estimated the loss cones for particles at the latitudes of the SAA using a full and an eccentric dipolar model in a field-line tracing program (Geopack-2005 by Tsyganenko) (below right). The calculations have been done at a typical LEO altitude of 800 km. The local loss cone angle α is computed from

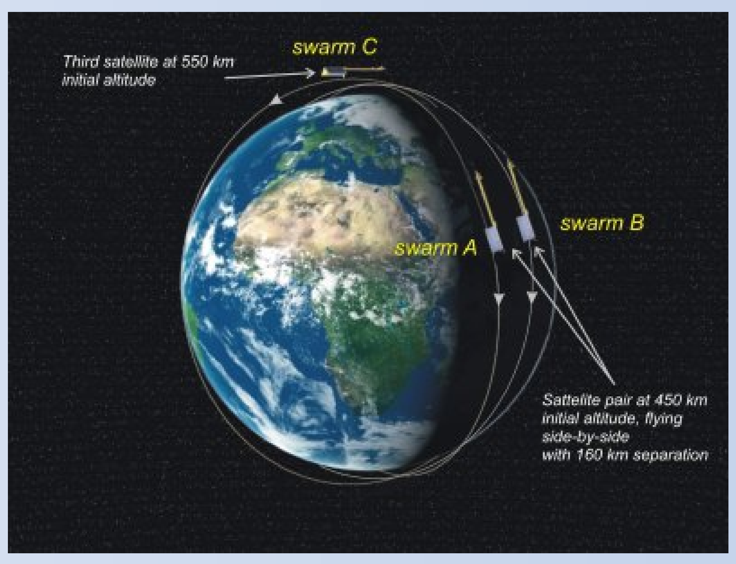
$$\alpha = \sin^{-1}\sqrt{B_0/B_m}$$

where B_o and B_m are magnetic field intensities at magnetic equator and mirror point respectively. The direction of drift is determined from the local declination.



It can be seen that if a simple dipolar model of the magnetic field is used, the loss cones are underestimated. However it is acknowledged that the wide usage of the L parameter in radiation belt models is not the same as assuming that the Earth's magnetic field is dipolar.

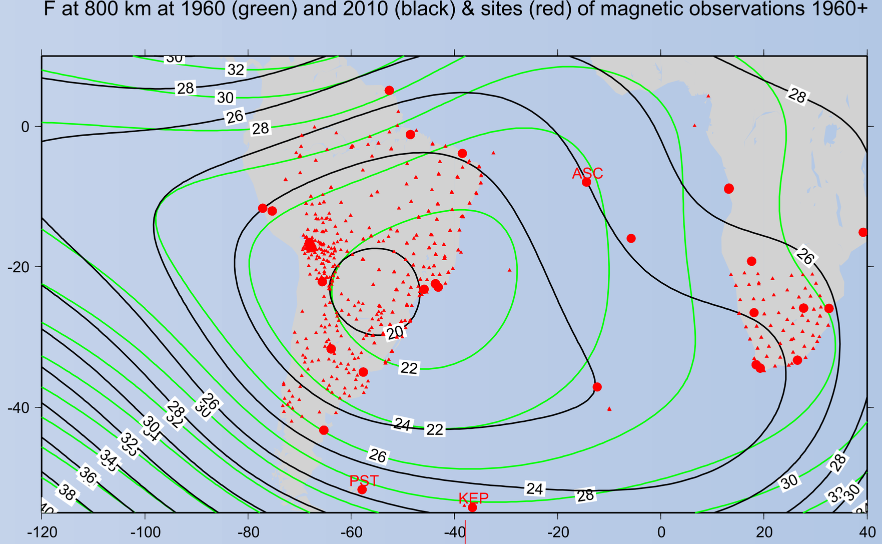
Swarm's contribution



Swarm is an ESA 3-satellite LEO mission due for launch July 2012. The magnetic data will provide accurate models of the magnetic field over the next 10 years and these will be essential to mapping the extent of the SAA during this time. It should also be possible to investigate the effect of solar activity on the SAA especially if the mission lasts longer than its expected 5 year lifespan. Ion and electron velocities, temperatures, electron numbers and electric fields will also be measured and these will help us better understand the lower regions of the inner radiation belts in the SAA.

Ground observations are also important (right) and the BGS operates 3 observatories in the south Atlantic (ASC, PST and KEP re-established Feb 2011).

F at 800 km at 1960 (green) and 2010 (black) & sites (red) of magnetic observations 1960+



Improved predictions of the magnetic field are important for mapping the SAA for satellite operators. Inverting magnetic data directly for core flow and acceleration (assuming flux is frozen which is deemed valid over the relatively short time spans of the data) and then advecting the resultant field forward in time improves forecast accuracy (Beggan & Whaler, 2010).

References and Acknowledgements

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