



The Impact of Space Weather on Inmarsat Satellite Fleet Operations

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April 2012, Boulder



Overview of the Inmarsat satellite fleet

Inmarsat's satellite design requirements

Operational impacts from space weather events

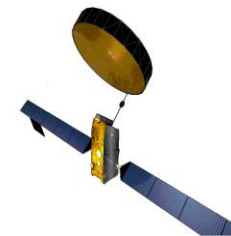
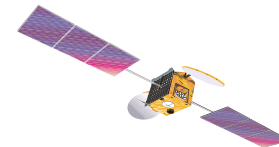
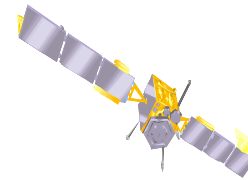
- **Short term (e.g. single event upsets)**
- **Longer term (e.g. solar array performance)**

Use of space weather observations

Future satellite design considerations and conclusions

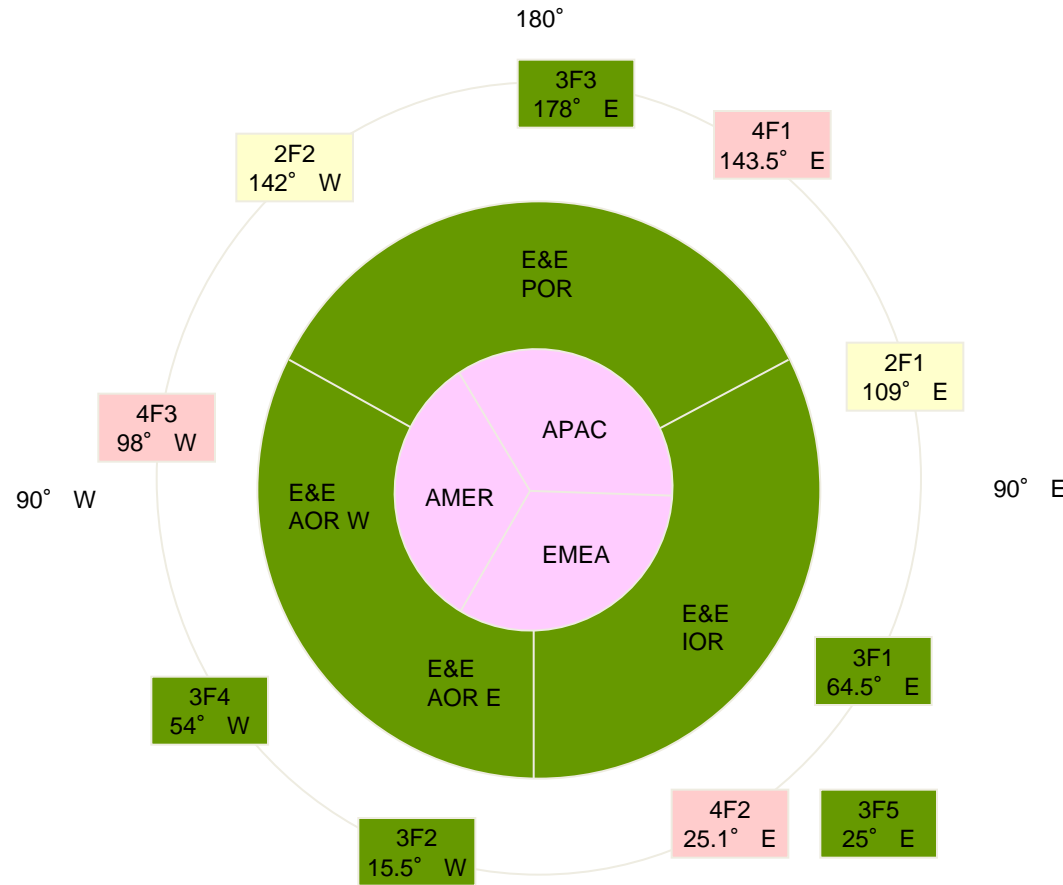
Inmarsat's Fleet

- 10 geostationary mobile communication satellites (L-band user link)
- 4 x Inmarsat-2 (2 still operational)
 - Launched 1990 to 1992
 - British Aerospace Eurostar 1000 platform
 - Providing voice, fax and maritime safety of life services
- 5 x Inmarsat-3
 - Launched 1996 to 1998
 - Lockheed Martin A4000 platform
 - Spot beam services and navigation
- 3 x Inmarsat-4
 - Launched 2005 to 2008
 - Astrium Eurostar 3000 platform
 - Spot beam services and navigation
- 4 more satellites on-order
 - Astrium/TAS Alphasat (2013)
 - 3 x Inmarsat-5, Boeing 702s (2013/14)

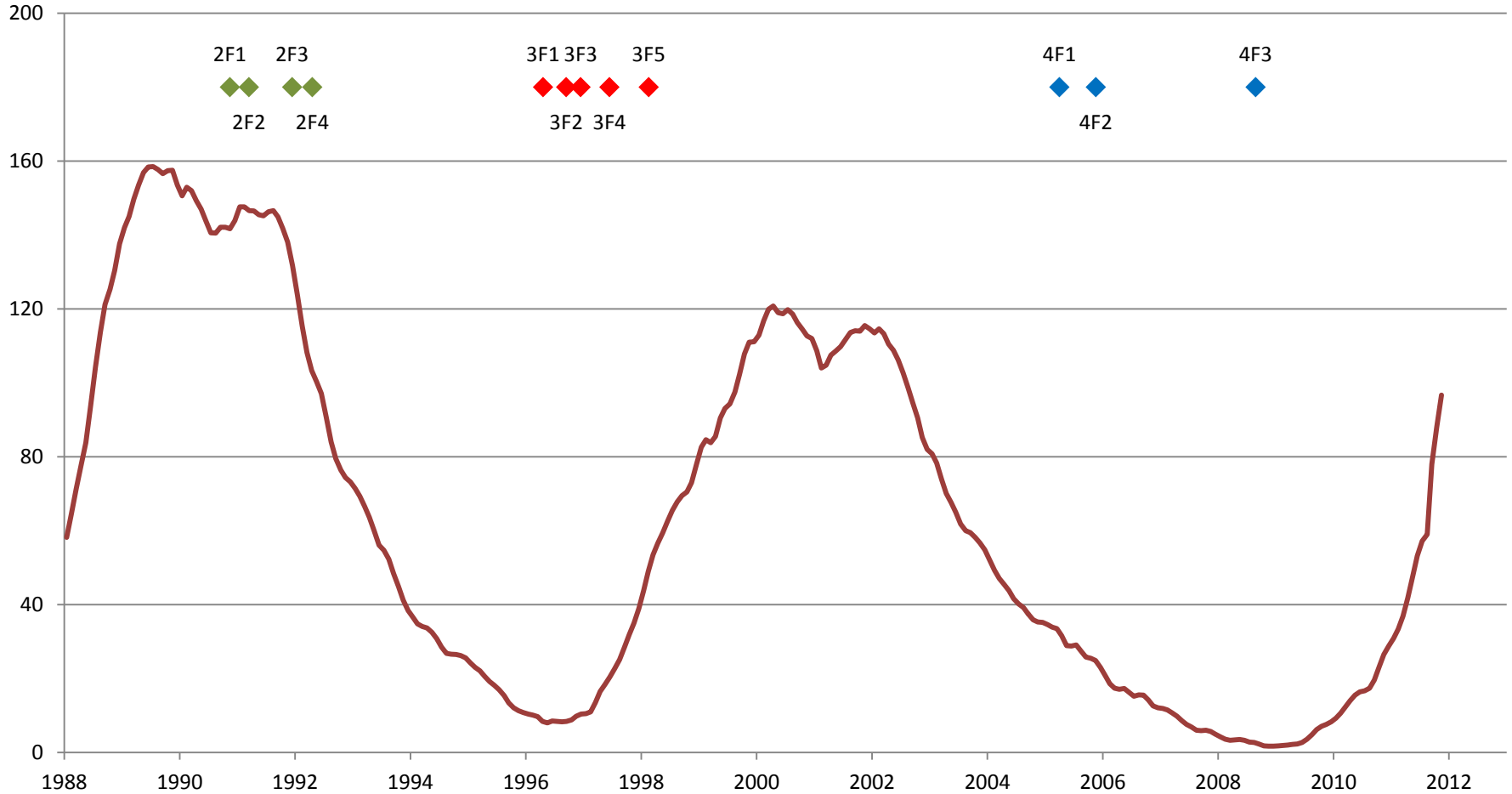


Inmarsat's Fleet (as of April 2012)

	Launch Date	Years in orbit	Location
2F1	30-Oct-90	21.48	109.0 E
2F2	05-Mar-91	21.16	142.0 W
<i>2F3</i>	<i>16-Dec-91</i>	<i>15.16</i>	<i>Decommissioned 2006</i>
<i>2F4</i>	<i>15-Apr-92</i>	<i>20.05</i>	<i>Decommissioned 2012</i>
3F1	03-Apr-96	16.08	64.5 E
3F2	06-Sep-96	15.65	15.5 W
3F3	18-Dec-96	15.27	178.1 E
3F4	03-Jun-97	14.92	54 W
3F5	04-Feb-98	14.20	24.75 E
4F1	12-Mar-05	7.14	143.5 E
4F2	08-Nov-05	6.48	25.1 E
4F3	18-Aug-08	3.70	97.65 W
	Total	171.45	



Satellite Launch Date vs Avg Sunspot Number



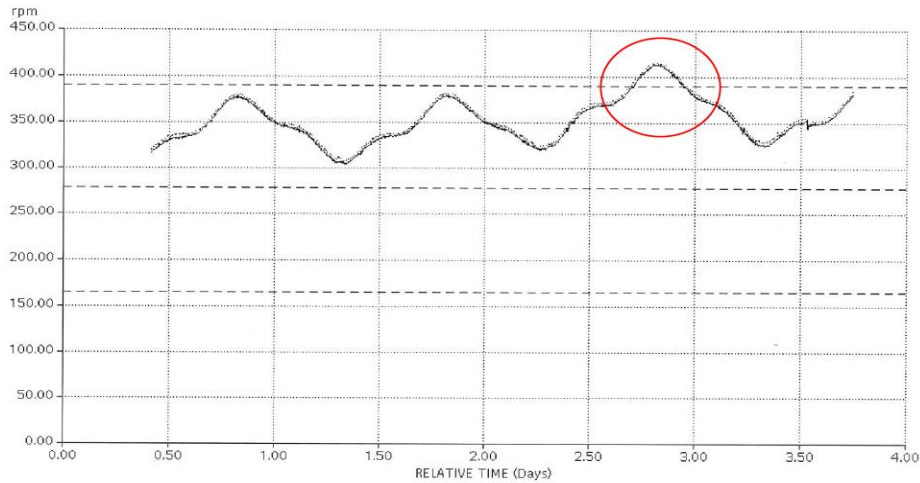
Satellite Design Requirements

- Like all commercial fleet operators, we place stringent requirements on the manufacturers of our satellites
 - Demonstrate proven flight heritage and/or extensive testing
 - Sound designs to ensure required levels of shielding, mitigation of single point failures and unit/system redundancy
- For the radiation environment the manufacturers have to demonstrate component/unit survivability for:
 - Trapped and plasma electron environments
 - Trapped, plasma and solar flare proton environments
 - Cosmic Ray and UV radiation
 - Micrometeoroides
 - Deep charging electron environment
 - Surface charging environment

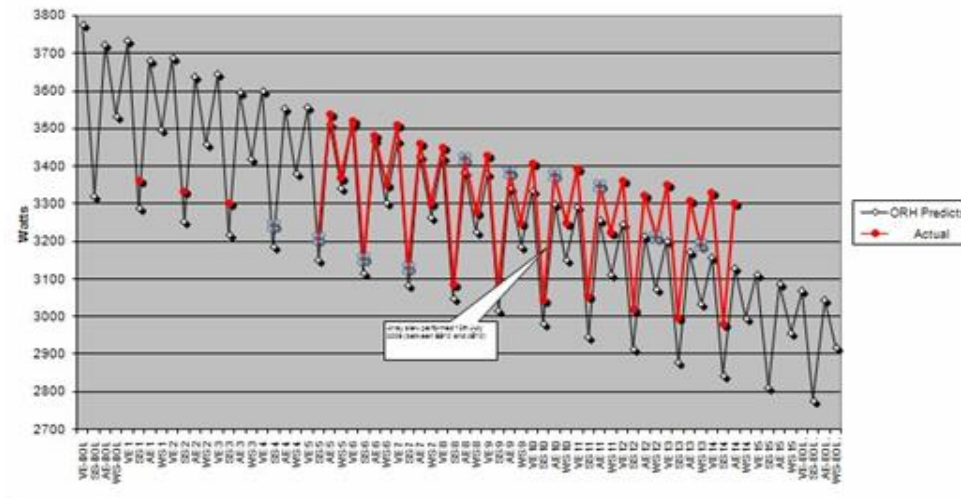
Operational Consideration - 1

- In the 170+ yrs of satellite operations we haven't changed a planned operational activity due to predicted or reported space weather activity....why?
 - Naivety, lack of timely/accurate actionable information or good design/operations? Or most likely a combination of these!
-that is not to say we don't see the effects of space weather
 - We see sporadic single event upsets (SEUs) across the fleet. Handled either using on-board redundancy or via ground system detection and recovery
 - Some of our satellites can suffer a SEU which results in a comms payload trip-off. Our ground control system has automation functionality to allow the detection and automatic quick recovery (within ~60 sec) rather than many minutes required for manual recovery.
 - We do see attitude disturbances coincident with periods of high solar activity. We respond reactively rather than pre-empting any possible impact e.g. we have aborted a number of manoeuvres
 - Long term exposure is monitored e.g. UV solar array degradation. Luckily to date degradation is less than predicted.

Operational Consideration - 2



Solar Array Performance
Predicted v Actual



Use Of Space Weather Data

- Our operations teams do subscribe to the NOAA notifications, information and web services
 - Used to provide context within which satellite issues are analysed
 - Post event analysis
- The lack of real-time actionable data means that we don't change our operational plan.
- What would help?
 - More accurate estimates of arrival time/location/magnitude of particles flux, magnetic orientation etc
 - Predicted effect at various GEO longitudes
- We also have to be careful of the 'management effect'; a lot of people not related to operations also subscribe to these notifications and can generate significant 'noise'. Also peaks of interest from the media...

Operations - Star Trackers

- Inmarsat's satellites have used infrared Earth sensors as part of the on-station attitude determination. Next generation of satellites will utilise star trackers.
- Operationally need to modify star trackers processing during periods of high solar activity to stop sensor 'dazzling' or 'blinding'
 - Switch to use gyros, pointing implications?
- Recent solar storm (03/07) saw multiple satellites experience star tracker 'blindness'
 - ESA's Venus Express (<http://www.space.com/14834-solar-storm-blinds-venus-express-spacecraft.html>)

"We were not able to detect any stars, so we decided to switch to the B unit, but we saw exactly the same thing," Camino told SPACE.com. "Both of them were blinded by heavy solar activity. Since then, we have not been able to get them back on track, so we are doing a lot of things in order to keep the spacecraft in a safe configuration." Octavio Camino, the Venus Express spacecraft operation manager
 - Sat X went to safe mode (Sun pointing), nearly 24 hrs to regain nominal pointing.
- Do we now need to make real-time use of space weather information to drive operations? We hope not, on-board systems should provide protection and automatic switch to gyros

Inmarsat's next steps....

- Inmarsat's next satellite, Alphasat (launched 2013), will include a Environment and Effects Facility (AEEF) detector (<http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=26290>)
 - Unit to study the behaviour of existing electronics technology to the space environment
 - Radiation surveyor able to detect and measure particle energy and type
 - 3 year mission (25E), data will be in the public domain.
- We are undertaking a study to examine data associated with equipment anomalies with historical space weather information
 - Aim is to see if we are able detect early anomaly signatures and provide feedback to manufacturers for design improvements or future requirements
- Inmarsat is one of the founder members of the Space Data Association (SDA), a not for profit operator lead organisation for improving safety of flight and space situational awareness (conjunction and RFI mitigation) it also has a database operational POCs which could provide a useful mechanism for hosting real-time space weather/satellite impact information.

Conclusions

- The Inmarsat satellites are certainly susceptible to space weather conditions, but they have been specifically designed to minimise the operational and service impacts caused by of these types of events.
- With our 170+ yrs of on-orbit operational heritage, which has included 9 satellites through a full solar cycle, Inmarsat has not to date suffered any prolonged service outage or permanent satellite component failure directly attributable to a solar or a more general space weather event.
 - This is a good indication that the engineering and oversight of the design of our satellites, some of which dates back over 25 years, has provided the level of protection expected
- Inmarsat doesn't currently use space weather information as a driver to direct operational decisions, but rather for post event analysis
-however, we will be looking at how we need to operate new satellite features within the space environment and how space weather information can play its part.