Space Weather
-Effects on Aviation

An ATM Perspective

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Space Weather

- Space Weather is a natural Phenomena and aviation operations have experienced the impact of previous 'normal' space weather events.
- The 'concept of operation' has evolved to provide mitigations, through diversity and redundant systems and operational procedures.
- The sun's output is not constant and the variations resulting in increased space weather are not currently predictable with a high degree of certainty.
- The interaction of solar emissions with the magnetosphere and upper atmosphere are also not fully understood.
- The key word relating to Space Weather is therefore **Uncertainty**
- As aviation operations and technologies evolve, the dependency on the technical infrastructure increases:
  - *Higher flight levels*
  - *Reduced lateral and longitudinal spacing*
  - *Future use of GNSS Altimetry (?)*
  - *Increased use of Satellite Communications and data-link*
  - *Increased use of GNSS for navigation and other aviation operations*
  - *Rationalisation of ground navigation facilities*
  - *technology, smaller chip sizes, lower supply voltages, reduced noise margins….*
- There is justification to assess aviation's resilience to Space Weather.
- The catalyst for current interest is the 2013 peak in the 11 Year solar cycle.
- **However, the Extreme Space Weather Event could happen at any time**

Extreme Space Weather Events

- The most significant Space Weather event was in September 1859, often referred to as the 'Carrington Event'.
  - Was a large Coronal Mass Ejection that was a 'direct hit' on the earth
  - 1859 was not significant in terms of Sunspot Count
  - Pre-technological age, but railway telegraphs burnt out.
  - Aurora were seen in Hawaii and Caribbean
  - Early magnetometer recordings exist,
  - Few events in the space Age.

- The UK Royal Academy of Engineering has reported on *"The impact of Extreme Space Weather on engineered systems and Infrastructure"*
  - http://www.raeng.org.uk/news/publications/list/reports/Space_Weather_Full_Report_Final.PDF
  - Considered to be a 1 in 100-200 Year risk.

- The impact of an Extreme, 'Carrington' sized event is **uncertain**, it was at least an order of magnitude greater than any event experienced during the space age.

- The Royal Academy of Engineering report suggested:

  Engineering out as much risk as reasonably possible and then adopting operational strategies to deal with the residual risk."

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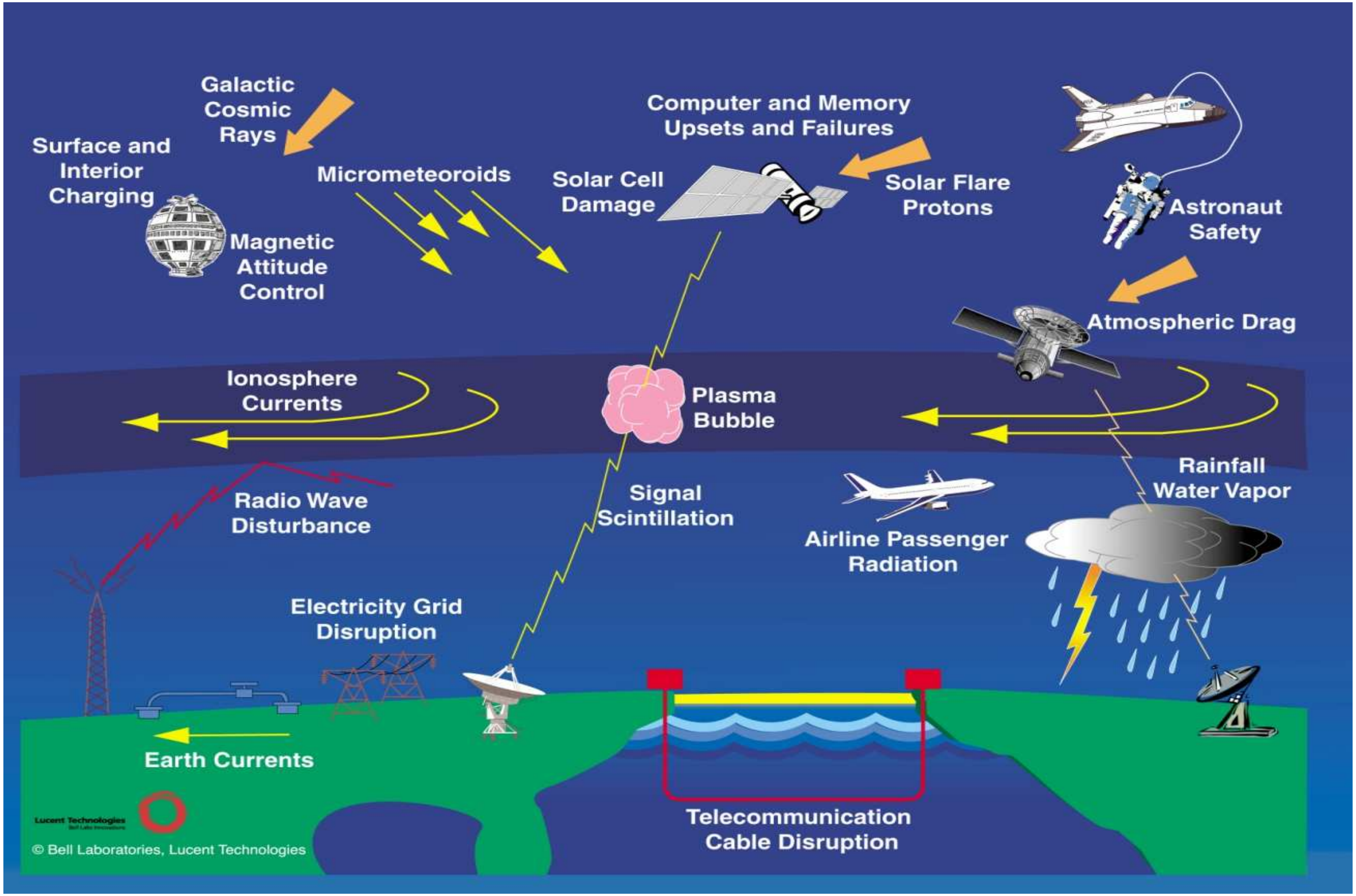
Space Weather: Potential Impacts



Space Weather May Disrupt Aviation

- **Radiological Issues** X and Gamma radiation is harmful to health and levels increase with altitude. (200 x ground level at FL300)

- **Airspace Issues** The earth's magnetic field offers reduced protection at polar and high latitudes. During periods of high solar activity, aircraft plan to avoid high latitude and polar routes. In an Extreme event, the impacted regions will migrate to lower latitudes.

- **System Disturbances and Failure** When solar high energy particles impact sensitive electronic devices, they can permanently damage devices, or cause 'Single Event Upsets'. These effects may impact ground, aircraft and satellite systems.
  - The impact of Ground Level Neutron events on systems are poorly understood.

- **Satellite Services** Solar radiation can cause:
  - Satellite anomalies and failures
  - Ionospheric delay leading to GNSS range errors
  - Ionospheric Scintillation causing loss of receiver lock

- **Aircraft Issues**, Aircraft at high flight levels have reduced levels of atmospheric protection. Potential impact on aircraft avionic systems

- **Terrestrial CNS systems**
  - increased solar radio noise
  - Disturbed High Frequency communications.

- **Power Supply Impact.** Geomagnetic storms can cause power network failures and false activation of protective devices (e.g. Quebec 1989).

  - ATM Systems are critically dependent on electrical power

- **ATC have to manage the consequences of Space Weather**

CNS Space Weather Resilience Assessment

SERVICE	CHARACTERISTICS and MITIGATIONS	IMPACT
HF Comms.	• Ionospheric Propagation • Oceanic Ops based on HF, but Sat-Com Required for RLSM Operations • Loss of Comms procedures in Oceanic Con-Ops.	Poor or Loss of HF Expected (Common Occurrence)
VHF Comms	• High Signal to Noise Ratios • Non-Ionospheric Propagation • Redundant equipment and overlapping coverage volumes. • Possible co-channel Auroral reflections.	
Sat Comms	• No Polar Coverage from Geo- stationary satellites • Coverage from Multiple satellites. • Trans Ionospheric Propagation • Scintillation not usually significant at temperate latitudes, but will increase in Extreme events • Has demonstrated robustness in previous space weather events.	May be subject to loss during Extreme Events
Terrestrial Navigation	• High Signal to Noise Ratios • Non-Ionospheric Propagation • Redundant equipment and overlapping coverage volumes.	
Satellite Navigation	• Coverage from Multiple satellites. • Trans Ionospheric Propagation • Scintillation not usually significant at temperate latitudes, but will increase in Extreme events	May be subject to loss during Extreme Events. Potential for loss of GNSS may suspend R Long SM in Oceanic Airspace.

Surveillance	• Non Ionospheric Propagation
	• Primary radar uses high sensitivity receivers,
	    o Solar noise often observed when sun at low elevation angles
	    o Increased Noise may reduce probability of detection at sun azimuth angle
	    o Noise removed in display processing
	    o Multi Radar tracking mitigates lower detection probabilities	

Impact of Extreme Event on Satellite Services

- **GNSS**
- Scintillation (rapid fluctuations) causing loss of receiver lock is the key issue.
  - Scintillation caused by precipitation of Solar particles into the Ionosphere may cause scattering of signals making the ionosphere almost impenetrable to GNSS frequencies.
- Potential loss of some GPS satellites due to ‘satellite upsets’, or drag causing orbital errors.
- Atomic clocks are susceptible to external radiation effects.
- Severe disruption and potential loss of service over an estimated 3 day period.
  - In 3 days, solar rotation would move the earth from being the major focus of a prolonged active solar region.
  - Estimated to be the time to regain control of a GNSS constellation from a major failure. Restoration of satellites, reboot and upload navigation data and orbit parameters, to restore capability.
- **Sat Com**
- Services at risk during a 3 day period as operates in same band and will be subject to similar influences to GNSS.
- Following exposure to high doses of radiation, satellites may experience shortened life and premature failure through receiving lifetime doses of intensive radiation in a short period. (Electronics and Solar Arrays)

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European Operations

- European Airspace is characterised by complex route structures and high traffic density.
  - TMAs are currently a tactical operation with high levels of ATC intervention.
- Terrestrial CNS systems will not be severely impacted by ionosphereic disturbances.
- En-route and terminal operations are currently not dependent on GNSS:
  - Not all aircraft carry GNSS
  - GNSS equipped aircraft are required to carry VOR and DME.
  - The exception is RNP APCH applications that can only be conducted with GNSS. (EGNOS and Baro Vnav)
- Dependence on GNSS is edging closer:
  - The implementation of A-RNP through the PBN Implementing Rule has the potential to increase dependency on GNSS.
  - Reversion to an RNAV operation based on VOR and DME is being planned.
  - The Rationalisation of ground navigation facilities is planning to maintain at least an RNAV 1 capability based on DME/DME Positioning.
- Space Weather is one of the vulnerabilities to be mitigated in the ATC operation.
- If there is an Extreme Space Weather event the European ATM system has the ability to quickly react to the impact, requests for descent, flow control etc.

Oceanic Operations

- Characterised by low complexity route structures and Low Traffic density.
  - Is a strategic operation with low levels of ATC intervention.
  - Oceanic ATC Clearances ensure conflict free routing across the Atlantic.
- Operations predicated on HF (2.8–18 MHz) SSB Voice Communications.
  - HF communications is known to suffer from space weather induced propagation issues.
  - Increasing numbers of aircraft carry datalink and L Band Satellite communications.
  - Anecdotal evidence is that 'sat-com always works when HF doesn't'.
- Radio Communications Failure procedures are standardised and promulgated.
  - 123.45 MHz for inter-a/c Comm, Sat Com aircraft can relay messages from a/c who have lost HF.
  - If total loss of comms, aircraft continue in accordance with last ATC clearance (Free of Conflicts)
- Oceanic Navigation through redundant GNSS and Inertial Reference Systems.
- Aircraft Collision Avoidance System (ACAS) Required on the Ocean as a safety net.
- Aircraft operators have 'company specific' Space Weather operating procedures which are unknown to ANSP's.
- As an example on 11 January 2012 two aircraft within Oceanic Airspace were advised by their Dispatch to request lower levels due to a radiation storm.
  - XXX Requested descent from FL350 to FL310 at 58N 030W
  - YYY Requested descent from FL350 to FL300 at 49N 020W
- These changes were accommodated by Shanwick, but would have been chaotic if all aircraft made similar requests,
  - particularly if Communications were compromised in an Extreme event.

ATM Procedures

- Currently no specific plan is in place for Extreme Space Weather in Oceanic Airspace:
- May require a mult-tier approach to events to maintain safety;
- **Extreme Event Forecast**
- Suspend reduced Long/Lat separations (based on FANS ADS Contracts)
- **Extreme Event Occurs**
- **Flights already cleared**;
  - Flights continue as cleared
  - Flights already in the Ocean follow radio fail procedures, including those still within domestic airspace yet to enter the OCA
  - Some flights may re-request/or divert and land before entry into Oceanic Airspace
- **Subsequent requests for Oceanic clearance;**
  - Initial period (x hours?) Subsequent requests for ATC clearance (via VHF CDO frequencies) to be issued utilising Non MNPS separations for all aircraft (outside MNPS airspace)
  - 2nd Phase(x-Hours-days?) subject to flight planning accuracies of aircraft MNPS status; ATC apply MNPS and Non MNPS separations accordingly (MNPSA changes?)
- Procedures need to be co-ordinated and agreed by all Operators and Oceanic Service providers through ICAO.
- Requires improvement in relevance of current and forecast information to be available to all stakeholders.

Summary

- Aviation has evolved through several solar cycles;
  - But technology and operations are changing and introducing new risks.
- Extreme 1:1-200 Year risks are likely to cause significant issues.
  - But great uncertainty as outside of experience base.
- In an Extreme Space Weather event:
  - The impact on UK domestic airspace is considered manageable, as the terrestrial CNS infrastructure is assessed as being resilient to Space weather effects'
  - Co-incident disturbance or loss of HF and satellite communications may impair ATC ability to control within Oceanic Airspace. (
  - Coincident loss of communications and GNSS may compromise Oceanic operations
- Further work is required to refine and harmonise aircraft operator and ATM procedures in Oceanic Airspace.
- Aviation requires greater understanding and improved forecasting to allow pre flight planning and operational decisions.
  - Current fidelity of forecasts is inadequate "something might happen tomorrow… somewhere …perhaps."
- Actions need to be proportionate

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