Impact-Driven Space Weather Scales

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Acknowledgement:
- International Forum for Space Weather Capability Assessment ->
- COSPAR/ISWAT (International Space Weather Action Team) Initiative
- Existing literature

Essential Space Environment Quantities (ESEQs):

Connecting space environment to impacts

NASA Space Weather Council Meeting
August 9, 2024

COSPAR/ISWAT (International Space Weather Action Teams) Initiative

The COSPAR ISWAT initiative is a global hub for collaborations addressing challenges across the field of space weather.

S: Space weather origins at the Sun	H: Heliosphere variability	G: Coupled geospace system
S1: Long-term solar variability	H1: Heliospheric magnetic field and solar wind	G1: Geomagnetic environment
S2: Ambient solar magnetic field, heating and spectral irradiance	H2: CME structure, evolution and propagation through heliosphere	G2a: Atmosphere variability
S3: Solar eruptions	H3: Radiation environment in heliosphere	G2b: Ionosphere variability
	H4: Space weather at other planets/planetary bodies	G3: Near-Earth radiation and plasma environment

Impacts

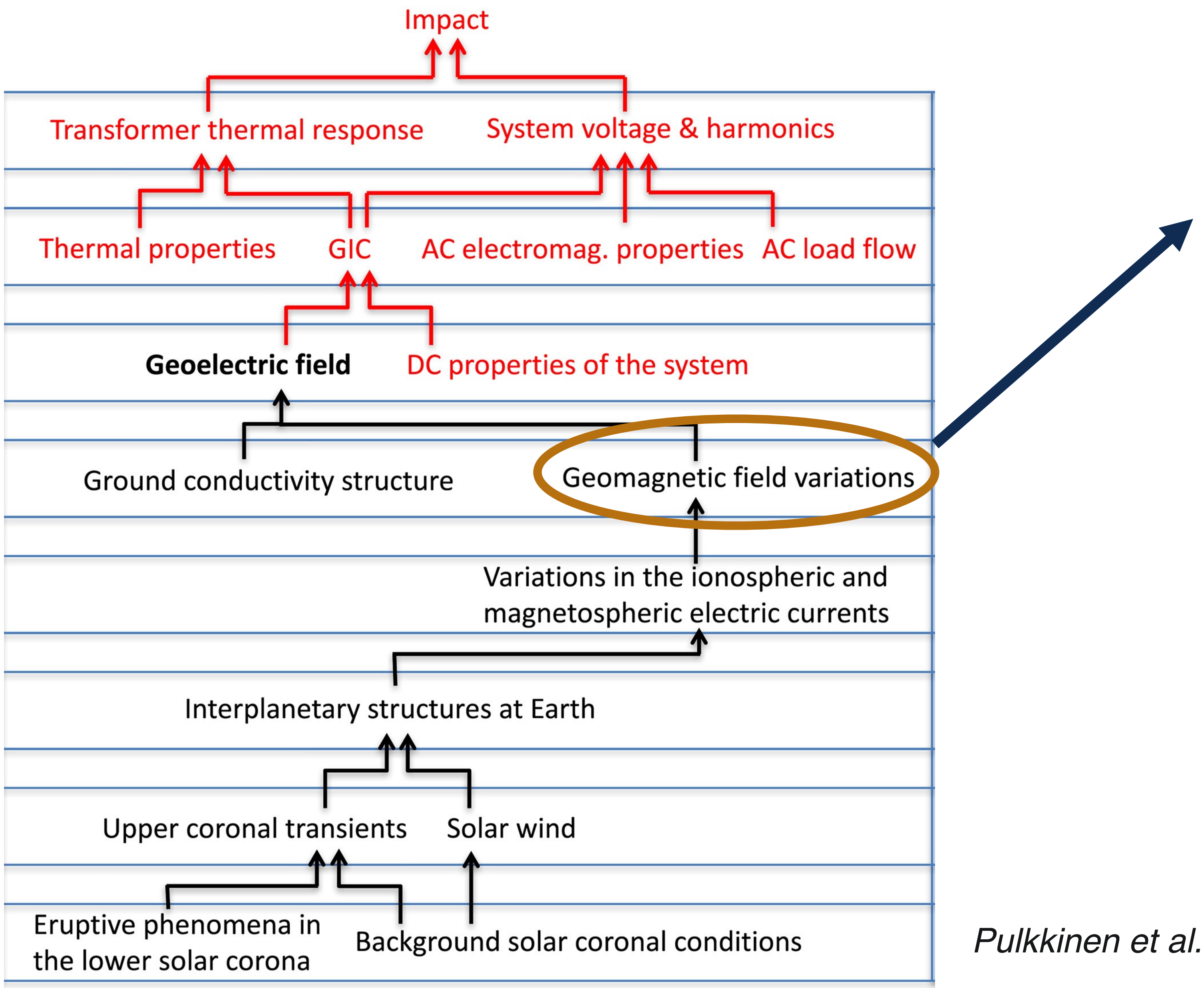
- Climate
- Electric power systems/GICs
- Satellite/debris drag
- Navigation/ Communications
- (Aero)space assets functions
- Human Exploration

Overarching Activities:

Assessment | Information Architecture | Data Utilization | Education/Outreach

Collaboration and exchange of ideas. The sum is worth more than its parts.

Power Grids/Geomagnetically Induced Currents

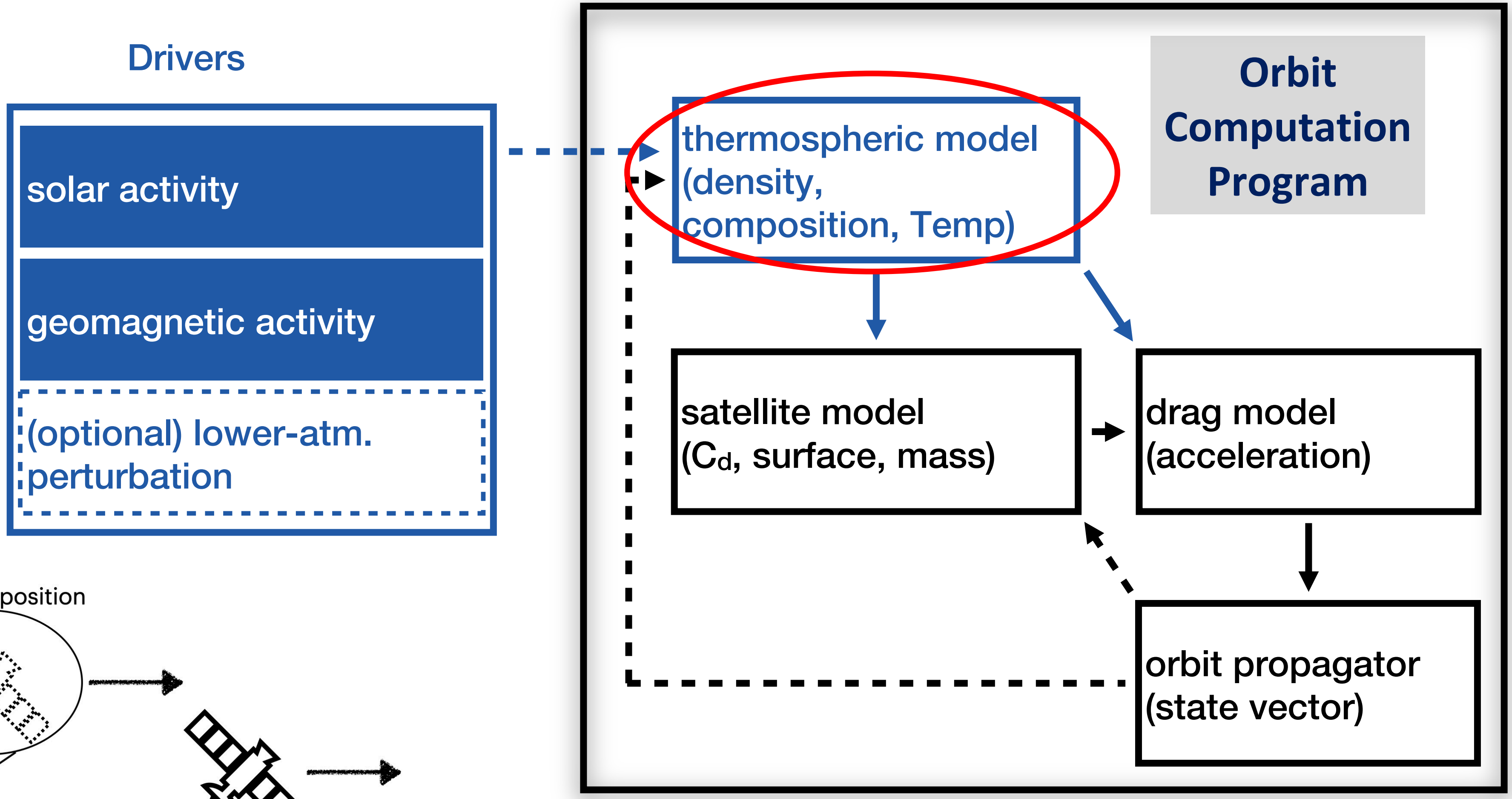


ESEQ: change of the magnetic field: db/dt

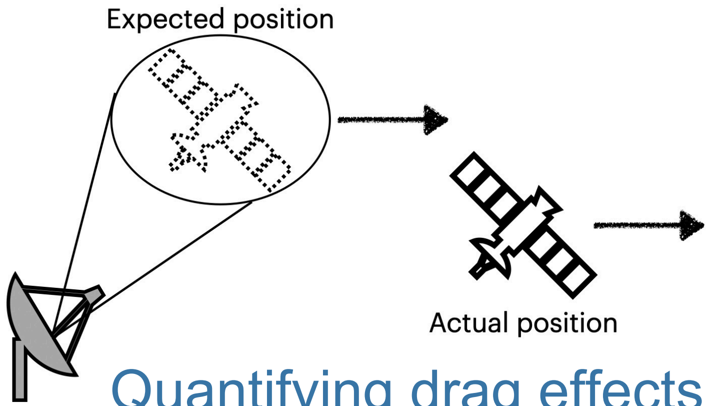
Pulkkinen et al., 2017

Satellite Drag

ESEQ: Thermospheric Density - the dominant source of uncertainty



Modified from Jack Wang et al.



Quantifying drag effects (sat position determination) using Thermospheric Density as a scale -- challenging

Nav and Communication (1)

- Amplitude scintillation index S4, phase scintillation Sigma_phi σ_ϕ
  - Describing the signal strength degradation of radio waves/GNSS signals traversing the ionosphere
  - Direct measurement of impact on the signal (correlates with density irregularities)
  - Dependent on receiver technology, not an objective measure of ionospheric state
  - Good for low-latitude
- ROTI: The Rate of TEC index (ROTI) is defined as standard deviation of the rate of TEC (ROT) assuming the ionosphere as a thin layer.
  - Good for high-lat/auroral zone

Nav and Communication (2): Ionospheric Storm Scale

$$P_{TEC} = 100 \times (O_{TEC} - R_{TEC})/R_{TEC},$$

$$P_{foF2} = 100 \times (O_{foF2} - R_{foF2})/R_{foF2},$$

Base on **Total Electron Content (TEC) and foF2 (F2 Layer Critical Frequency)**

I0, IP1, IP2, IP3, IN1, IN2, and IN3

0: quiet

1: moderate

2: strong

3: severe

P: positive storm

N: negative storm

Users:

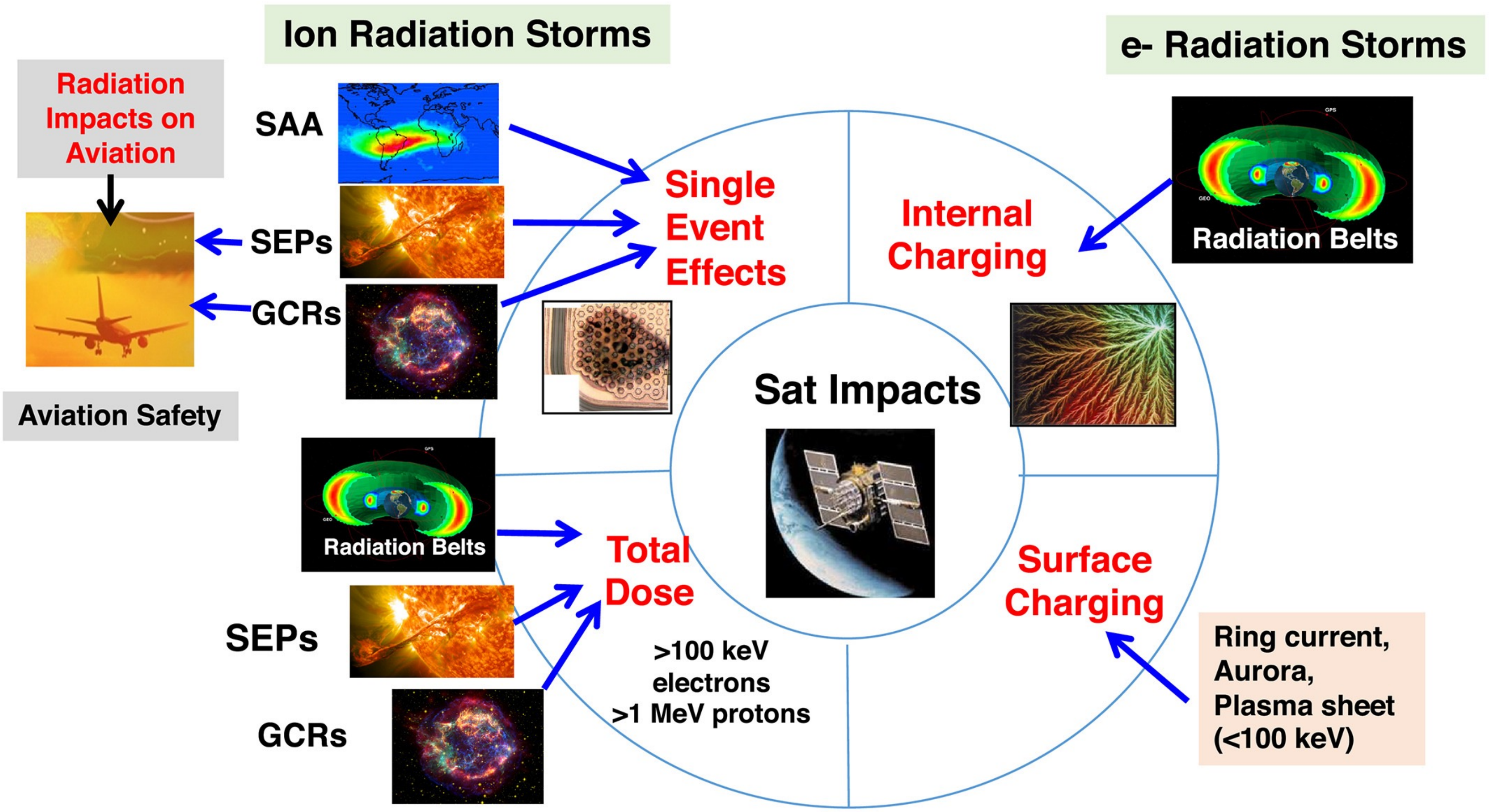
Global Navigation Satellite Systems (GNSS)

HF Communication Systems

Both equatorial and polar

Nishioka et al., 2017, Space Weather

Impacts on Space Assets and Aviation



Mission Concept/Planning/Design Mission Launch

Mission Operations Anomaly Resolution

Zheng et al., 2019

Impacts on Satellite and Aviation

Table 11. Essential Space Environment Quantities (ESEQs): their corresponding impacts and temporal scales.

Impacts	Impact Quantity	ESEQ	Time Scales
Surface Charging	>10keV e- flux	>10keV e- flux; Te; Ne	seconds
Internal Charging	>100 fA/cm^2 (100 mils)	1MeV and>2MeV e- flux	24-hour, 72hr averaged
Single Event Effects	SEE rate (100 mils)	>30MeV p+flux	5-min, daily, weekly (worst)
Total Dose in orbit and in the atmosphere	Dose in Silicon (100 mils; 4 mils)	30–50MeV p+flux; >1.5MeV e- flux 1–10MeV p+	5-min, Hourly, Daily, weekly, yearly
Aviation	Dose rate in aircraft (D-index) and single event rates in avionics	>300MeV p+flux; spectral parameter (power law with rigidity)	5-min, Hourly

Zheng et al., 2024

D-index: based on dose rates at aviation altitudes produced by solar protons

Meier MM & Matthiä D, 2014

Impacts on Human Exploration

Radiation storms due to Solar Energetic Particles (SEPs)

>100 MeV proton flux (JSC/SRAG operation)

Threshold: 1pfu (particle flux unit)

NOAA's S-scale is based on >10 MeV proton flux levels

Summary: Scales/Indices Useful for End-Users

User specific

Tailored

Nav and Communication: Source and Impacts

Table 1. Ionospheric phenomena, area, duration and utilities which affect radio communication, GNSS, and satellite communications.

Phenomena	Affecting area	Affecting duration	Affected Ionospheric region	Affecting utilities
Short Wave Blackout from solar flare	Dayside of the Earth, maximum around equator region	Several min – several hours	D region	HF, VHF, LF, VLF
Short Wave Blackout from REP events	Mid latitudes	Several min - several hours	D region	HF, LF, VLF
Solar Radio Burst	Dayside of the Earth, maximum around equator region	Several min – several hours	–	Various
Polar Cap Absorption	High Latitude Region	Several min – several days	D region	HF
Auroral disturbances	Auroral Oval	Several hours	D and E region	HF, GNSS
Ionospheric positive storm	Global	Several hours	F region	GNSS
Ionospheric negative storm	Global	Several hours	F region	HF
TIDs	Global	Several hours	F region	GNSS, VHF
EPBs	Local post-sunset and nighttime of equatorial and mid-latitude region	Several hours after local sunset	F region	GNSS
Es layer	Dayside of the Earth	Several min - hours	Es	HF, VHF
Polar patches	Polar regions	Several hours	F region	HF, GNSS, satcom

Red ones: flare or SEPs
External sources

Complexities in sources and impacts

Ishii et al., 2024