The Socioeconomic Impacts of the Upper Atmosphere Effects on LEO Satellites, Communication and Navigation Systems

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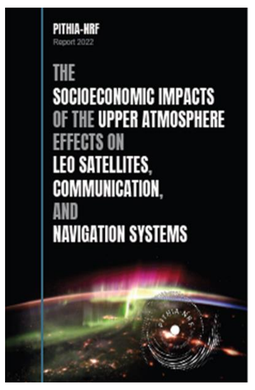
Key Points

- This **review** is one of the results of the project **PITHIA Network of Research Facilities (PITHIA-NRF),** a research infrastructure funded by the EU's Horizon 2020 Research and Innovation program.
- **SWx is a low probability high-impact event**, with costs to society not dissimilar from those caused by major natural disasters.
- The **science of quantifying their socioeconomic impacts of upper atmosphere phenomena is not yet mature.**
- The literature tends to focus only on a subset of infrastructures and SWx phenomena affecting them, **without fully exploring the total costs associated with SWx**.
- There is no comprehensive theoretical framework for risk analysis in this field.
- The **lack of important modeling information** and **modern society's lack of experience** with extremely large events hinders advances needed by governments, asset owners, and business to mitigate the risks posed by SWx.

The effects of upper atmosphere space weather on the systems

Impacted systems	SPACE-BASED SYSTEMS		GROUND-BASED SYSTEMS		
Impacted services	**LEO cellular and data SATCOM VLF-MF communications and broadcasting**	**EO (with LEO satellites), Space-based SAR**	**PNT with GNSS and GBAS**	**Astronimical observation systems (LOFAR)**	**Terrestrial radio systems (HF communications)**
Impacting UAP	Ionospheric plasma bubbles; Multipath Attenuation Doppler	Faraday Rotation; Ionospheric Scintillation; Atmospheric drag	Large TEC gradients; Ionospheric plasma bubbles; TIDS	Geomagnetic storms; Auroral jets intensification; Ionospheric plasma bubbles	PCA; Sporadic E-layer; TIDS; Ionization depletions
Effects	Rapid fluctuations in the amplitude and phase of the radio signal leading to repeated disruption of communications links	Loss of phase coherence across SAR aperture; Prohibits remote sensing	Loss of phase lock and data loss; Range errors	Radio signal refraction	Blackout of HF radio frequencies
Worst-case scenario duration and spatial extent of effecs	Intermittent occurrence over several days worldwide	SAR: 1 hour on the whole dayside of the Earth; EO: asset loss	Intermittent occurrence over several days worldwide		2 or 3 hours in all regions at low- and mid-latitude on the dayside of the Earth; Several days at high latitudes (PCA)



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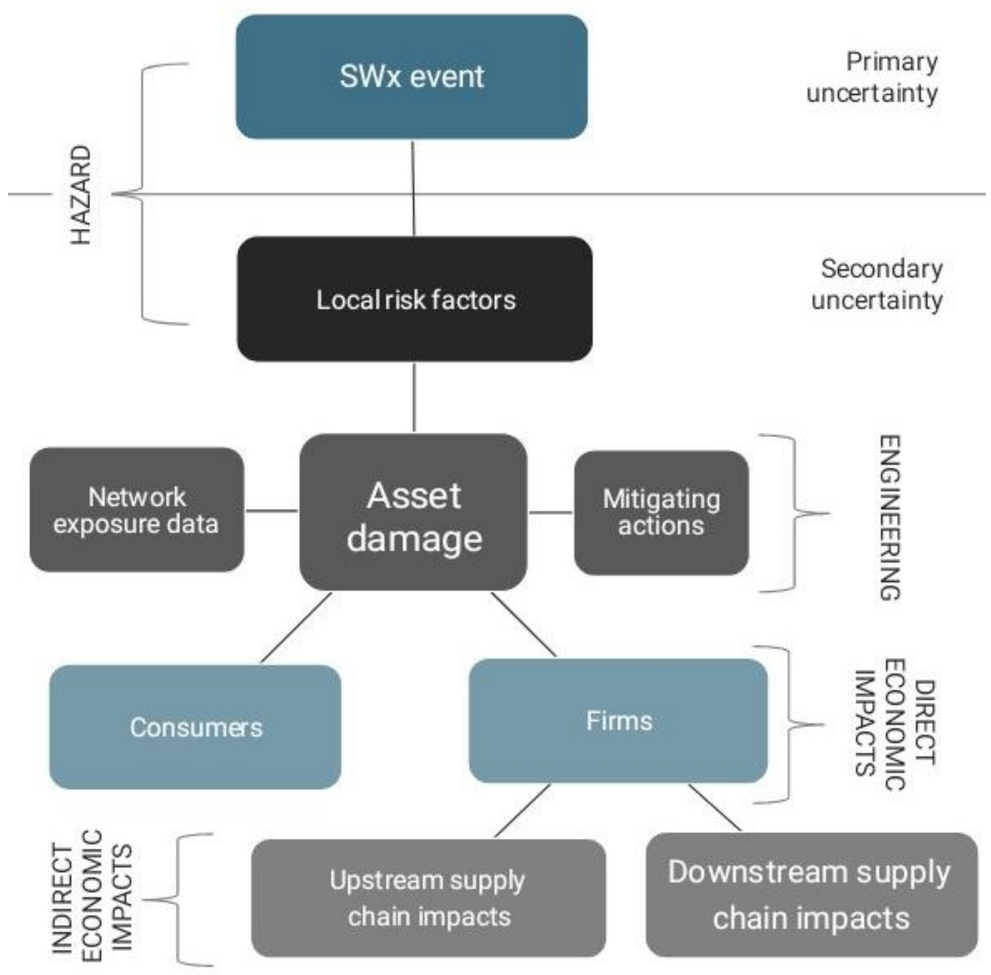
Economic costs associated with upper atmosphere phenomena



Plasmasphere Ionosphere Thermosphere Integrated Research Environment and Access services: a Network of Research Facilities (PITHIA-NRF) www.pithia-nrf.eu

Type of estimated cost for infrastructure

Entity	Cost Type	Type of estimated cost per infrastructure			
		Space-borne infrastructure	Ground-based infrastructure		
		LEO Satellites	PNT	AOS	TRS
Infrastructure network operator	Direct	✓	✓		
	Indirect				
	Mitigation	✓			
Commercial and industrial customers	Direct	✓	✓		✓
	Indirect		✓		✓
	Mitigation				
Households	Direct				✓
	Indirect				
	Mitigation				

	GNSS Application		
Scenario: 1-3 days to 14 days PNT services outage	Europe (PwC, 2016)	USA (ABT Associates, 2017)	Canada (HAL, 2019)
Precision Agriculture	Not stated	$30-100 million	$0,5 million
Surveying	€197,5 million	$30-100 million	$0,8-1,7 million
Road Transport and Logistics	€0,8-2,4 billion	$20-100 million	Not stated
	LEO Satellites		
Scenario: 1-in-100 years (Carrington event, 1859)	World (PwC, 2016)	World (ABT Associates, 2017)	World (Odenwald et al., 2006)
Global direct + indirect economic costs	€1 billion	$4-200 billion	€30 billion
	Aviation		
Scenario: 2-3 hours HF communications blackout in low- and mid-latitude regions or several days at high-latitudes	Europe (PwC, 2016)	USA (ABT Associates, 2017)	Canada (HAL, 2019)
Cost of delaying, canceling, or rerouting flights	€812 million	$1-30 million	Not stated
Passengers' value of lost time	€14,7 million	$6-200 million	Not stated
Total	€0,83 billlion	$7-230 million	$1,75 billion