To what extent did the space weather gap analysis rely on GDC?

Paul O'Brien
The Aerospace Corporation

Briefing to Space Weather Roundtable

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With acknowledgement to the Gap Analysis Team and R. Bishop

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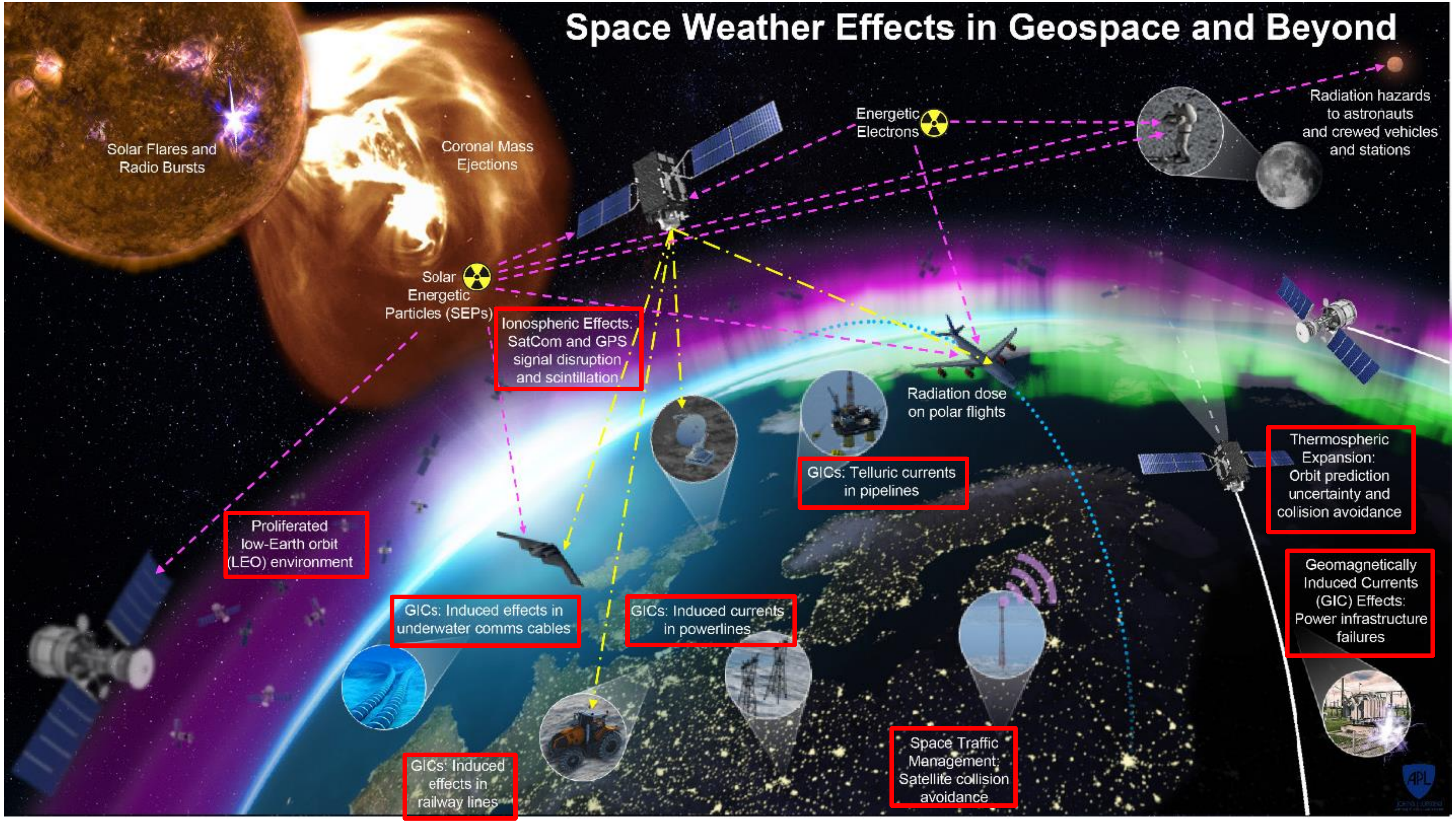
All figures are taken from the NASA Space Weather Gap Analysis Report
https://science.nasa.gov/science-pink/s3fs-public/atoms/files/GapAnalysisReport_full_final.pdf

Introduction

- Space Weather Science and Observation Gap Analysis for NASA. Compiled by APL 9/20-4/21
- Committee
  - *Angelos Vourlidas (chair), Drew Turner (co-chair), Doug Biesecker, Anthea Coster, Alec Engell, George Ho, Tom Immel, Catherine Keys, Lou Lanzerotti, Gang Lu, Noé Lugaz, Janet Luhmann, Leila Mays, Paul O'Brien, Eddie Semones, Harlan Spence, Lisa Upton, Stephen White*
- Ex-officio:
  - *Jim Spann, Elsayed Talaat, Mike Wiltberger, James Favors, Reiner Friedel*
- Primarily focused on observation gaps, with emphasis on near-real-time data

https://science.nasa.gov/science-pink/s3fs-public/atoms/files/GapAnalysisReport_full_final.pdf

Space Weather Effects Associated with GDC Science and Observations



- The ionosphere and thermosphere affect many technologies:
- Sat. Tracking
- Sat. Comm.
- Sat. Navigation
- Collision avoidance
- Re-entry
- Power lines
- Undersea cables
- Rail lines

GDC Informs Many Aspects of Space Weather

GDC's Role in Filling Space Weather Gaps

- GDC's ionosphere / thermosphere (IT) science is expected to contribute significantly to improving models and forecasts of IT space weather and its impacts
  - *New understanding*
  - *More "ground truth" data to train and validate models*
- GDC's expected real-time downlink was not defined at the time the Gap Analysis was performed, but it can be expected to improve many of the real-time gaps identified in the analysis

Table 2-1. Top-ranked current SWx observation gap categories and corresponding research gaps

Rank	Current Observation Gaps	Research Gaps
1	Solar/solar wind observations, including off-SEL (e.g., Sun–Earth L4 and L5) and beyond 1 AU	SEP occurrence and properties at a given inner heliospheric location; interplanetary (IP) propagation of solar transients (e.g., B_z, time of arrival [ToA])
2	Ionospheric key observables	Response to variable solar, solar wind, thermospheric, and magnetospheric conditions; high resolution global state; cross-scale and -altitude dependencies and variability; driving from lower atmosphere
3	Solar wind in peri-geospace (dayside, magnetic local time [MLT]~ 10–14)	Fine-scale structure of solar wind (SW)-transients; spatiotemporal evolution and turbulence
4	Thermospheric key observables	Expansion, heating, and cooling processes over a range of scales (<100 km to global) and altitudes; response to variable solar, ionospheric, and magnetospheric conditions; driving from lower atmosphere
5	Ionospheric D- and E-region EPP and E- and F-region cusp and auroral precipitation	Impacts of energetic particle, cusp, and auroral precipitation on ionosphere–thermosphere system; cross-scale (<100 km to global) and spatiotemporal nature of precipitation and consequences on ionosphere–thermosphere system (e.g., conductivity, heating, chemistry and cooling)
6	Ring current and radiation belt electrons	Role of magnetospheric dynamics, mesoscale injections, and variety of wave-particle interactions acting in concert to shape these trapped energetic particle populations, driving geomagnetic storms and radiation belt enhancements and depletions
7	Plasma sheet electrons and injections/bursts from cislunar into GEO and MEO regions	Nature of kinetic- to mesoscale processes (e.g., reconnection, turbulence) affecting global-scale magnetospheric dynamics and magnetosphere–ionosphere coupling

GDC has much to contribute in the Space Weather observation and research gaps

Observation Parameters and Gap Relationship

Instrument	Physical Quantity	Symbol	Supported Gap
AETHER	Thermal Plasma Density	Ne	2, 5
	Thermal Electron Temperature	Te	2, 5
	Density Fluctuations	ΔNe	2, 5
	E-field fluctuations	$\Delta \boldsymbol{E}$	2, 5
CAPE	Energy Range (0.01-30keV)		2, 5
	Electron Spectra		2, 5
	Ion Spectra (25eV - 40keV)		2, 5
MOSAIC	Neutral Wind Vector	**U**	4
	Neutral Density	Nn	4
	Neutral Temperature	Tn	4
	Neutral Composition		4
	Ion Drift Velocity	**V**	2, 5
	Ion Density	Ni	2, 5
	Ion Temperature	Ti	2, 5
	Ion Composition		2, 5
ProFile	Slant TEC	sTEC	2, 5
	Scintillation	S4, σ_ϕ	2, 5
TPS	Ion Drift Vector	**V**	2, 5
	Ion Density	Ni	
	Ion Temperature	Ti	
	Ion Composition (major constituents)		
NEMISIS	Magnetometer	**B**	2, 5
Dosimeter	Energetic Particle Flux		5

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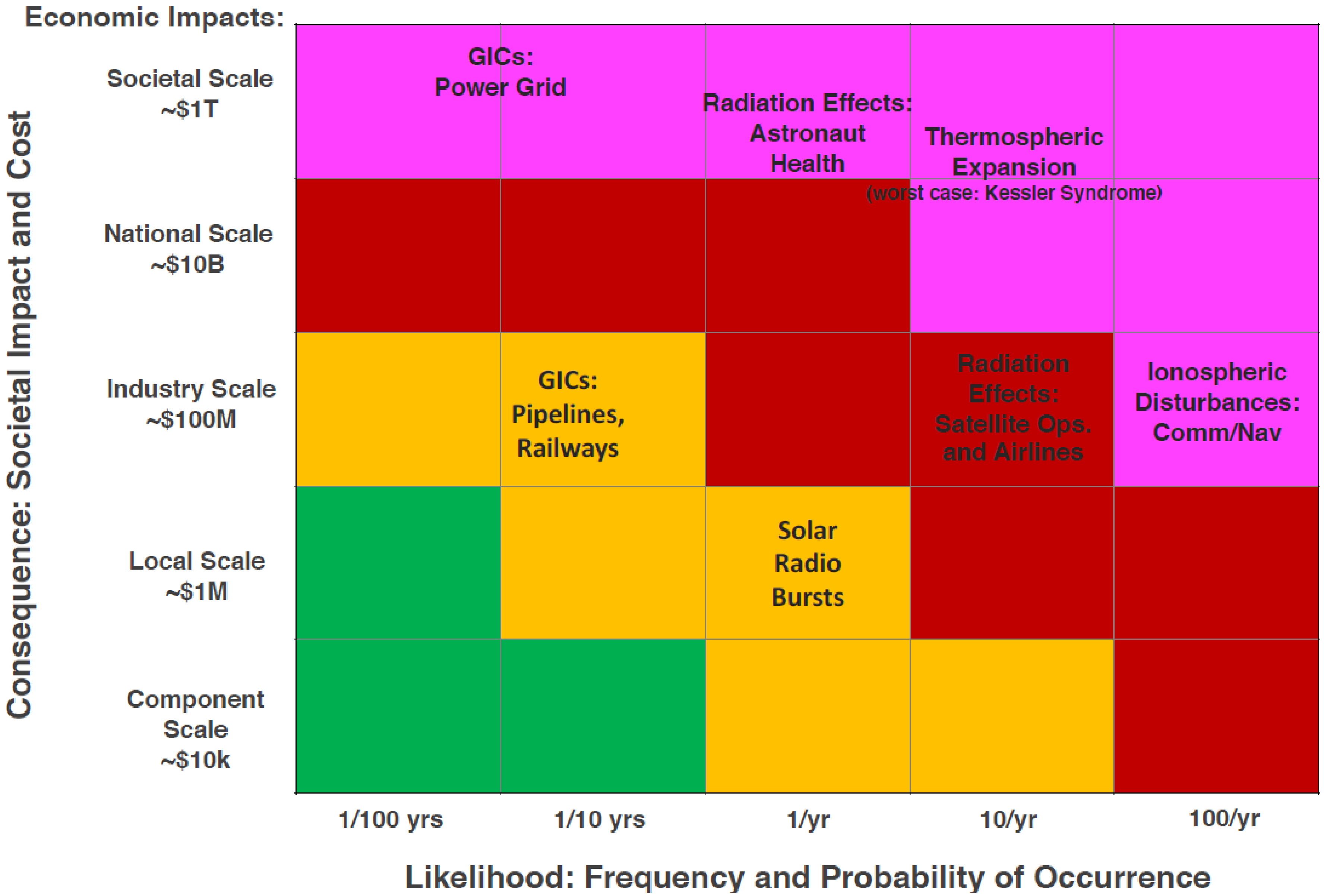
Conclusion

- GDC provides valuable multi-point, globally distributed data to help close ITM gaps
  - *2+ altitudes, 4 orbit planes*
    - All sensors besides ProFile will provide data only at s/c altitude (in-situ)
    - ProFile (GPS RO) provides altitude profiles
  - *Lead-trail vehicle observations to resolve spatial vs temporal ambiguities*
  - *Cross-track orbit separation to resolve longitude / local time spatial structures*
  - *Various configurations over mission*
- Gaps that will remain:
  - *Continuous global real time coverage of the ITM system (there will presumably be a real-time beacon with some coverage, TBD)*
  - *Measurement of locally precipitating energetic particles >~40 keV that can affect D and E region ionosphere (dosimeters are not able to resolve this most of the time)*

BACKUPS

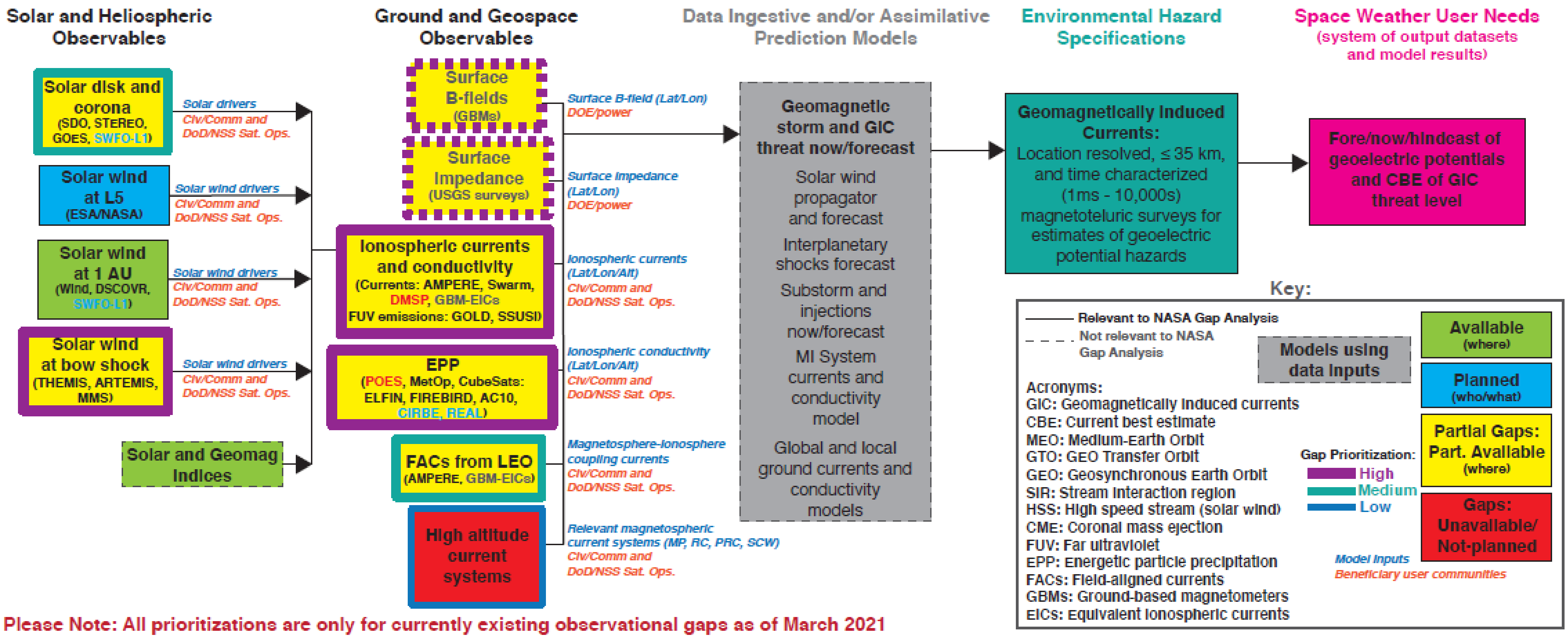
GDC Baseline Science Objectives

GDC Mission Goals	GDC Baseline Science Objectives — The GDC Threshold mission is Goal 1, Objectives 1.1, 1.2, 1.3 only
GDC Goal 1: **(high latitude forcing)** *Understand how the high-latitude ionosphere-thermosphere system responds to variable solar wind/magnetosphere forcing.*	**Objective 1.1 (High-latitude neutral wind formation and evolution)** *Determine how high-latitude plasma convection and auroral precipitation drive thermospheric neutral winds.*
	Objective 1.2 (High-latitude plasma density structure formation) *Determine how localized, coherent plasma density features arise and evolve.*
	Objective 1.3 (High-latitude neutral density structure formation) *Determine how neutral winds, auroral precipitation, and collisional heating drive high-latitude neutral density structures.*
GDC Goal 2: **(global processes)** *Understand how internal processes in the global ionosphere-thermosphere system redistribute mass, momentum, and energy.*	**Objective 2.1 (Pathways for magnetospheric driving of low- and mid-latitude electrodynamics)** *Determine the relative importance of penetration electric fields and disturbance winds in driving plasma density variations at mid- and low-latitude during geomagnetically active conditions.*
	Objective 2.2 (Formation and evolution of propagating atmospheric disturbances) *Identify the processes that create and dissipate propagating structures within the ionosphere and thermosphere during geomagnetically quiet and active conditions.*
	Objective 2.3 (Drivers of low- and mid-latitude chemical composition changes) *Determine the connections between winds and neutral density / composition variations at mid- and low-latitudes during geomagnetically quiet and active conditions.*
	Objective 2.4 (Hemispheric asymmetries) *Determine how hemispheric asymmetries in the Earth's magnetic field, seasonal variations, and magnetospheric input affect the ionosphere-thermosphere system.*



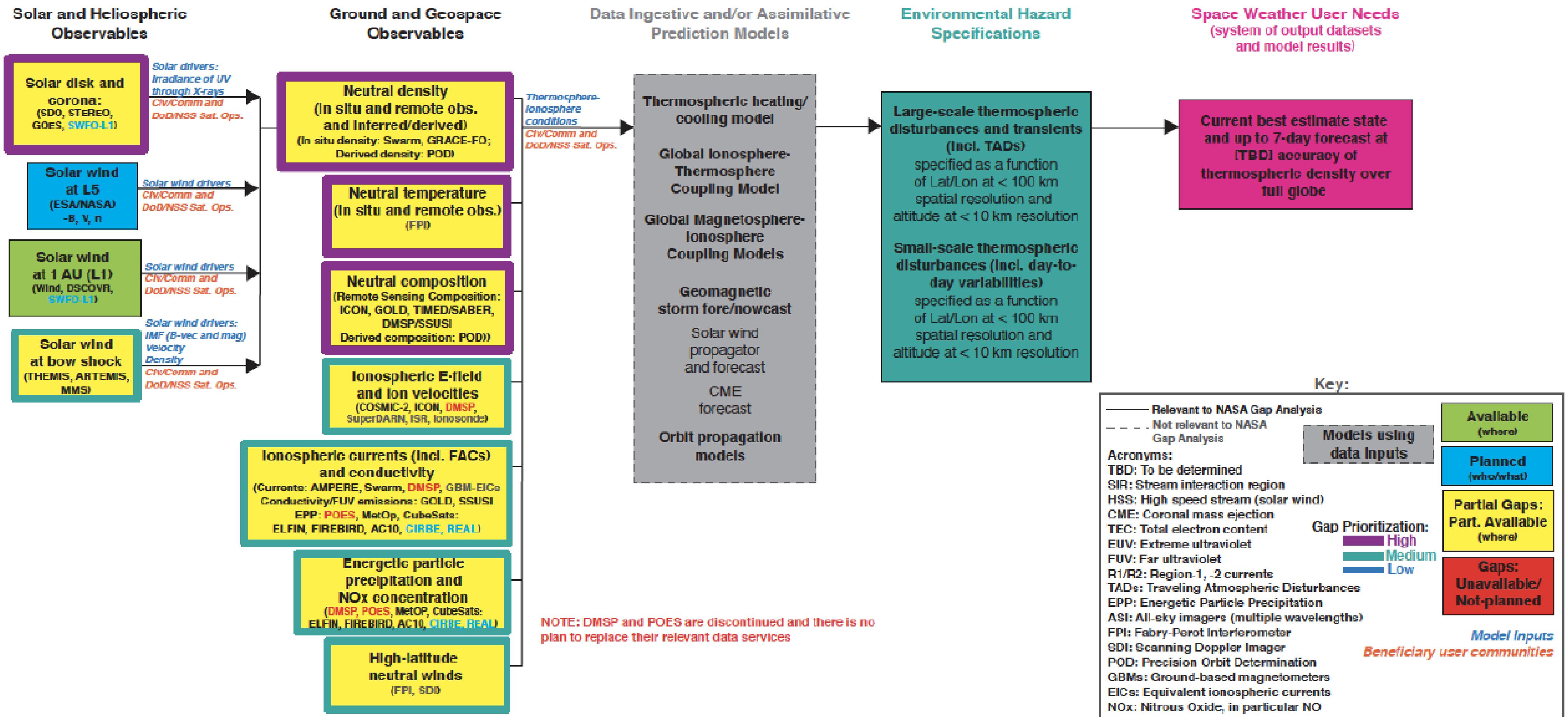
Economic Impacts:
Societal Scale ~$1T
National Scale ~$10B
Industry Scale ~$100M
Local Scale ~$1M
Component Scale ~$10k
Consequence: Societal Impact and Cost
GICs: Power Grid
Radiation Effects: Astronaut Health
Thermospheric Expansion
(worst case: Kessler Syndrome)
GICs: Pipelines, Railways
Radiation Effects: Satellite Ops. and Airlines
Ionospheric Disturbances: Comm/Nav
Solar Radio Bursts
1/100 yrs
1/10 yrs
1/yr
10/yr
100/yr
Likelihood: Frequency and Probability of Occurrence

Geomagnetically Induced Currents



Please Note: All prioritizations are only for currently existing observational gaps as of March 2021

Thermospheric Expansion



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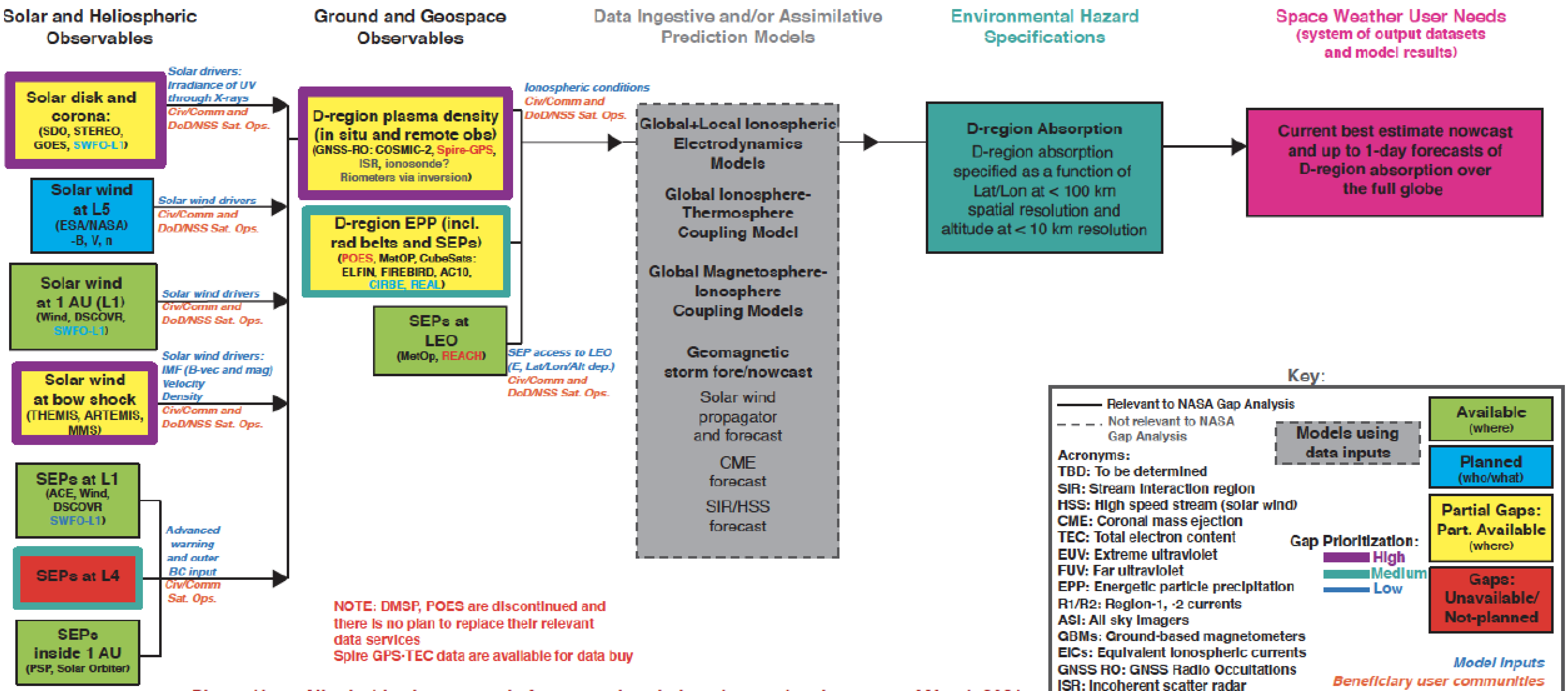
Ionospheric Disturbances: D-Region Absorption



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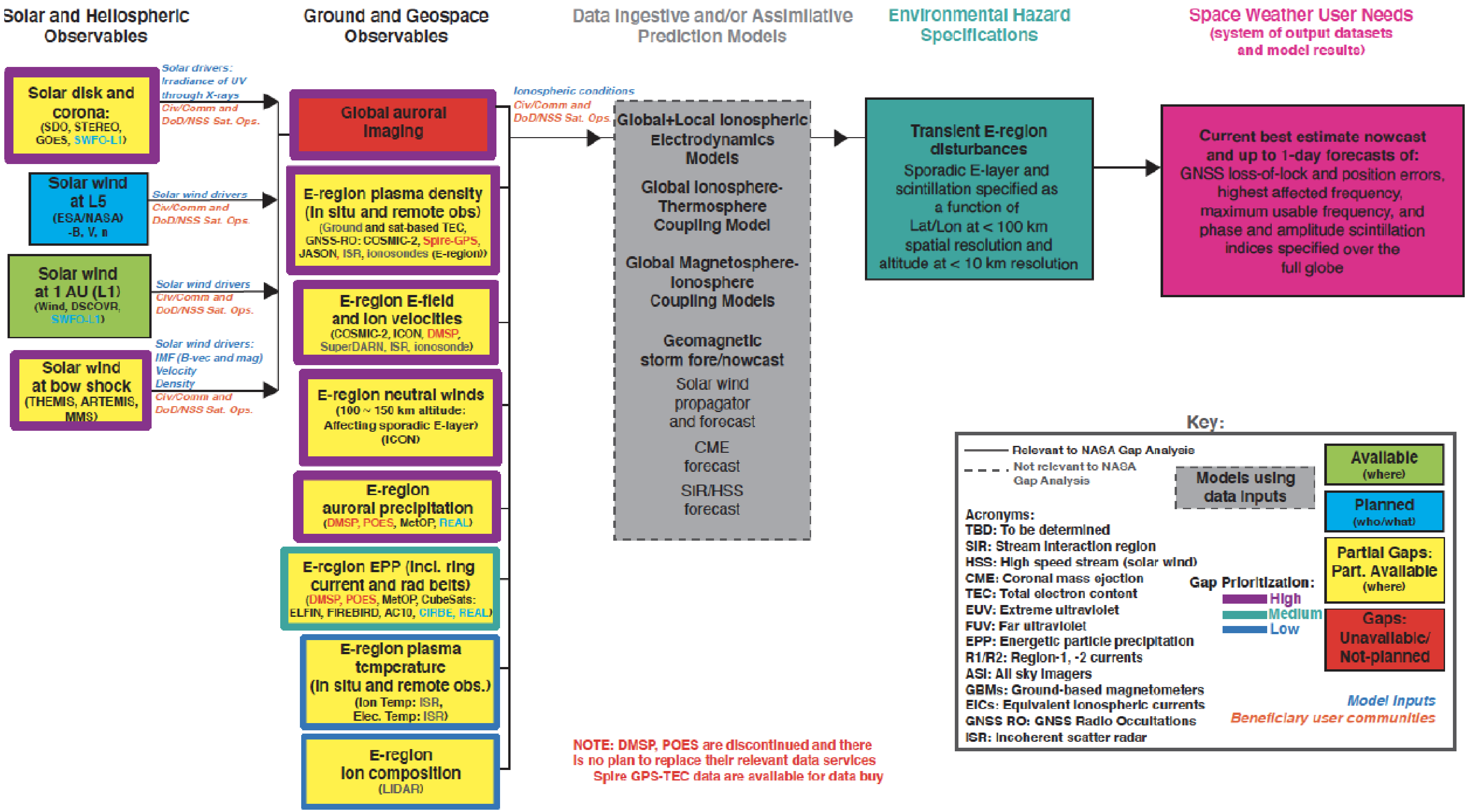
Ionospheric Disturbances: E-Region Sporadic E-Layer and Scintillation



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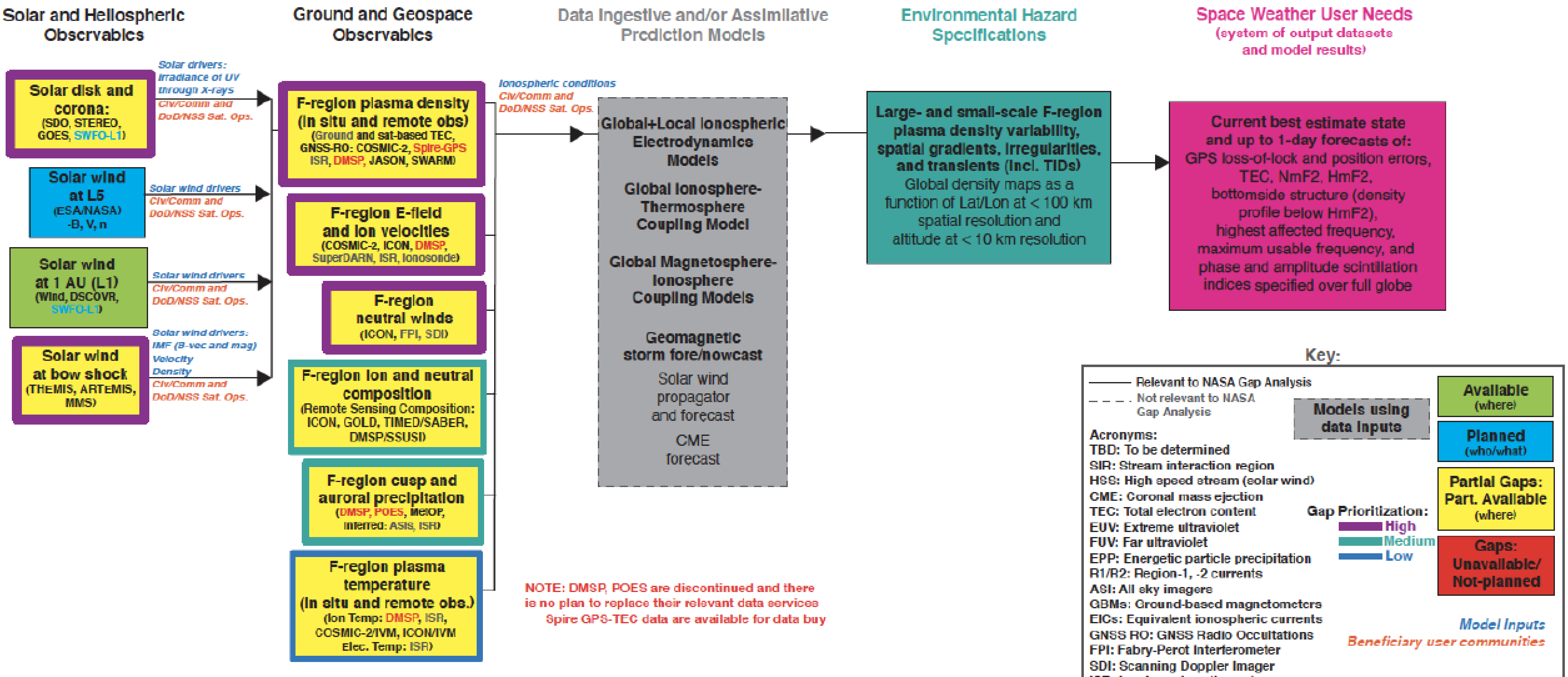
Ionospheric Disturbances: F-Region Structure and Variability



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