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Charge and process

Advancing space weather science to protect society's technological infrastructure: a COSPAR/ILWS roadmap

Summarized by

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We live in the changing atmosphere of a powerful neighbor: space weather and its impacts are there all the time!

Domain volume, non-linearities, multi-process and cross-scale couplings, and hystereses require focused study before we can claim understanding and before we can expect to reliably forecast.

Major advances are possible with moderate investments in critical, state-of-the-art observations and models, through inter-agency, inter-national coordination, strengthening the existing Sun-Earth system observatory.

ESA/NASA Solar and Heliospheric Observatory (SOHO)

COSPAR/ILWS Charge

- The RoadMap
  - focuses on high-priority challenges in key areas of research
  - leading to a better understanding of the space environment and
  - a demonstrable improvement in the provision of timely, reliable information
  - pertinent to effects on civilian space- and ground-based systems,
  - for all stakeholders around the world.
- The RoadMap prioritizes those advances that can be made on short, intermediate and decadal time scales, identifying gaps and opportunities from a predominantly, but not exclusively, geocentric perspective.
- "Space weather refers to the variable state of the coupled space environment related to changing conditions on the Sun and in the terrestrial atmosphere."

e-Home: http://www.lmsal.com/~schryver/COSPARrm/

Roadmap process and status

- Three face-to-face meetings, many telecons and email exchanges
- Discussions at forums and organizations
- Community input
- Draft presented at 2014 COSPAR meeting
- Seeking comments from all stakeholders
- Comparison to agency plans and community roadmaps
- Integrated written report by November 2014

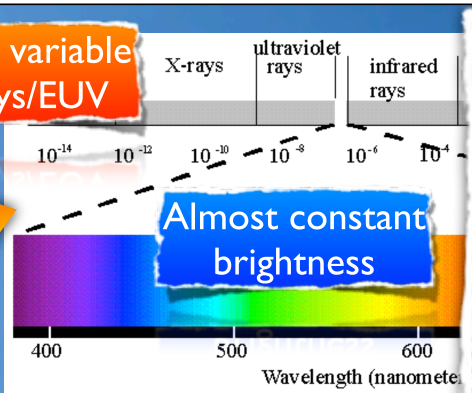
What the Sun sends our way

Light (X-ray to radio)

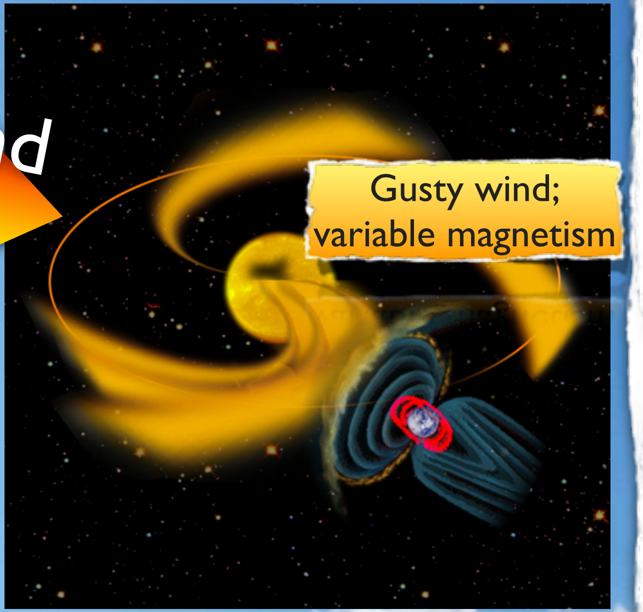
Magnetized wind

Particle radiation

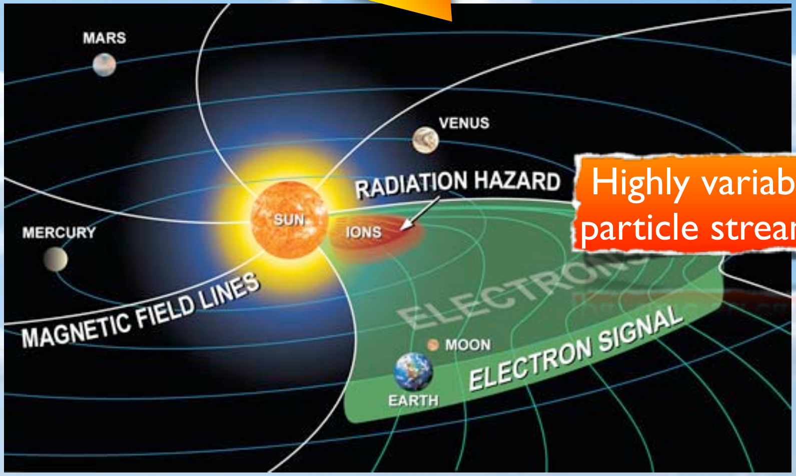
Highly variable X-rays/EUV



Almost constant brightness

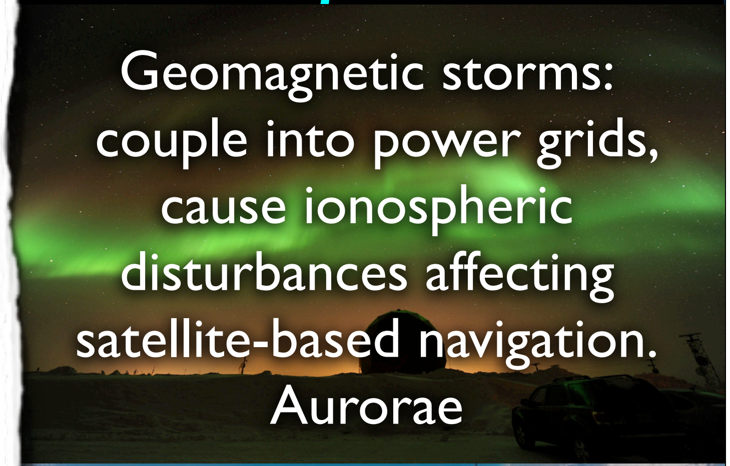


Gusty wind; variable magnetism

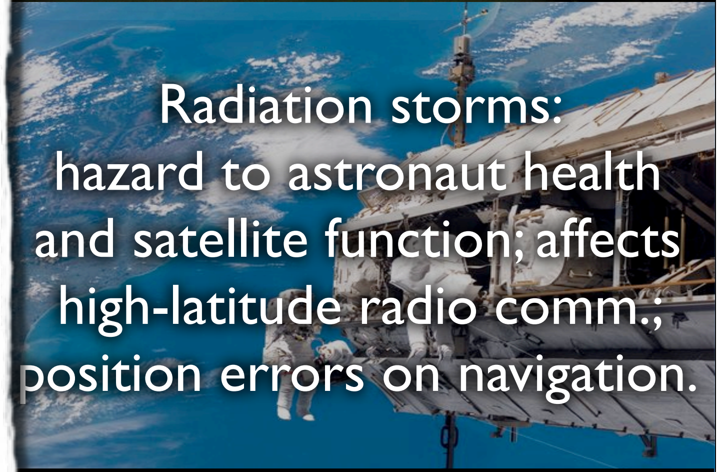


Highly variable particle streams

Examples of space weather phenomena:



Geomagnetic storms: couple into power grids, cause ionospheric disturbances affecting satellite-based navigation. Aurorae



Radiation storms: hazard to astronaut health and satellite function; affects high-latitude radio comm.; position errors on navigation.

Radio blackouts. Satellite drag affecting orbits and re-entry.

Considering user needs

- Detailed example: Geomagnetic Storm Forecasts (information in priority order)

1. Onset time
    - Forecast lead time: 1-3 days, depending on CME speed
    - Forecast accuracy: Threshold: +/- 12 hours
      Objective: +/- 1 hour
2. Intensity – G1-G5
    - Forecast lead time: 1-3 days, depending on CME speed
    - Forecast accuracy: Threshold: +/- 1 G-scale unit
      Objective: within 1 G-scale unit
3. Storm duration
    - Forecast lead time: 1-3 days, depending on CME speed
    - Forecast accuracy: Threshold: +/- 6 hours (relative to storm onset)
      Objective: +/- 1 hour (relative to storm onset)
4. Geographical extent
    - Forecast lead time: 30-60 minutes
    - Forecast accuracy: Threshold: +/- 1000 km
      Objective: +/- 100 km

Information from SWPC

- Radiation storms: top priority: SEP climatological extreme specification and RB environmental nowcast
- Trans-ionospheric radio signals: Long-term and short-term forecasts

Differential needs and feasibilities

Recommendation for next steps towards meeting user needs.

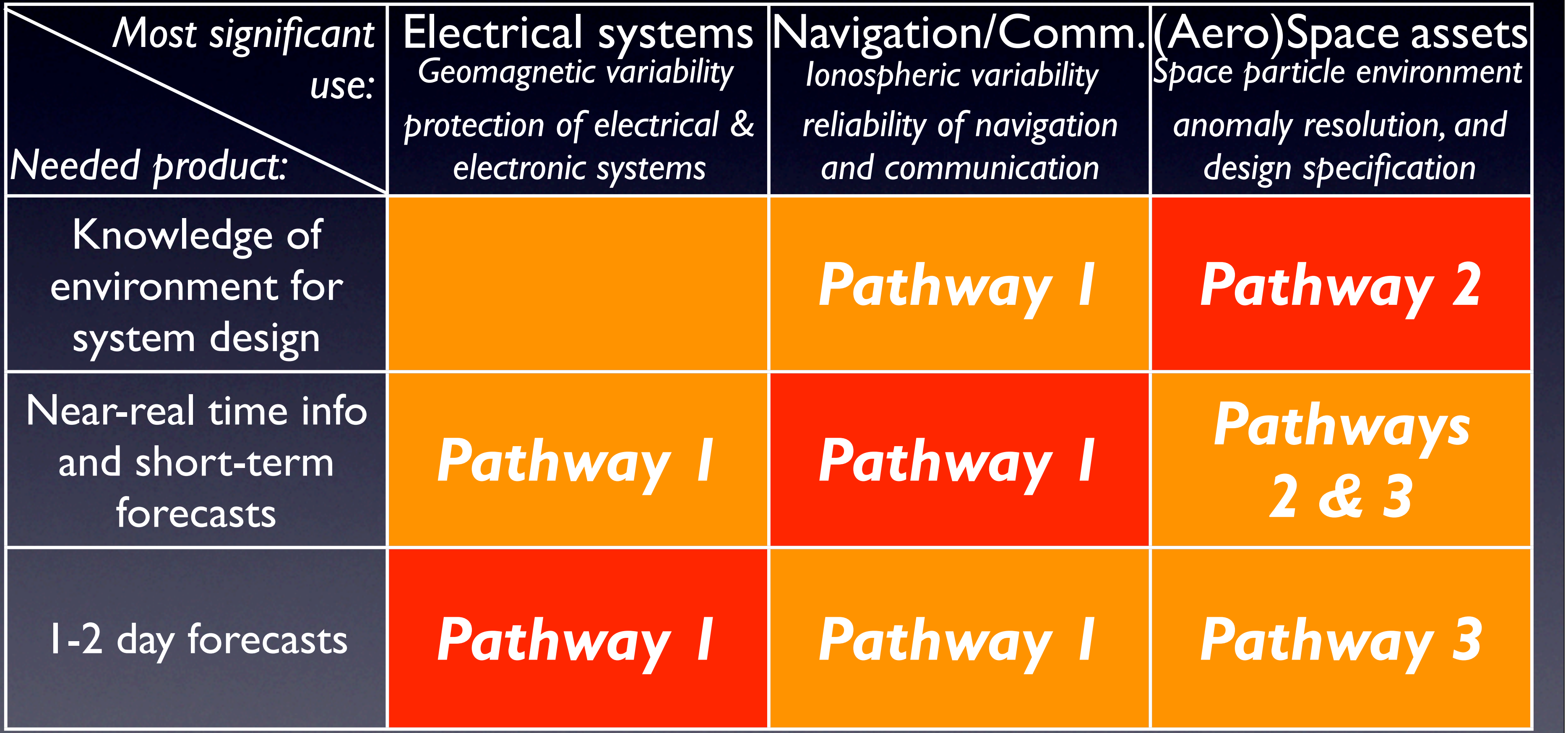
Character of requirements

Most significant use: / *Needed product:*	Electrical systems *Geomagnetic variability* *protection of electrical & electronic systems*	Navigation/Comm. *Ionospheric variability* *reliability of navigation and communication*	(Aero)Space assets *Space particle environment* *anomaly resolution, and design specification*
Knowledge of environment for system design	🟧	🟧	🟥
Near-real time info and short-term forecasts	🟧	🟥	🟧
1-2 day forecasts	🟥	🟧	🟧

Differential needs and feasibilities

Recommendation for next steps towards meeting user needs, grouped to enable advances on phased paths.

Character of requirements



Most significant use: *Needed product:*	Electrical systems *Geomagnetic variability* *protection of electrical & electronic systems*	Navigation/Comm. *Ionospheric variability* *reliability of navigation and communication*	(Aero)Space assets *Space particle environment* *anomaly resolution, and design specification*
Knowledge of environment for system design		***Pathway 1***	***Pathway 2***
Near-real time info and short-term forecasts	***Pathway 1***	***Pathway 1***	***Pathways 2 & 3***
1-2 day forecasts	***Pathway 1***	***Pathway 1***	***Pathway 3***

Impact chains of space weather

Character of recommendation

	User group: *A. Research and engineering* *B. Space weather services* *C. Sectors of society*	*Scientific impact:* *Weak links: ...* *Opportunities: ...* *Challenges: ...*	*Usage character:* *1. Environmental specification and matched engineering/operations.* *2. Monitoring, env. specification, and short-term forecasts.* *3. Longer-term forecasts based on advanced data-driven modeling.*
Research: observational, computational, and theoretical needs	...	...	...
Teaming: coordinated collaborative research environment	...	...	...
Bridging communities: collaboration between agencies and communities	...	...	...

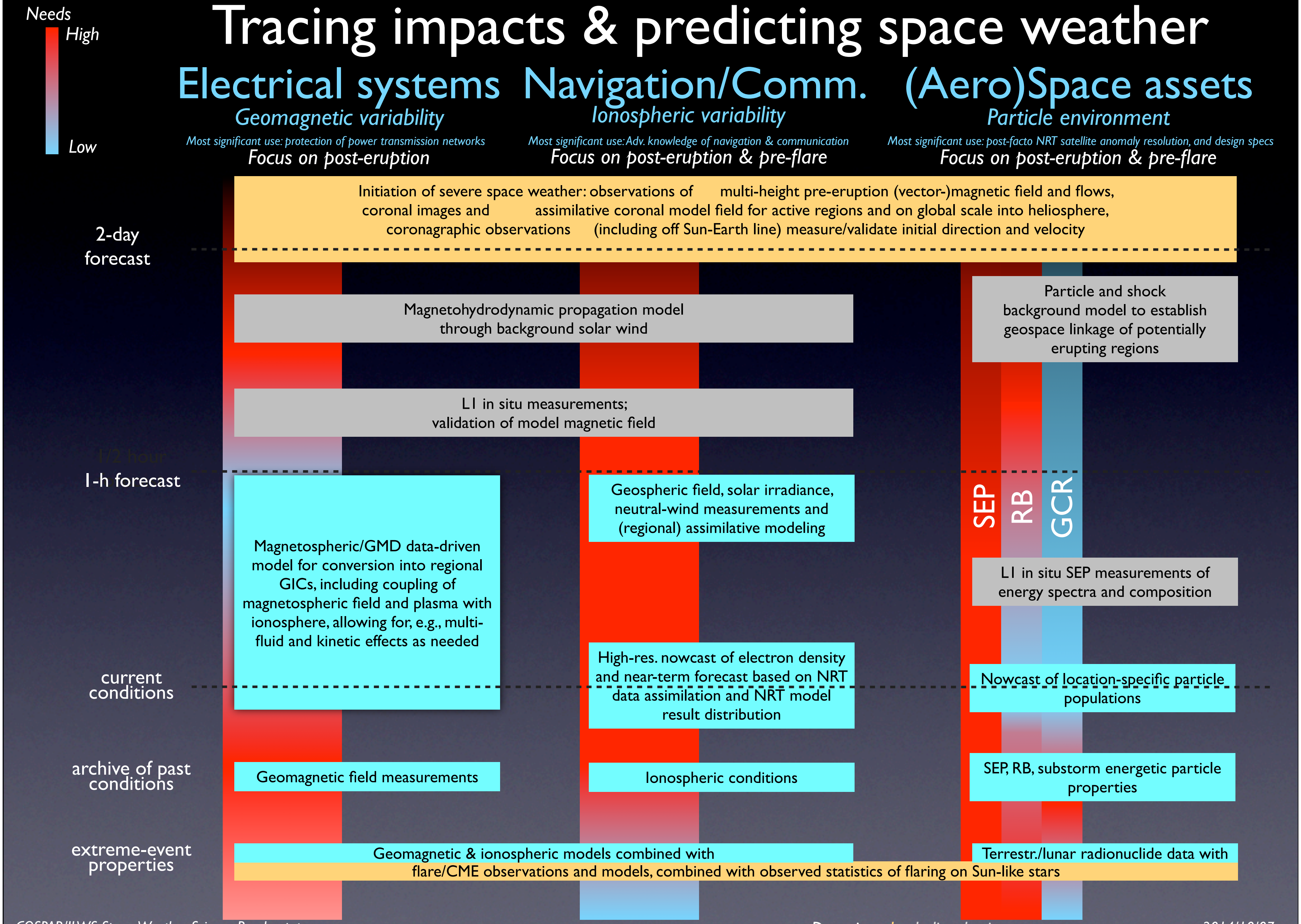
Recent advances: general

- Increased awareness of space weather as impacts are recognized to be potentially up to tens of billions of dollars
- Growing data base of events for study, and increased availability and sharing of data
- Development of end-to-end models and visualization tools
- Improvements in space-weather services

Recent advances: science

- Growing Sun-Earth system coverage by multi-site/multi-scale in-situ sensors and multi-perspective/multi-spectral remote sensing from X-ray to radio
- Increasing realism of physics-based computer models
- Development of end-to-end models and visualization tools
- Deepening understanding of nonlinearities, instabilities, storage-and-release mechanisms, particles and waves in MHD/thermodynamic environments, ...

Tracing impacts & predicting space weather



Electrical systems

Geomagnetic variability

Most significant use: protection of power transmission networks

Focus on post-eruption

Navigation/Comm.

Ionospheric variability

Most significant use: Adv. knowledge of navigation & communication

Focus on post-eruption & pre-flare

(Aero)Space assets

Particle environment

Most significant use: post-facto NRT satellite anomaly resolution, and design specs

Focus on post-eruption & pre-flare

Initiation of severe space weather: observations of multi-height pre-eruption (vector-)magnetic field and flows, coronal images and assimilative coronal model field for active regions and on global scale into heliosphere, coronagraphic observations (including off Sun-Earth line) measure/validate initial direction and velocity

Magnetohydrodynamic propagation model through background solar wind

Particle and shock background model to establish geospace linkage of potentially erupting regions

L1 in situ measurements; validation of model magnetic field

Magnetospheric/GMD data-driven model for conversion into regional GICs, including coupling of magnetospheric field and plasma with ionosphere, allowing for, e.g., multi-fluid and kinetic effects as needed

Geospheric field, solar irradiance, neutral-wind measurements and (regional) assimilative modeling

L1 in situ SEP measurements of energy spectra and composition

High-res. nowcast of electron density and near-term forecast based on NRT data assimilation and NRT model result distribution

Nowcast of location-specific particle populations

Geomagnetic field measurements

Ionospheric conditions

SEP, RB, substorm energetic particle properties

Geomagnetic & ionospheric models combined with

Terrestr./lunar radionuclide data with

flare/CME observations and models, combined with observed statistics of flaring on Sun-like stars

COSPAR/ILWS Space Weather Science Roadmap team

Domain: solar, heliospheric, geospace

v. 2014/10/07

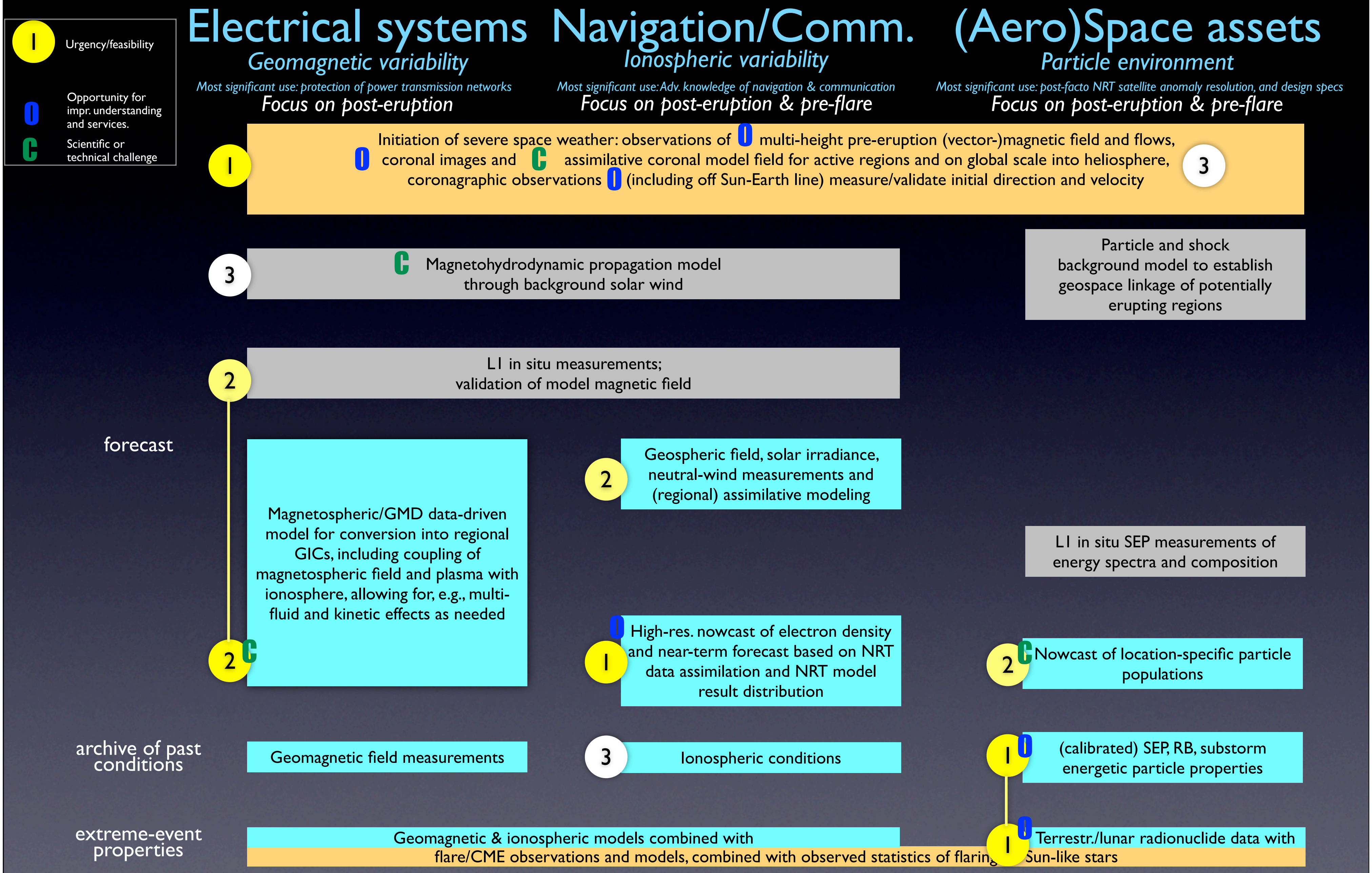
Fundamental questions

- What will leave the Sun?
- How will things evolve en-route to geospace?
- What will it cause to happen in geospace?
- How will that affect technology?
- How can that affect society?
- How can society respond to the threat?
- How does any of these steps depend on what came before? *[Hysteresis, pre-conditioning, ... "event studies" should become "interval studies of the system"]*

Guiding philosophy

- Advance understanding of an intrinsically coupled, non-linear system full of hysteresis / preconditioning
- Look for timely, pragmatic, affordable, feasible implementations, anticipating advances across the disciplines, considering scientific value, urgency, cost, and technological readiness, for an international setting
- Recommendations reach across adjacent sciences, service providers, and affected and interested societal parties
- Consider needs for observations, IT capabilities, and supporting international infrastructure

Tracing impacts & predicting space weather



1 Urgency/feasibility

O Opportunity for impr. understanding and services.

C Scientific or technical challenge

Electrical systems

Geomagnetic variability

Most significant use: protection of power transmission networks

Focus on post-eruption

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3 C Magnetohydrodynamic propagation model through background solar wind

Particle and shock background model to establish geospace linkage of potentially erupting regions

2 L1 in situ measurements; validation of model magnetic field

forecast

2 C Magnetospheric/GMD data-driven model for conversion into regional GICs, including coupling of magnetospheric field and plasma with ionosphere, allowing for, e.g., multi-fluid and kinetic effects as needed

2 Geospheric field, solar irradiance, neutral-wind measurements and (regional) assimilative modeling

L1 in situ SEP measurements of energy spectra and composition

1 O High-res. nowcast of electron density and near-term forecast based on NRT data assimilation and NRT model result distribution

2 C Nowcast of location-specific particle populations

archive of past conditions

Geomagnetic field measurements

3 Ionospheric conditions

1 O (calibrated) SEP, RB, substorm energetic particle properties

extreme-event properties

Geomagnetic & ionospheric models combined with flare/CME observations and models, combined with observed statistics of flaring Sun-like stars

1 O Terrestr./lunar radionuclide data with


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Recommendations

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Highest-priority recommendations

In a collaborative international effort:

Research: observational, computational, and theoretical needs

1. **“Augment the system observatory”**
2. **“Know what $\vec{B}$ is coming”**
3. **“Focus on the GDM-GIC response”**
4. **“Quantify what to expect”**

Teaming: coordinated collaborative research environment

I. **“Uncover susceptibility”**
II. **“Focus resources”**
III. **“Ease access to data”**
IV. **“Grow coverage affordably”**

Bridging communities: collaboration between agencies and communities

A. **“Trust partners”**
B. **“Learn about SWx and its impacts”**
C. **“Evolve priorities”**
D. **“Make use of advancing knowledge”**
E. **“Avoid duplication and mistakes”**

Highest-priority recommendations

Research: observational, computational, and theoretical needs

In a collaborative international effort:

1. **“Augment the system observatory”: Advance the international Sun-Earth system observatory along with data-driven models to improve forecasts based on understanding of real-world events through the development of innovative approaches to data incorporation, including data-driving, data assimilation, and ensemble modeling**

2. **“Know what $\vec{B}$ is coming”: Understand space weather origins at the Sun, initially prioritizing post-event solar eruption modeling to develop multi-day forecasts of geomagnetic disturbance times and strengths, after propagation through the heliosphere**

3. **“Focus on the GDM-GIC response”: Understand the geospace response, including that of the magnetosphere to solar wind and internal processes, and the resulting generation of GICs and harsh space radiation, and including the role of driving the ionosphere from below**

4. **“Quantify what to expect”: Develop comprehensive space environment specification, first to aid scientific research and engineering designs, later to support forecasts**

Highest-priority recommendations

Teaming: coordinated collaborative research environment

In a collaborative international effort:

I. **"Uncover susceptibility": Quantify vulnerability** of humans and of society's infrastructure to space weather jointly with stakeholder groups.

II. **"Focus resources": Strengthen environments in which coordinated observing supports model development:** (a) state-of-the-art environments for numerical experimentation and (b) focus areas of comprehensive observational coverage, as tools to advance understanding of the Sun-Earth system, to validate forecast tools, and to guide requirements for operational forecasting.

III. **"Ease access to data": Standardize (meta-)data and product metrics and harmonize access to data and model archives:** for observational and model data products, for data dissemination, for archive access, for intercalibration, for tests of models and forecasts.

IV. **"Grow coverage affordably": Optimize observational coverage:** Increase coverage of the Sun-Earth system by combining observations with data-driven models, by optimizing use of existing ground-based and space-based resources, by developing affordable new instrumentation and exploring alternative techniques, and through partnerships between scientific and industry sectors.

Highest-priority recommendations

Bridging communities: collaboration between agencies and communities

In a collaborative international effort:

A. **“Trust partners”: Implement an open space-weather data and information policy:** Promote data sharing through (1) open data policies, (2) trusted brokers for access to space-weather impact data, and (3) partnerships with the private sector.

B. **“Learn about SWx and its impacts”: Identify, develop, and provide access to quality education and information materials for all stakeholder groups:** Identify and collect or develop educational materials on space weather and its societal impacts, and support resource hubs for these, and for space-weather related data and data products.

C. **“Evolve priorities”: Execute an international, inter-agency assessment of the state of the field to evolve priorities subject to scientific, technological, and user-base developments:** perform comprehensive assessments of the state of the science of space weather on a 5-year basis to update prioritization data, models, and research infrastructure.

D. **“Make use of advancing knowlege”: Develop settings to transition research tools to operations.** Collaborative activities to evaluate skills of models at forecasting/specifying parameters of high operational value. Determine the suitability of research models for use in a space weather service center. Identify performance gaps in research and (operational) models and encourage developments in high-priority areas.

E. **“Avoid duplication and mistakes”: Partner with the weather and solid-Earth communities** to improve understanding of the couplings between weather and space-weather variability and to quantify potential climate impacts by space weather; to transfer “lessons learned” from the climate/weather communities on data assimilation and ensemble modeling and the development of forecasts and their standards based on that.

Recommendations by pathway

on observational, computational, and theoretical needs

Pathway 1: ... for impacts of GMD/GIC on electrical systems

to obtain >1d forecasts of incoming CME field, and anticipated geomagnetic response, and ionospheric disturbances.

Pathway 2: ... for the particle environment of (aero)space assets

to improve environmental specification and near-real-time conditions

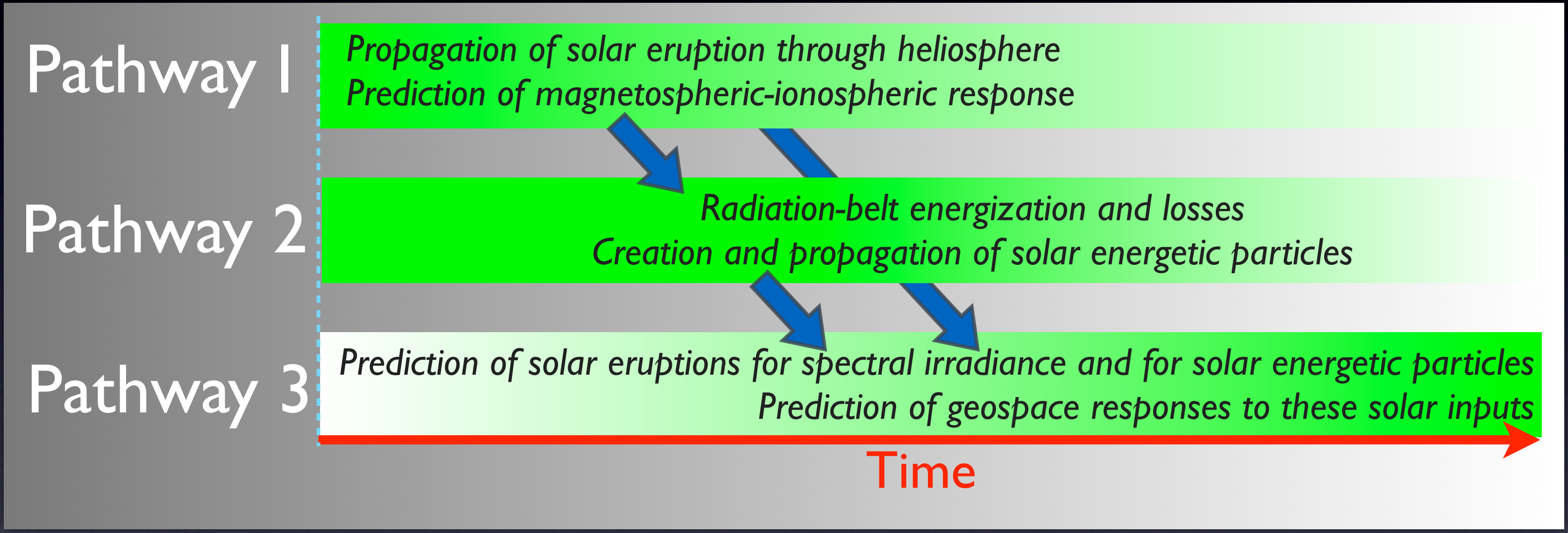
Pathway 3: ... to enable pre-event forecasts of flares and SEPs

to enable short-term forecasts, including all-clear conditions, for particles and ionospheric conditions

N.B. Pathways reflect a merged weighting based on assessed societal impact, scientific need, estimated feasibility, likelihood of near-term success, and sequencing in a logical order of progression.

Recommendations by pathway

on observational, computational, and theoretical needs



Pathway 1

Propagation of solar eruption through heliosphere
Prediction of magnetospheric-ionospheric response

Pathway 2

Radiation-belt energization and losses
Creation and propagation of solar energetic particles

Pathway 3

Prediction of solar eruptions for spectral irradiance and for solar energetic particles
Prediction of geospace responses to these solar inputs

N.B. Pathways reflect a merged weighting based on assessed societal impact, scientific need, estimated feasibility, likelihood of near-term success, and sequencing in a logical order of progression.

Pathway 1: observational, computational, and theoretical needs to forecast geospace consequences of CMEs more than 1day

Sorted by cost and short-term feasibility, by priority within each list:

Maintain existing essential capabilities:

- Earth-perspective magnetic maps (GBO, SDO) and X/EUV images at arcsec and few-second res. (SDO; Hinode);
- solar coronagraphy, best from multiple perspectives (L1: SoHO, and well off Sun-Earth line; STEREO);
- in-situ solar-wind plasma and magnetic field at, or upstream of, Sun-Earth L1 (ACE, SoHO; DSCOVR);
- for a few years, measure the interaction across the bowshock/magnetopause (as now with Cluster/ARTEMIS/THEMIS; soon with MMS), to better understand wind-magnetosphere coupling;
- satellite measurements of magnetospheric magnetic and electric fields, plasma parameters, soft auroral and trapped energetic particle fluxes (e.g., Van Allen Probes, LANL satellites, GOES, ELECTRO-L, POES, DMSP);
- ground-based sensors for Sun, heliosphere, magnetosphere, and iono-/thermo-/mesosphere to complement satellite data.

Archival research, develop data infrastructure, or modeling capabilities:

- near-real time 3D models of active-region magnetic fields to assess destabilization and to estimate energies;
- data-driven models for the global solar surface–coronal field;
- data-driven ensemble models of the solar wind including magnetic field;
- data assimilation techniques for the global ionosphere-magnetosphere system for nowcasts and near-term forecasts to optimally use coordinated ground and space based observations to meet user needs. Compare models and observations, ideally in select locations where laboratory-like test beds exist or can be developed at a few informative latitudes.
- system-level research into large-scale morphological changes in the Earth's magnetotail and embedded energetic particle populations (using data from, among others, SuperDARN, SuperMAG, AMPERE, etc.);
- system-level study of particle transport/acceleration/losses in the inner magnetosphere;
- stimulate research to improve global geospace modeling beyond MHD (kinetic, hybrid, ...)
- develop the ability to use chromospheric and coronal polarimetry for full-Sun corona-to-heliosphere field *models*.

Focus on solar, heliospheric, or geospace

Pathway 1: observational, computational, and theoretical needs for impacts of GMD/GIC on electrical systems

Sorted by cost and short-term feasibility, by priority within each list:

Continued:

Deployment of new/additional instrumentation:

To determine the magnetic structure that was ejected from the solar region:

- binocular imaging of the solar corona at ~1-arcsecond and at least 1-min. resolution ~10–20° separation;
- observe the solar vector-field at and near the surface and the overlying corona at <200-km resolution to quantify ejection of compact and low-lying current systems from solar active regions;

To quantify the geospace processes leading to (sub-)storm activity:

- (define criteria for) expanded in-situ coverage of the Earth's magnetosphere, particularly in the dipole-tail transition region (building on MMS) to determine the magnetospheric state in current (THEMIS/Cluster) and future high-apogee constellations, using hosted payloads and cubesats as appropriate;
- (define needs, then) increase ground- and space-based instrumentation to complement satellite data of magnetospheric and ionospheric variability, including geomagnetic data above 55° magnetic latitude with 100-km spacing in select locations, ideally in association with ionospheric radars, and ionospheric measurements to cover observations gaps (e.g., over ocean areas);

To understand the solar magnetic structure entering the heliosphere and to model its propagation:

- an observatory to expand solar-surface magnetography at all latitudes and off the Sun-Earth line [for which the Solar Orbiter provides valuable initial experimental views];
- large ground-based solar telescopes to perform multi-wavelength spectro-polarimetry to probe magnetized structures at a range of heights in the solar atmosphere and from sub-active-region to global-corona spatial scales;

To quantify the evolution of the inner-magnetospheric plasma content:

- launch optical monitors to measure global particle precipitation [such as POLAR and IMAGE] to be used in data assimilation models for GMD and ionospheric variability.

Pathway 1: observational, computational, and theoretical needs for impacts of GMD/GIC on electrical systems

Sorted by cost and short-term feasibility, by priority within each list:

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- launch optical monitors to measure global particle precipitation [such as POLAR and IMAGE] to be used in data assimilation models for GMD and ionospheric variability.

Pathway 2: observational, computational, and theoretical needs for the radiation-belt environment

Sorted by cost and short-term feasibility, by priority within each list:

In addition to the remote-sensing and modeling requirements for Pathway 1:

Maintain existing essential capabilities:

- develop particle-environment nowcasts for LEO to GEO based on observations of electron and ion populations (hard/~MeV and soft/~keV; e.g., GOES, ..., striving for intercalibrated data sets with better background rejection, for at least a solar cycle), and of the magnetospheric field [see Tier-1 GMD/GIC recs.];
- maintain a complement of spacecraft with high resolution particle and field measurements and defined inter-spacecraft separations (e.g., the Van Allen Probes).

Archival research, develop data infrastructure, or modeling capabilities:

- specify the frequency distributions for fluences of energetic particle populations [SEP, RB, GCR] for the specific environment under consideration, and maintain access to past conditions;
- develop data-driven and data-assimilative models for the soft and energetic particle populations for forecast purposes, and validate these based on archival information;
- develop and experiment with assimilative integrated models for RB particle populations towards forecast development including ionosphere, thermosphere and magnetosphere, including the coupling from lower-atmospheric domains.

Deployment of new/additional instrumentation:

- deploy and continue operation of high- and low-energy particle and electromagnetic field instruments to ensure dense spatial coverage from LEO to GEO and long term coverage of environment variability (including JAXA's ERG: Exploration and energization of Radiation in Geospace; launch in 2015). Combine science-quality and monitoring instruments for (cross) calibrations, resolution of angular distributions, and coverage of energy range.

Pathway 3: observational, computational, and theoretical needs to enable pre-event forecasts of flares and SEPs

Sorted by cost and short-term feasibility, by priority within each list:

In addition to the remote-sensing and modeling requirements for Pathway 1:

Maintain existing essential capabilities:

- observe inner-heliospheric shocks at radio wavelengths;
- maintain for some years multi-point in-situ observations of SEPs on and off Sun-Earth line throughout the inner heliosphere (e.g., L1, STEREO). Maintain measurements of heavy ion composition (L1/ACE, STEREO; near-future: GOES-R).

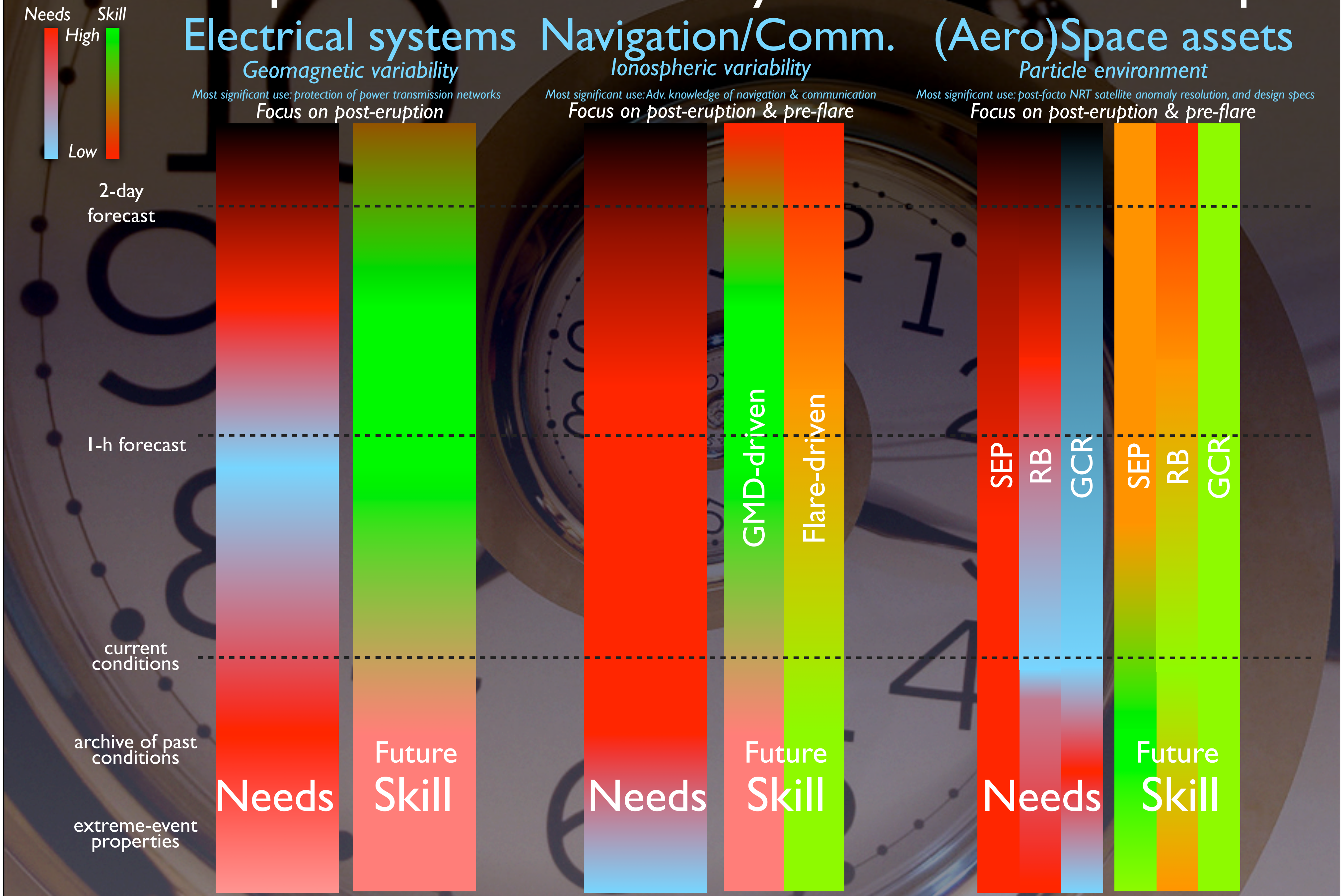
Archival research, develop data infrastructure, or modeling capabilities:

- develop data-driven predictive modeling capability for field eruptions from the Sun through the inner heliosphere;
- investigation of observed energetic particle energization and propagation within the inner-heliospheric field, aiming to develop at least probabilistic forecasting of SEP properties [see also Pathway I. for heliospheric data-driven modeling];
- ensemble modeling of active regions subject to perturbations, to understand field instabilities and energy conversions, including bulk kinetic motion, SSI, and energetic particles.

Deployment of new/additional instrumentation:

- new multi-point in-situ observations of SEPs off Sun-Earth line throughout the inner heliosphere to improve models of the heliospheric field and understand population evolutions en route to Earth (e.g., Solar Orbiter, Solar Probe Plus);
- maintain and further develop ground- and space-based ionospheric observation platforms, complemented by space-based instrumentation to obtain electron density as a function of height and to fill observation gaps that now exist, such as over ocean areas.

Anticipated advances 3-10y from SWx roadmap



Electrical systems

Geomagnetic variability

Most significant use: protection of power transmission networks

Focus on post-eruption

Navigation/Comm.

Ionospheric variability

Most significant use: Adv. knowledge of navigation & communication

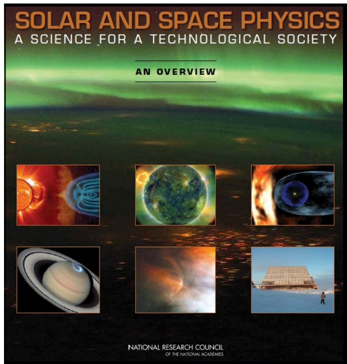
Focus on post-eruption & pre-flare

(Aero)Space assets

Particle environment

Most significant use: post-facto NRT satellite anomaly resolution, and design specs

Focus on post-eruption & pre-flare



In context:

Compared to the US NRC/SSB Decadal Survey:
“Solar and Space Physics”

NRC/SSB decadal survey:

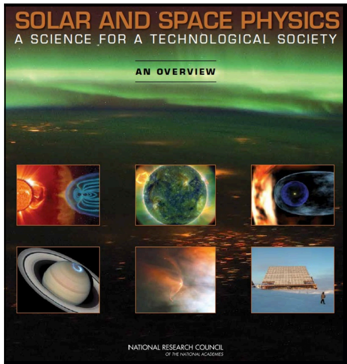
In making its recommendations, the committee was guided by the following principles:

- To make transformational scientific progress, the Sun, Earth, and heliosphere must be studied as a coupled system;
- To understand the coupled system requires that each subdiscipline be able to make measurable advances in achieving its key scientific goals; and
- Success across the entire field requires that the various elements of solar and space physics research programs—the enabling foundation comprising theory, modeling, data analysis, innovation, and education, as well as ground-based facilities and small-, medium-, and large-class space missions—be deployed with careful attention to both the mix of assets and to the schedule (cadence) that optimizes their utility over time.

COSPAR/ILWS roadmap:

“... the domain of space weather is vast – extending from deep within the Sun to far outside the planetary orbits – and the physics complex – including couplings between various types physical processes that link scales and domains from the microscopic to large parts of the solar system. Consequently, advanced understanding of space weather requires a coordinated international effort to effectively provide awareness of the processes within the Sun-Earth system through observation-driven models.”

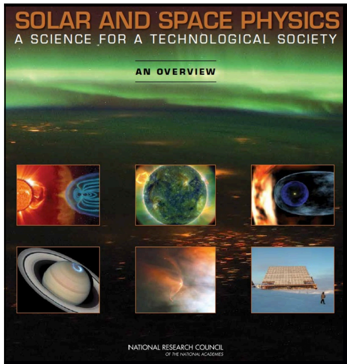
“Use of the existing ensemble of components of the Sun-Earth system observatory with its rich diversity of resources and vantage points, and the scientific expertise behind these, as a foundation will enable significant advances in its capabilities by adding small to moderate state-of-the-art new capabilities designed to fill capability gaps and to work towards an international collaborative effort. Such a strategy requires urgent action to utilize and grow the currently existing fledgling system observatory: key instrumentation, as identified in the roadmap, needs to be sustained, ...”


SOLAR AND SPACE PHYSICS
A SCIENCE FOR A TECHNOLOGICAL SOCIETY
AN OVERVIEW
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

In context:

Compared to the US NRC/SSB Decadal Survey: "Solar and Space Physics"

NRC/SSB decadal survey: Priority questions:	*COSPAR/ILWS roadmap:*
I. How are solar magnetic fields created and destroyed?	
a) What are the detailed origins of the solar cycle?	*Not part of the roadmap charge.*
b) How is energy transferred through the solar atmosphere to the rest of the solar system? c) What is the role of magnetic reconnection in energy release in coronal mass ejections and flares?	*Corresponds to "Research" #2 and #3.*
II. How does Earth's magnetosphere store and release solar energy?	
a) What are the interactions and feedbacks that connect the magnetosphere, solar wind, and ionosphere? b) How are plasmas produced, lost, and energized in the magnetosphere?	*Corresponds to "Research" #3.*
c) How do planetary magnetospheres interact with their ionospheres, atmospheres, and the solar wind?	*Earth focus: "Research" #3.*
III. How does Earth's atmosphere couple to its space environment?	
a) How does Earth's atmosphere couple to its space environment? b) How does the ionosphere-thermosphere system regulate the flow of solar energy throughout geospace? c) How do terrestrial weather and climate affect conditions in near-Earth space?	*Corresponds to "Research" #3.*
IV. How does the Sun carve its place in the Galaxy?	
a) How does the Sun's magnetic field shape the dynamic heliosphere? b) How does our Sun interact with the interstellar medium?	*Not part of the roadmap charge.*



In context:

Compared to the US NRC/SSB Decadal Survey: "Solar and Space Physics"

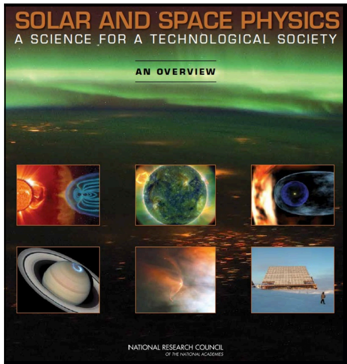
NRC/SSB priority recommendations:

1. Maintain and complete the present program. Most importantly, the decadal survey recommends that NASA an NSF maintain and complete the current research programs in solar and space physics. The decadal survey recommends continued support in the near term for the key existing program elements that constitute the HSO [Heliophysics System Observatory].
2. Implement the DRIVE initiative: the decadal survey recommends as its highest priority after completion of the current program an array of actions collectively known as the DRIVE initiative ... DIVERSIFY observing platforms with microsatellites and midscale ground-based assets; REALIZE scientific potential by sufficiently funding operations and data analysis; INTEGRATE observing platforms and strengthen ties between agencies and disciplines; VENTURE forward with science centers and with instruments and technology development; EDUCATE, empower, and inspire the next generation of space researchers.
3. Enhance the Explorer program [by] increasing the cadence of the Heliophysics Explorer program to one mission every two to three years.

COSPAR/ILWS priority recommendations:
Research 1.: "Advance the international Sun-Earth system observatory"; Research 2&3: need for existing capabilities, MMS, Solar Probe,Plus, Solar Orbiter, ICON/GOLD.

Teaming II ("strengthen ... coordinated observing"), III ("Standardize data ... harmonize access to data and model archives"), IV. ("Optimize observational coverage") Collaboration B, ("... education and information materials for all stakeholder groups") C ("... international, interagency assessment ... to evolve priorities"), E ("Partner with the weather community").

Teaming IV: "Optimize observational coverage".



In context:

Compared to the US NRC/SSB Decadal Survey: "Solar and Space Physics"

NRC/SSB priority recommendations (cnt'd):

4. Solar-terrestrial probe mission science:
    a)... understand the outer heliosphere and its interaction with the interstellar medium;
    b)... the notional Dynamical Neutral Atmosphere-Ionosphere Coupling
    c)... Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation
5. Living With a Star Mission Science ... a comprehensive investigation of how Earth's atmosphere absorbs solar wind energy.

Space weather and space climatology ... establish a space weather research program to effectively transition research to operations.

COSPAR/ILWS priority recommendations:

Not part of the roadmap charge.

Research #3; notional related instrumentation #3,4, but mainly to be addressed by GBO network.
Research #3; related notional instrumentation #3,4, but with focus on GMD-GIC connection from magnetotail to ionospheric current closure instead of plasmas.
Research #3; notional instrumentation #3,4.

Roadmap focuses on science of space weather, but comments on the need for transition from research to operations, see Collaboration C.

Contrasts: COSPAR/ILWS roadmap (1) emphasizes urgent action to strengthen "HSO", and (2) articulates a need to understand how to determine what magnetic configuration left the Sun, how that moves through the heliosphere towards Earth, and how that shapes SEP populations and their propagation.

Roadmap summary

Comments and questions: *cosparinput@lmsal.com*
Team site: http://www.lmsal.com/~schryver/COSPARrm/

In a collaborative international effort:

1. Advance the international Sun-Earth system observatory along with data-driven models to improve forecasts based on understanding of real-world events;
2. Understand space-weather origins, initially prioritizing post-event solar eruption modeling;
3. Understand the geospace response, initially prioritizing magnetospheric field response to solar wind and internal processes;
4. Develop space climate specification and forecast tools.

I. Quantify SWx vulnerability of humans and of society's infrastructure with user groups;
II. Strengthen environments in which coordinated observing supports model development;
III. Standardize data and product metrics, and data and model archive access;
IV. Optimize coverage of the components of the Sun-society system.

A. Open space-weather data and information policy;
B. Access to quality education/information materials;
C. Regularly assess the state of the field to adjust priorities;
D. Develop environments to transition research tools to operations;
E. Partner with climate/weather stakeholders.