Space weather impacts and predictions: relevant spatial and temporal scales

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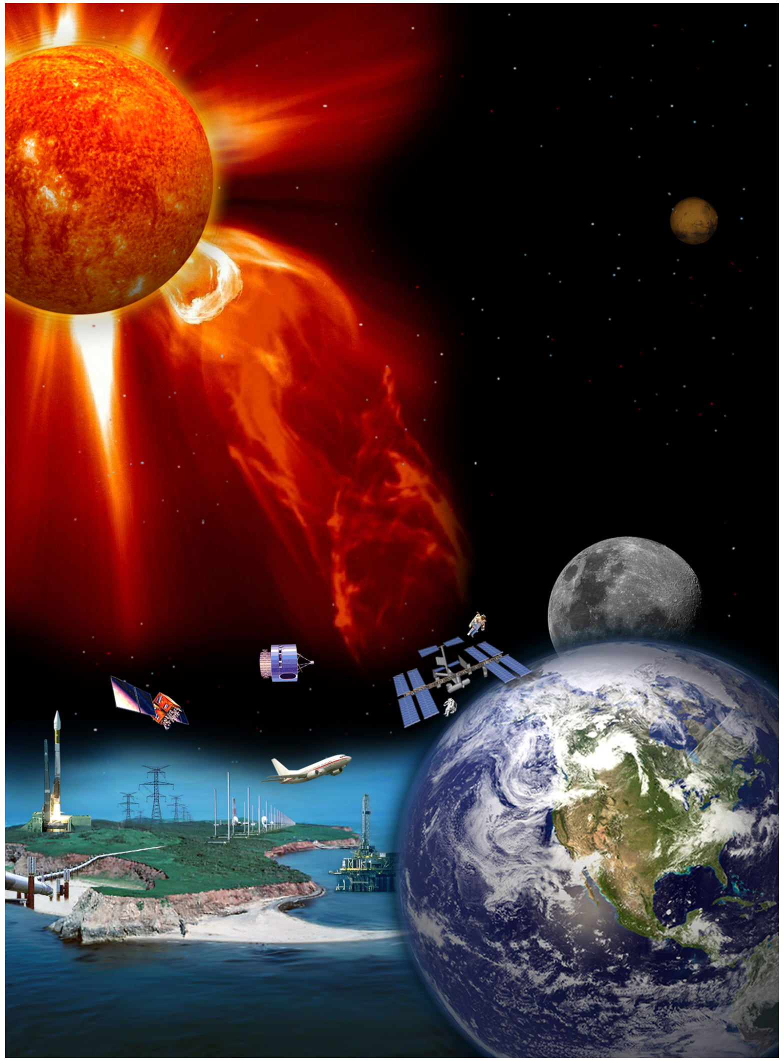
Contents

- Identification of end-user needs (and the spatiotemporal context).
  - Power transmission industry.
  - Human spaceflight.
- Addressing the end-user needs (and dealing with the spatiotemporal complexity of the relevant space environmental phenomena).
  - Geomagnetic storm benchmarks.
  - Solar energetic particle (SEP) predictions.

Identification of end-user needs

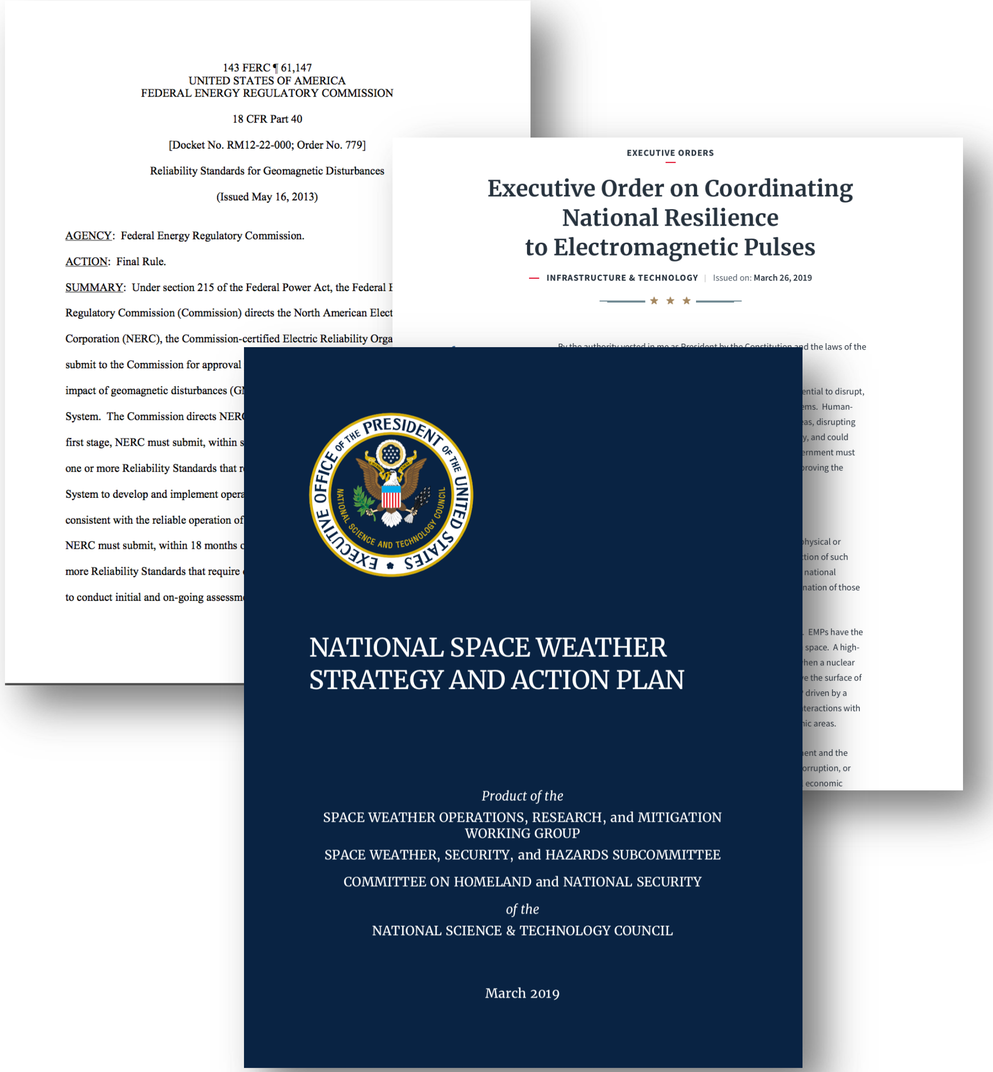
End-user needs

- If we acknowledge space weather as the societal dimension of heliophysics, understanding the impacts and associated end-user needs are the foundation of the field.
- Our space weather work must be informed by those needs and strive toward generating information that is actionable.



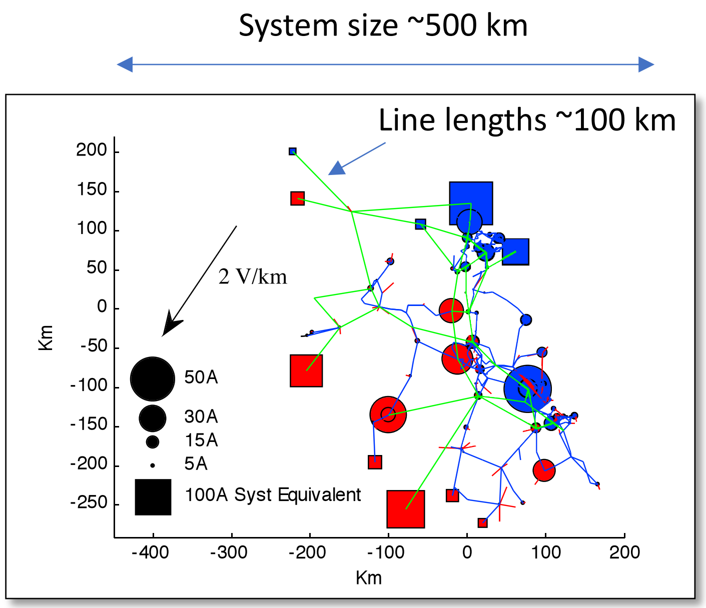
End-user needs – power transmission industry

- While also predictions are of interest, the main U.S. focus right now is on hazard assessments.
- To enable hazard assessments, space weather extremes need to be communicated to the end-user in the form of benchmarks.

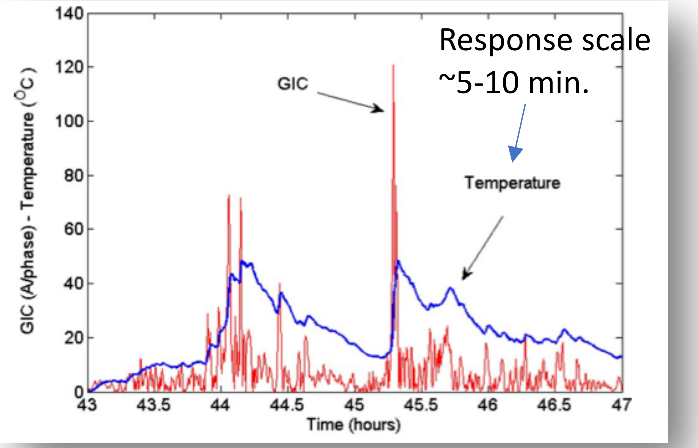


GMD benchmark requirements

- Science side needs to provide information about a physical parameter that is directly applicable/actionable to further engineering analyses. (geoelectric field)
- We need to address the following key characteristics of the extreme geoelectric fields:
    i. Amplitude. (Element 1)
    ii. Spatial structure. (Element 2)
    iii. Temporal waveform. (Element 3)
        - Full 1-3 day storm characterized.
        - 1-10 s sampling to capture rapid enhancements that may compromise voltage stability.
        - Longer duration enhancements necessary for thermal heating-related problems.
- Science analyses also need to characterize the occurrence rates of i-iii.



Pulkkinen et al. (2012)



Marti et al. (2013)

GMD benchmark requirements

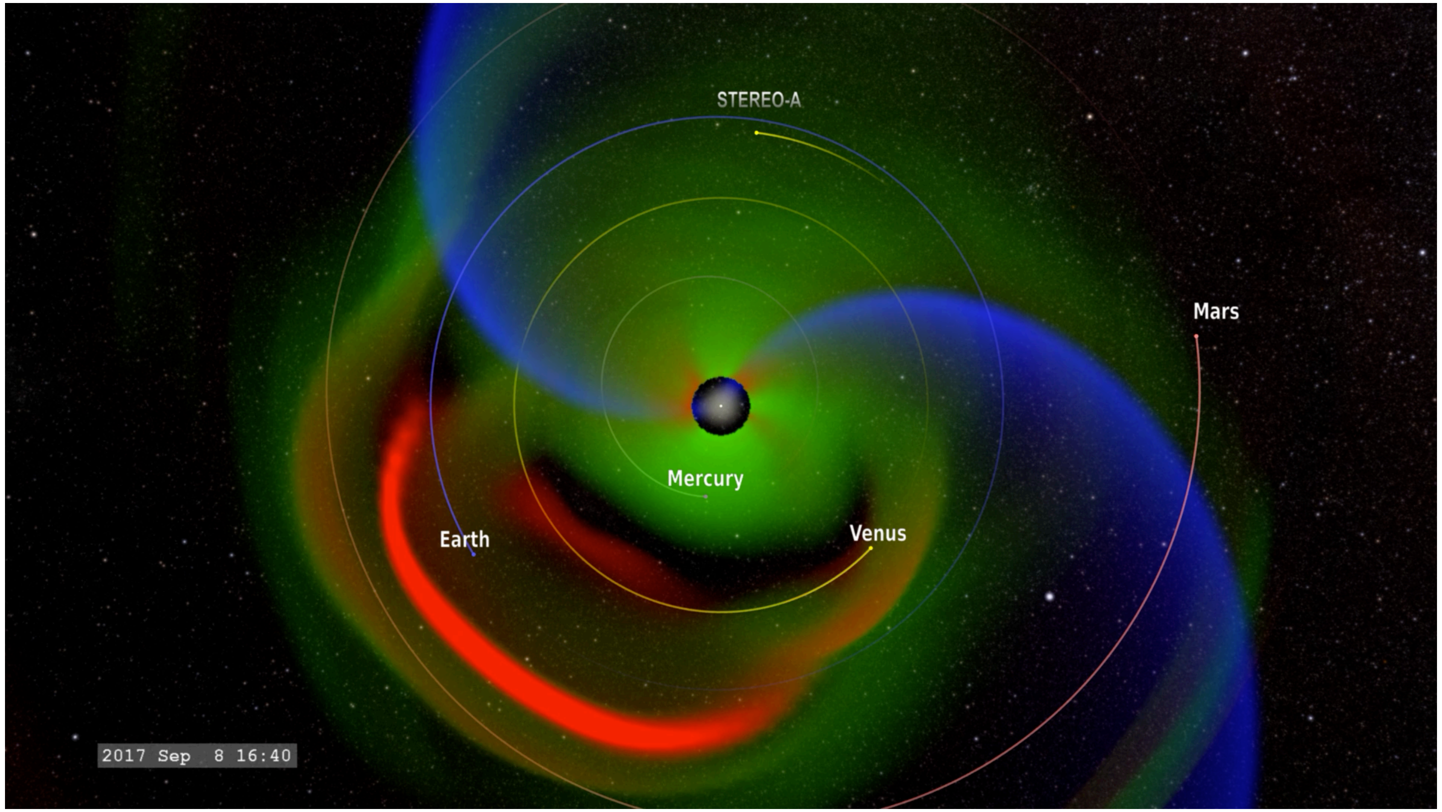
- The geomagnetic induction process that generates the geoelectric field is dependent on external and internal factors:
  iv. Many different near space electric currents systems contribute to driving of geomagnetic induction. The effect of the geomagnetic latitude, and possibly local time, needs to be taken into account. (Element 4)
  v. The local ground conductivity dictates the ground response. Local geology needs to be taken into account. (Element 5)

End-user needs – human spaceflight

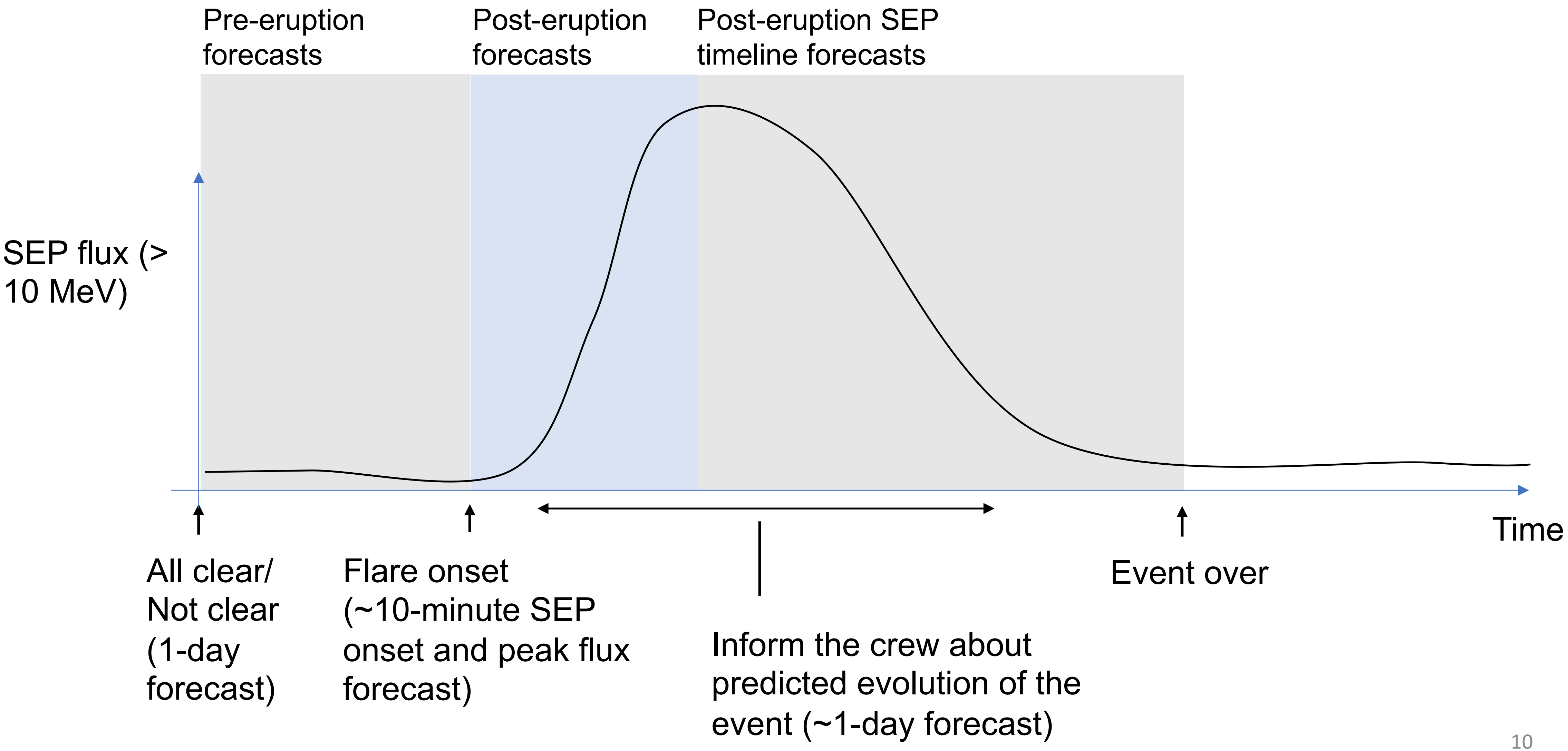
- While low-inclination LEO (ISS orbit) is fairly benign from the space radiation perspective, deep space environment experienced in the Artemis program poses a much more significant challenge.
- The key problem is ionizing radiation: > 10 MeV ions for EVAs and > 100 MeV ions for the crew inside the vehicle.
- Primary sources for energetic ions contributing to possible problems include galactic cosmic rays, SEPs and inner radiation belt – only the SEP component discussed here.

End-user needs – human spaceflight

- Due to the SEP challenge, Artemis will have storm shelter as a part of the ops. The shelter needs to be deployed in 30 min from (*Townsend et al*., 2018) ➔ Predictive capability plays a critical role in the ops.
- We need to have information about elevated, likely mostly CME shock-driven, energetic ion fluxes at the location of the vehicle.



End-user needs – human spaceflight



Addressing the end-user needs

GMD benchmark(s) – spatiotemporal representation per the NERC standard

$$\bar{E}(x,y,t) = \begin{bmatrix} E_x(x,y,t) \\ E_y(x,y,t) \end{bmatrix}$$

$$\approx E_{peak}(x,y) \begin{bmatrix} f_x(t) g_x(x,y) \\ f_y(t) g_y(x,y) \end{bmatrix}$$

Assume spatially homogeneous field

$$\approx E_{peak}(x,y) \begin{bmatrix} f_x(t) \\ f_y(t) \end{bmatrix} \cdot 1$$

Factorize & approximate the primary dependencies

$$\approx E_0 \cdot \alpha(y) \cdot \beta(x,y) \begin{bmatrix} f_x(t) \\ f_y(t) \end{bmatrix} \cdot 1$$

Latitude dependence

Ground response dependence

$\bar{E}(x,y,t)$ depends on:
- External excitation $\bar{B}_{ext}(x,y,t)$
- Ground response dictated by $\sigma(x,y,z)$

GMD benchmark(s) – regional vs localized enhancements

Pulkkinen et al. (2015)

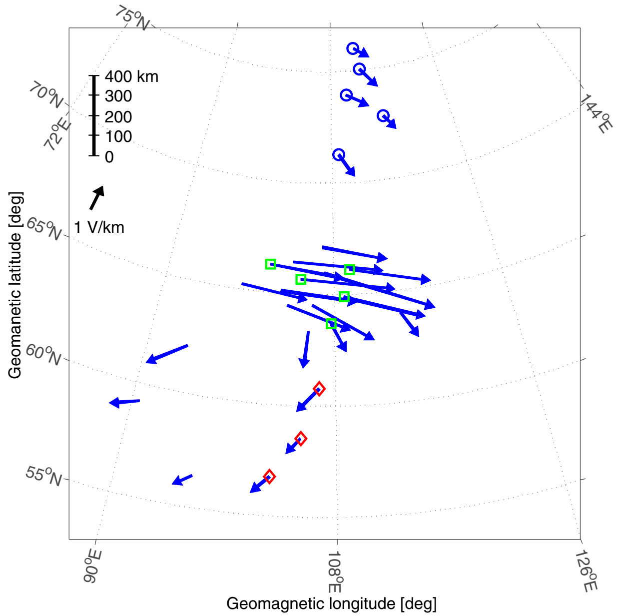


Fig. 1 Computed geoelectric field distribution on November 24, 2001 at 07:32 UT. The *colored circles* show the three station groups used in spatial averaging: *blue*, *green*, and *red* groups. The *green* group generates the largest average geoelectric field magnitude of 2.8 V/km. Note that the maximum geoelectric field amplitude indicated in the top of the figure refers to a single station maximum, not to group average. Corrected geomagnetic coordinates and Oblique Mercator map projection are used

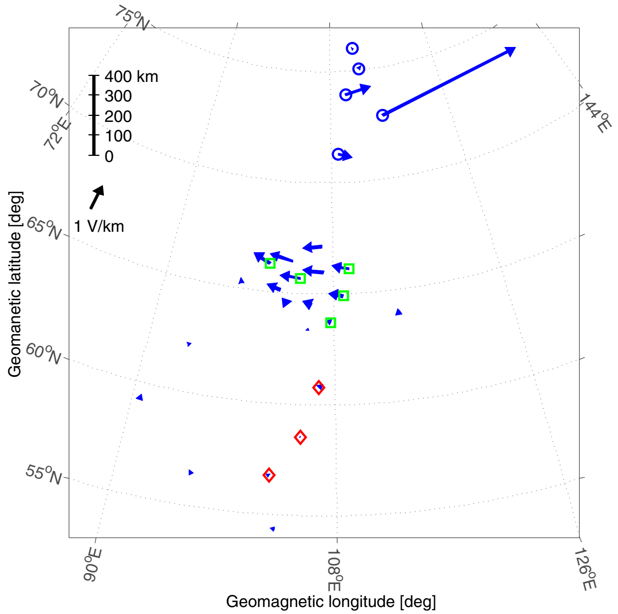


Fig. 3 Same as Fig. 1 but for October 30, 2003 at 16:49 UT. A station in the *blue* group experiences the largest single station geoelectric field magnitude of 5.7 V/km. The spatially averaged field magnitudes for *blue*, *green*, and *red* groups are 1.5, 0.6, and 0.1 V/km, respectively

E_0 quantified with a spatial average

E-field applied regionally

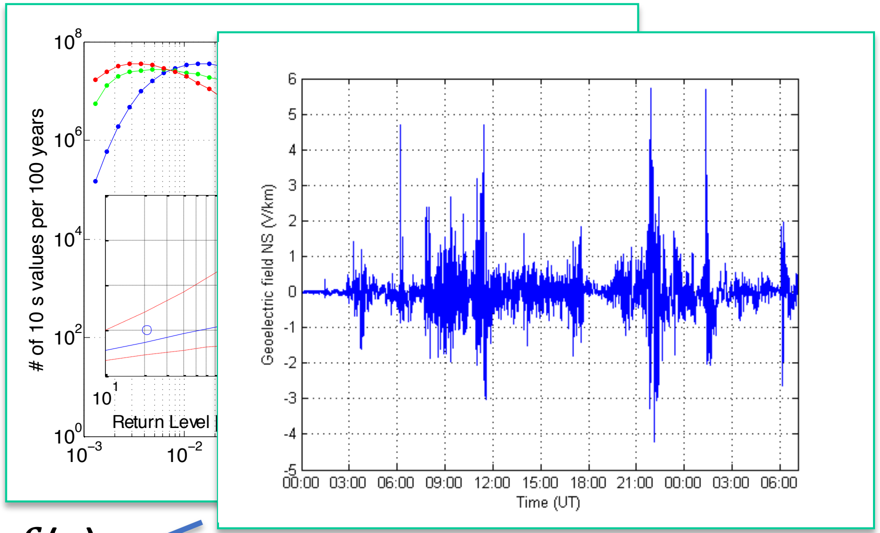
E_0 quantified with individual stations

E-field applied locally

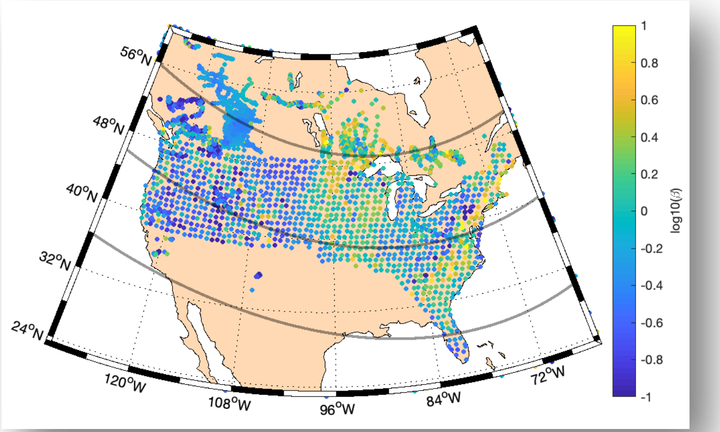
GMD benchmark(s)

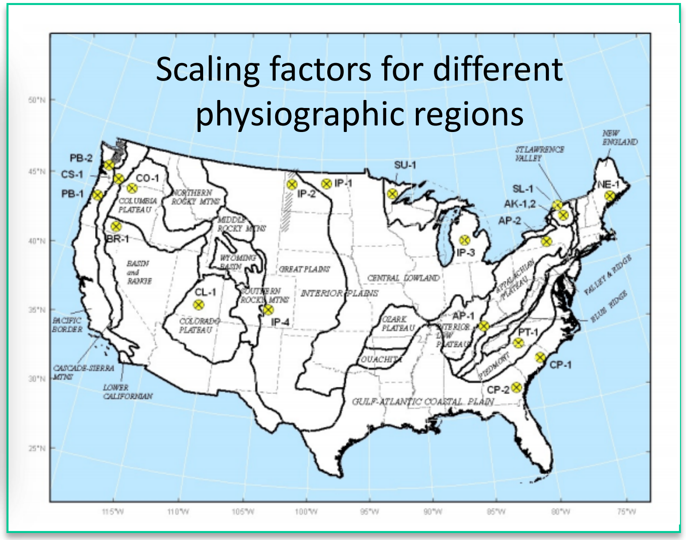
NERC GMD benchmark white paper

- Element 1: amplitude E_0
- Element 2: spatial structure
- Element 3: reference temporal waveform $f(t)$
- Element 4: geomagnetic latitude dependence $\alpha(y)$
- Element 5: dependence on the local ground conductivity $\beta(x,y)$

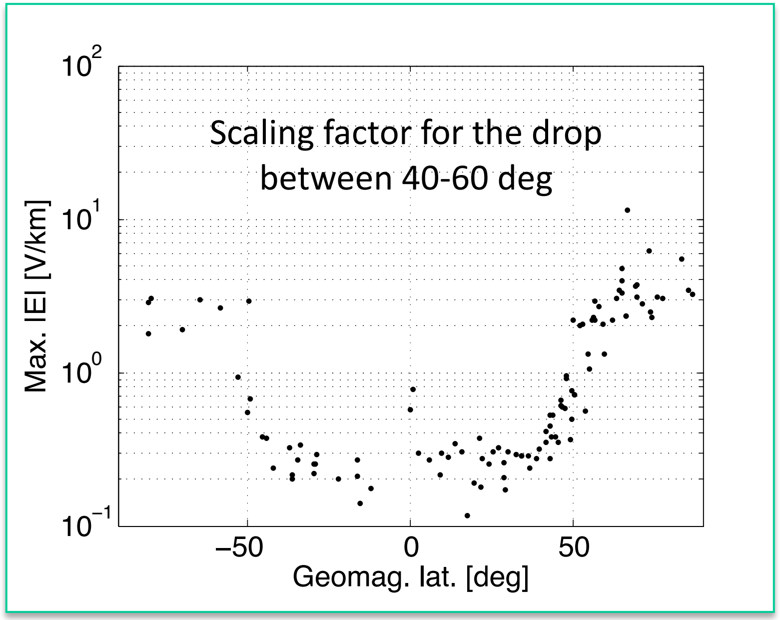


Scaling factors from MT surveys





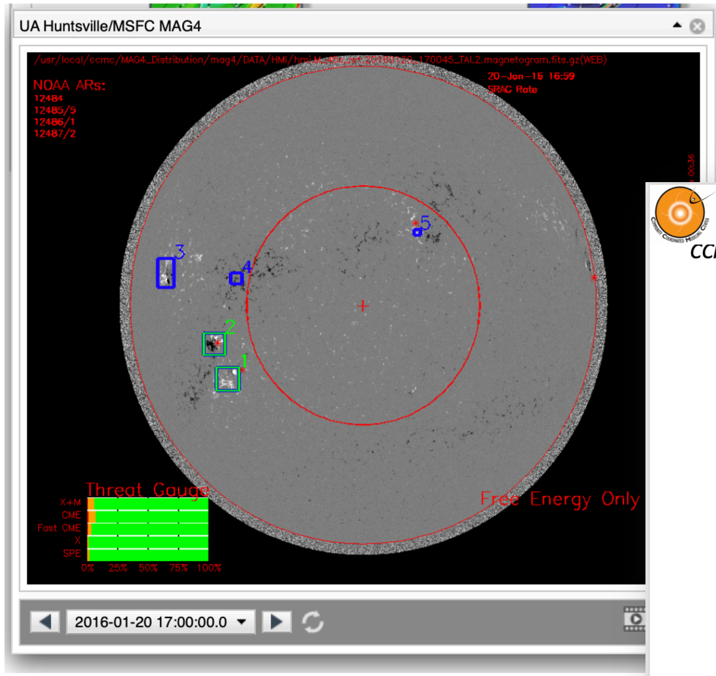
Scaling factors for different physiographic regions

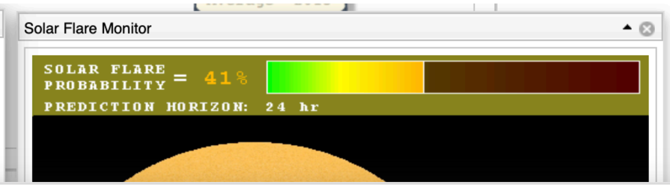


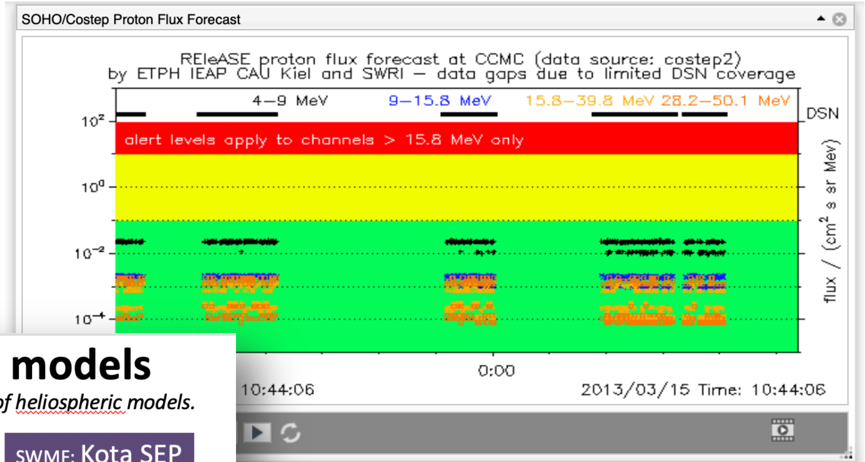
Scaling factor for the drop between 40-60 deg

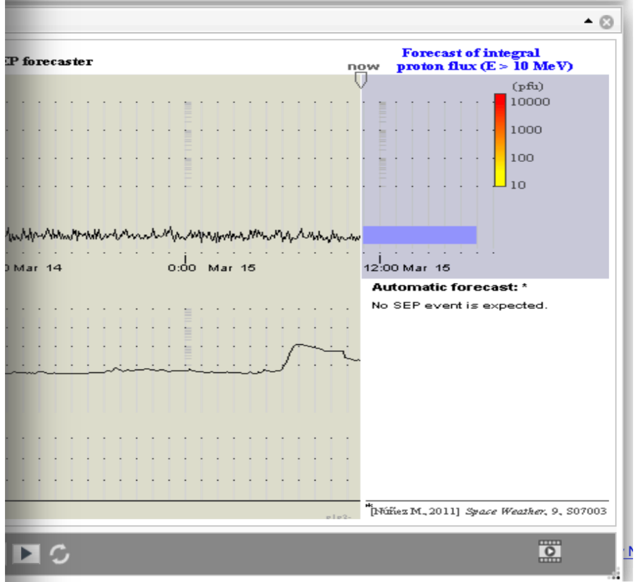
SEP prediction approaches

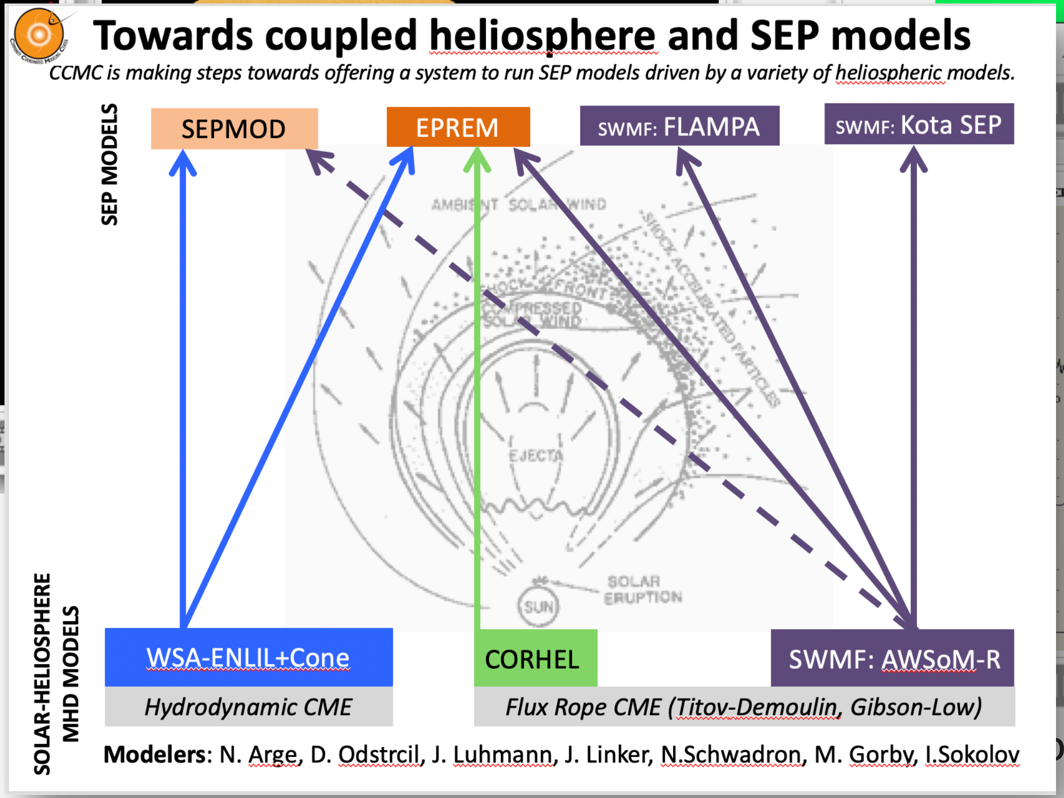
Models available at iswa.gsfc.nasa.gov & ccmc.gsfc.nasa.gov











All clear/pre-eruption forecasts

Post-eruption timeline forecasts
Mays et al. (2017)

on forecasts

Conclusions

- From the space weather standpoint, end-user impacts and needs are the fundamental driver for identifying i) actionable physical parameters of interest, ii) relevant spatiotemporal scales.
- “Unfortunately” it is often necessary to address a blend of global and local spatial scales and a wide range of temporal scales – space weather challenges our understanding of the heliophysics system.
- Empirical, first-principles, handwaving etc. approaches all being used – the nature of the approach does not matter as long as it works.
- It is not all about predictions: In some applications general characterization of extreme environments is currently of greater interest.

Backup

Integrated Exploration Manifest: 2019-2024