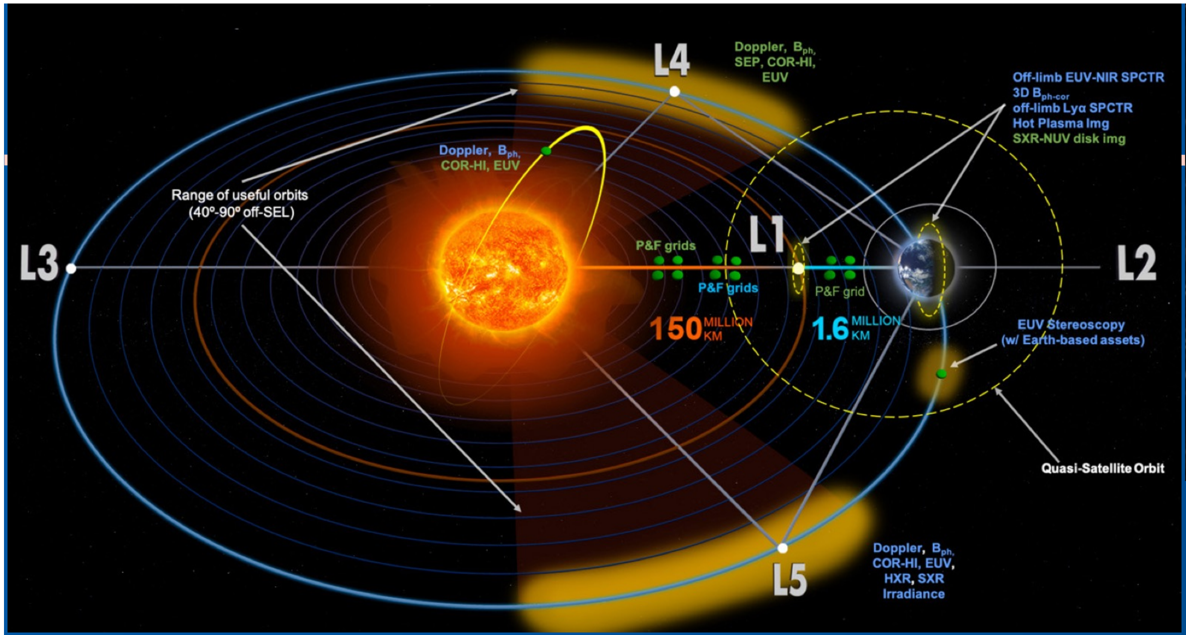

NASA Space Weather Gap Filling Analysis, and Other Steps Forward

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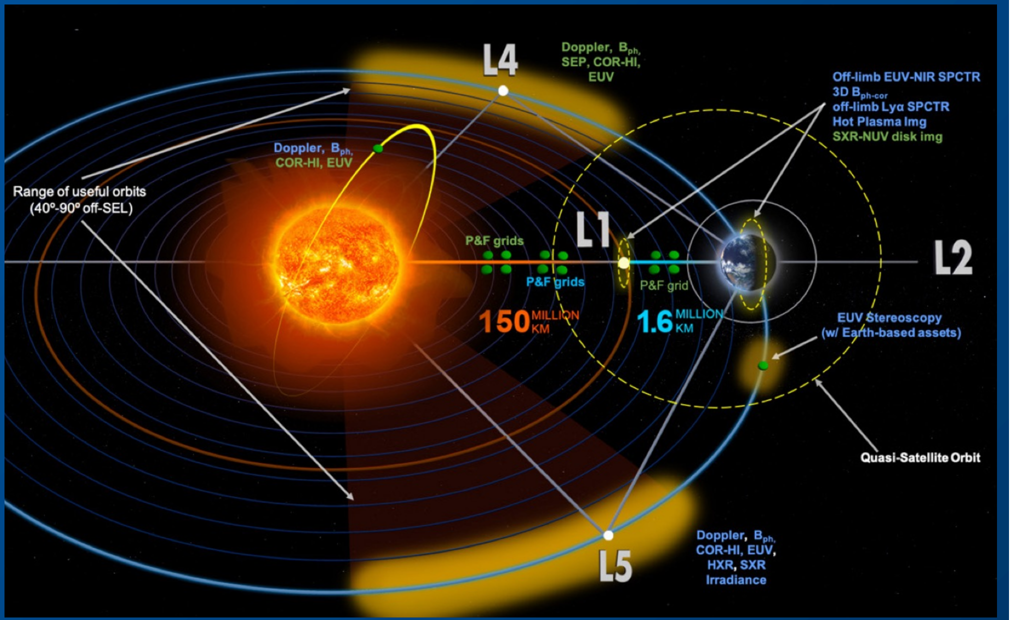
based on numerous discussions with researchers from UNH, UCB, APL, GSFC and other institutions.

Some material from past Space Weather Gap Analysis Exercises/Reports

Past Gap Analyses: Risks and Recommendations

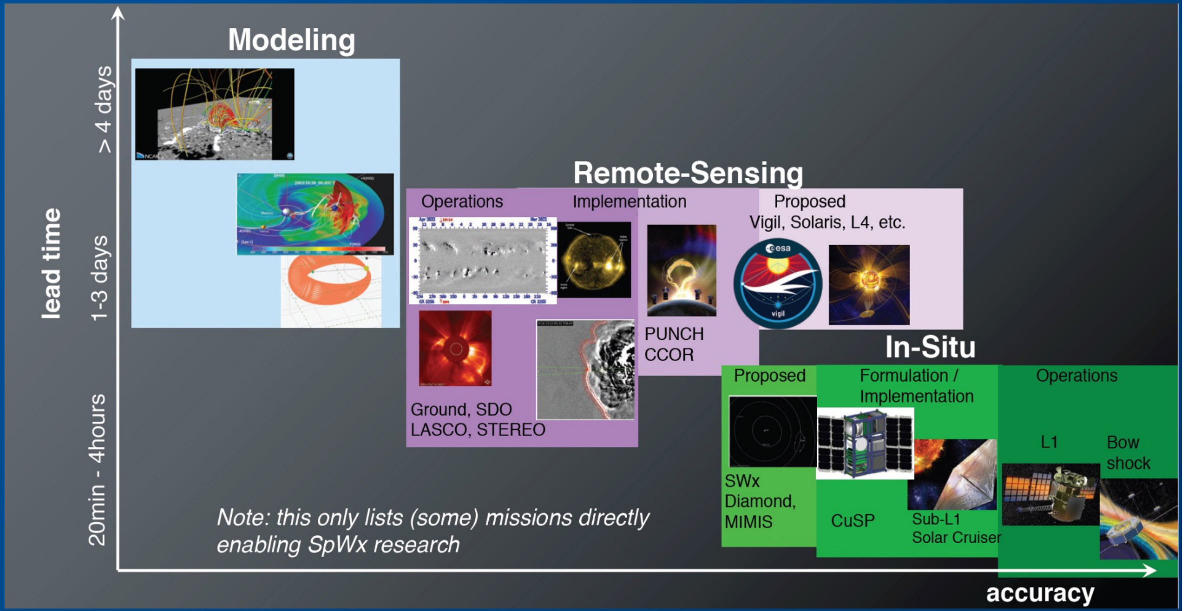
- Top Risks have been identified:
  - **GICs;**
  - **Radiation effects on astronauts for (cis)lunar and beyond;**
  - **Thermospheric expansion.**
- Most important new observations have been identified:
  - Systems-science planning of the HSO.
  - **Solar, coronal and solar wind observations including from off the Sun-Earth line (very data constrained).**
  - Ionosphere-thermosphere measurements.
  - Solar wind from closer to the bow shock.



From NASA Gap Analysis Report, 2021

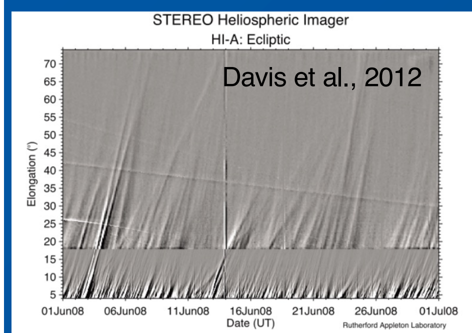
Observing System Experiments (OSEs)

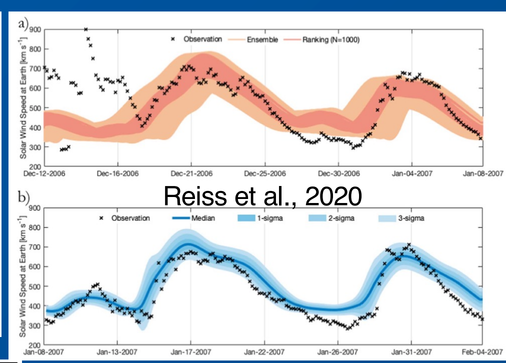
- Space weather differs from space science as cost-benefit analyses are required.
  - This is currently lacking.
  - **We know (±) what should be done overall, but we don't know what is the best thing to do for a given $.**
- First Recommendation for Gap Filling:
  - Determine space weather topics where **Observing System Experiments (OSEs)** can already be performed.
  - Create new scheme for such an endeavor.
    - Some of these exist somewhat (SEP scoreboard) but are not externally funded.
    - Similar to LWS but significantly more coordinated. Or could be center-like.
    - This is not O2R2O. It is using data from science missions for space weather science.
  - It should include modeling through data assimilation, data-constrained ensemble modeling and data-driven modeling.
- **Potential example**: forecasting Bz (remote vs. in-situ vs. model).

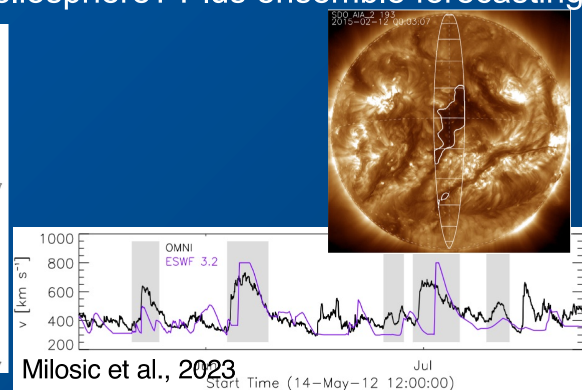


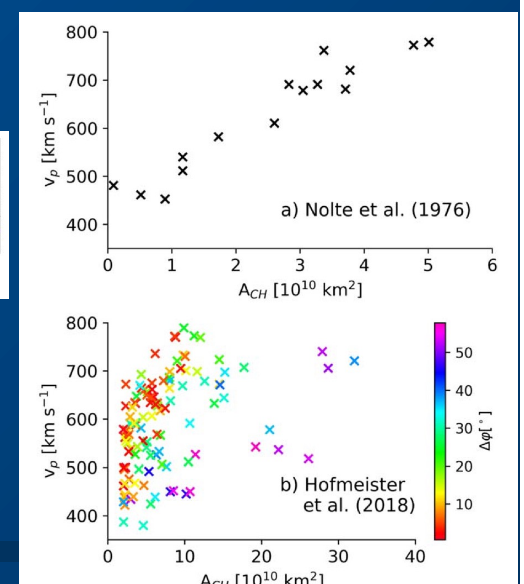
OSE Example: High-Speed Stream Forecasts

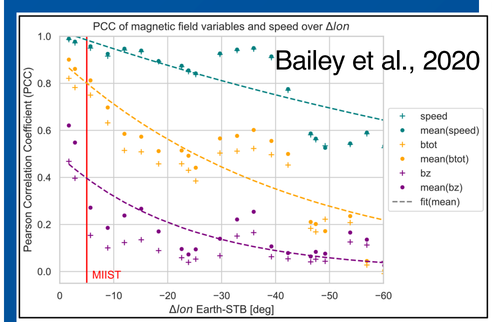
- Significant work in the past decade. What works best?
  - Wang-Sheeley-Arge (WSA) model with CR magnetogram, with ADAPT (WSA-ADAPT)?
  - AI/ML/empirical forecasts from solar EUV observations from L1, L1 + L5, L1 + L4 + L5?
  - Remote observations off the Sun-Earth line with STEREO/HI-1. Plus ensemble forecasting of simple numerical models?
  - Full MHD models with CR magnetogram or with ADAPT or with flux transport?
  - In-situ measurements from L1, L1 + L5, L1 + near-Earth heliosphere? Plus ensemble forecasting or data assimilation?



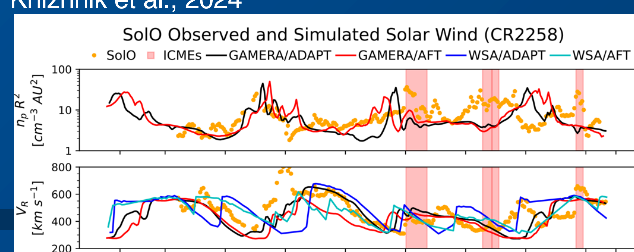






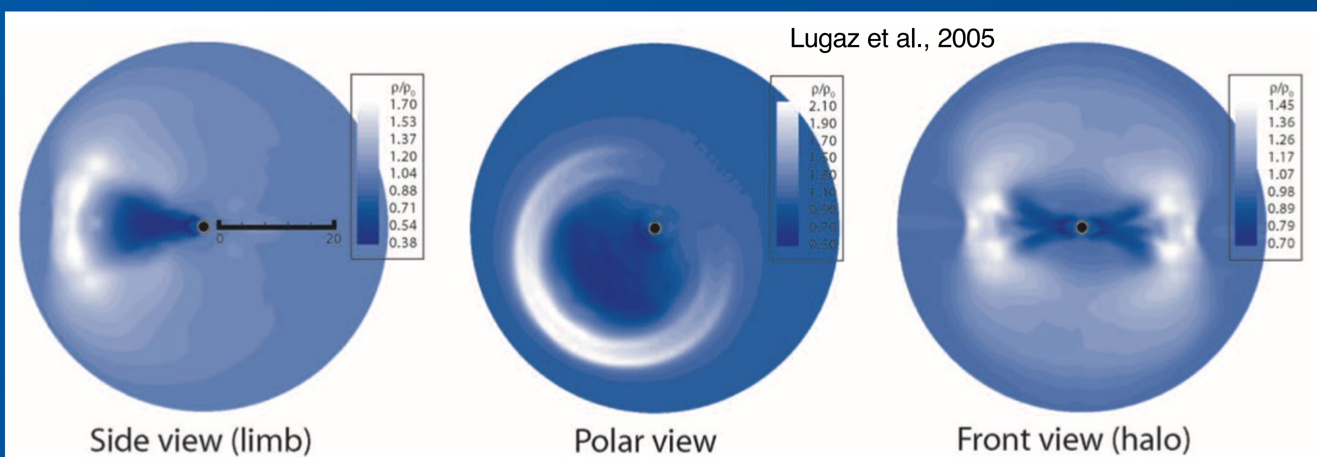


Knizhnik et al., 2024



Observing System Simulation Experiments (OSSEs)

- For some problems (e.g., Bz forecasting), future space weather advances may require data never taken before (e.g., polar orbit, simultaneous L4+L5 magnetograms).
- Need to define and fund Observing System Simulation Experiments (OSSEs).
- Some of the gap filling could be done with Space Weather adds-on onto science missions.
  - First step is near-real time data (working examples).
  - Next step is space weather instrument add-on on science missions (could be a similar scheme as TechDemo)
  - Additional step involves cross-SMD collaboration (radiation measurements on planetary or Earth-observing missions).



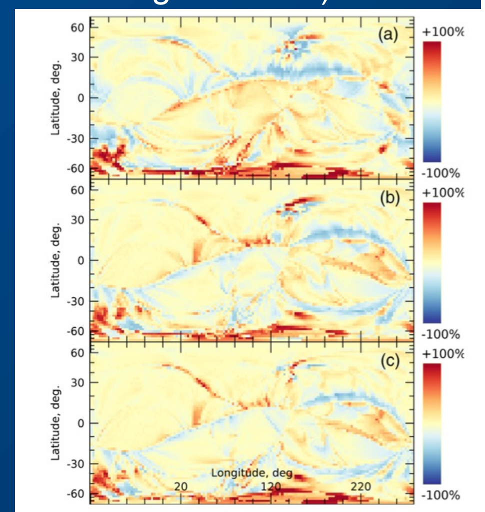


Figure 2. Difference in solar wind speed between the "ground truth" and the synoptic magnetic field maps from (a) Earth/L_1, (b) $L_1 + L_5$, and (c) $L_1 + L_5 + L_4$.

Pevtsov et al., 2020

Summary

- Space weather gap analyses have been performed over the past 4 years. Key risks:
  - GICs. Need accurate ToA forecasts (LT effects) and significant work on solar wind-M-ITM-ground coupling.
  - Radiation on human beyond LEO. Very data constrained.
  - Thermospheric density and spacecraft drag.
- Many observational solutions have been described.
  - Dedicated multi-point, multi-viewpoint measurements and observations in the inner heliosphere.
- OSEs and OSSEs are needed to go to gap-filling strategies.
  - Modeling effort for OSSEs need to be funded (we don't have SEP events with 5+ measurements).
    - This does not fit neatly into existing science or O2R2O research.
  - Any space weather gap filling work should include OSEs.
  - Targets should be forecasting a) Bz, b) radiation at the Moon/Mars, c) GICs, and d) thermospheric drag.
- Cost **needs** to be considered or clear bounds need to be given to the exercise. Example:
  - Data assimilation and ensemble forecasting could improve existing MAE for CME arrival time from 10 hours to 8 hours.
  - A 10-spacecraft approach combined with investment in modeling could be identified to improve to 24-hour advanced warning with ±0.5 h MAE.
  - A 3-spacecraft approach could be identified to improve to 4-hour advanced warning with ± 0.25 h MAE.
  - Another 3-spacecraft approach could be identified to improve to 24-hour advanced warning with ± 6 h MAE.