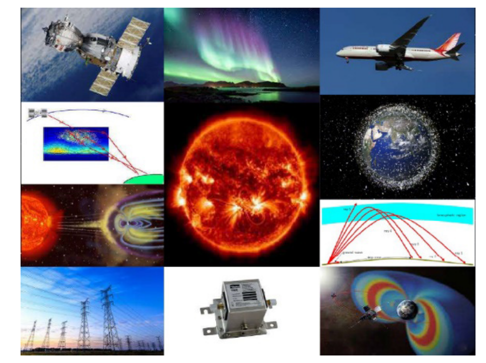
Science and Technology Facilities Council

RAL Space

The COSPAR PSW-ISWAT 2025+ Space Weather Roadmap



Mario M. Bisi [a], Maria M. Kuznetsova [b], Edmund Henley [c], Angelos Vourlidas [d], Martin A. Reiss [b], Sean Bruinsma [e], Manuela Temmer [f], Biagio Forte [g], Yihua Zheng [b], Yihua Yan [h], Kathryn Whitman [i], Ioanna Tsagouri [j], Camilla Scolini [k], Ian G. Richardson [l,m], Alexei A. Pevtsov [n], Evangelos Paouris [d], Hermann J. Opgenoorth [o,p], Sophie A. Murray [q], Joseph I. Minow [r], Arnaud Masson [s], Richard A. Marshall [t], Ian R. Mann [u], Insoo Jun [v], Vania Jordanova [w], David R. Jackson [c], Mamoru Ishii [x,y], Stephan G. Heinemann [f], Jingnan Guo [z], Manolis K. Georgoulis [d,aa], Shing F. Fung [ab], Joaquim E. R. Costa [ac], C. Nick Arge [ad], and Chiu Wiegand [b].

[a] RAL Space, United Kingdom Research and Innovation, Science & Technology Facilities Council, Rutherford Appleton Laboratory, Harwell Campus, Oxfordshire, OX11 0QX, United Kingdom. [b] NASA Goddard Space Flight Center, Community Coordinated Modeling Center, Greenbelt, MD 20771, United States of America. [c] Met Office, FitzRoy Road, Exeter EX1 3PB, United Kingdom. [d] Johns Hopkins University Applied Physics Laboratory, 11000 Johns Hopkins Rd, Laurel, MD 20723, United States of America. [e] GET/CNES, Space Geodesy Office, 18 avenue Edouard Belin, 31400 Toulouse, France. [f] Institute of Physics, University of Graz, Universitätsplatz 5, A-8010 Graz, Austria. [g] Department of Electronic and Electrical Engineering, University of Bath, BA2 7AY Bath, United Kingdom. [h] State Key Laboratory of Solar Activity and Space Weather, National Space Science Center, Chinese Academy of Sciences, Beijing 100190, China. [I] KBR, 601 Jefferson St, Houston, TX 77002. [j] National Observatory of Athens, Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, Metaxa and Vas. Pavlou, GR-15236 Penteli, Greece. [k] European Research Council Executive Agency, Place Rogier 16, 1049 Brussels, Belgium. [l] Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, United States of America. [m] Department of Astronomy, University of Maryland, College Park, MD 20742, United States of America. [n] National Solar Observatory, 3665 Discovery Drive, 3rd Floor, Boulder, CO 80303, United States of America. [o] Department of Physics, Umea University, SE-90187 Umea, Sweden. [p] Department of Physics and Astronomy, Univ. of Leicester, University Road, LE1 7RH, Leicester, United Kingdom. [q] Astronomy & Astrophysics Section, School of Cosmic Physics, Dublin Institute for Advanced Studies, DIAS Dunsink Observatory, Dublin D15 XR2R, Ireland. [r] NASA Marshall Space Flight Center, NASA Engineering and Safety Center, Huntsville, AL 35812, United States of America. [s] European Space Agency, European Space Astronomy Center, Camino Bajo del Castillo, Urbanización Villafranca del Castillo, Villanueva de la Cañada, 28692, Madrid, Spain. [t] Bureau of Meteorology, Melbourne, VIC, Australia. [u] Department of Physics, University of Alberta, Edmonton, Alberta, T6G 2E1 Canada. [v] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109, United States of America. [w] Los Alamos National Laboratory, Los Alamos, New Mexico 87545, United States of America. [x] Radio Research Institute, National Institute of Information and Communications Technology, Nukui-kita Koganei Tokyo 184-8795, Japan. [y] Institute for Space-Earth Environmental Research, Chikusa-ku, Nagoya 464-8601, Japan. [z] University of Science and Technology of China, JinZhai Rd. 96, Hefei, China. [aa] RCAAM of the Academy of Athens, 11527 Athens, Greece (on leave). [ab] NASA Goddard Space Flight Center, ITM Physics Laboratory, Greenbelt, MD 20771, United States of America. [ac] National Institute for Space Research, Av. Astronautas, 1758, S.J. Campos, Brazil. [ad] NASA Goddard Space Flight Center, Solar Physics Laboratory, Greenbelt, MD 20771, United States of America.

1. Abstract [1]

In February 2020, right at the start of the COVID-19 Pandemic, the COSPAR Panel on Space Weather (PSW) in conjunction with the COSPAR International Space Weather Action Teams (ISWAT) Initiative embarked upon a multi-faceted update to the 2015 COSPAR International Living With a Star (ILWS) space-weather roadmap (Schrijver *et al*., 2015).

The approach to be taken was for a community-driven space-weather roadmap to be developed within 2-3 years of commencing, including papers across two distinct Special Issues of the COSPAR Advances in Space Research journal. With various delays initiated by the pandemic, and then other factors coming into play, the first Special Issue was only released in December 2023. This special issue focussed primarily on the research as a driving force for advancing space weather through ISWAT.

The second special issue (at time of abstract submission) has all its papers submitted with an expected publishing date in late Northern hemisphere summer of 2025 (just ahead of the UKSWSE III Meeting). This second Special issue focusses on overarching sub-domains of space weather, key impact pathways, international collaboration and coordination, learning from terrestrial forecasting, an overview of the COSPAR ISWAT Initiative, and an overarching high-level summary (Bisi *et al*., 2025) of all the key recommendations across the ~60 papers collectively making up the COSPAR PSW-ILWS 2025+ Space Weather Roadmap.

With the completion of final papers of this, now, near-six year endeavour, we will present the journey of the space-weather roadmap update and provide a high-level summary of the many outcomes and recommendations.

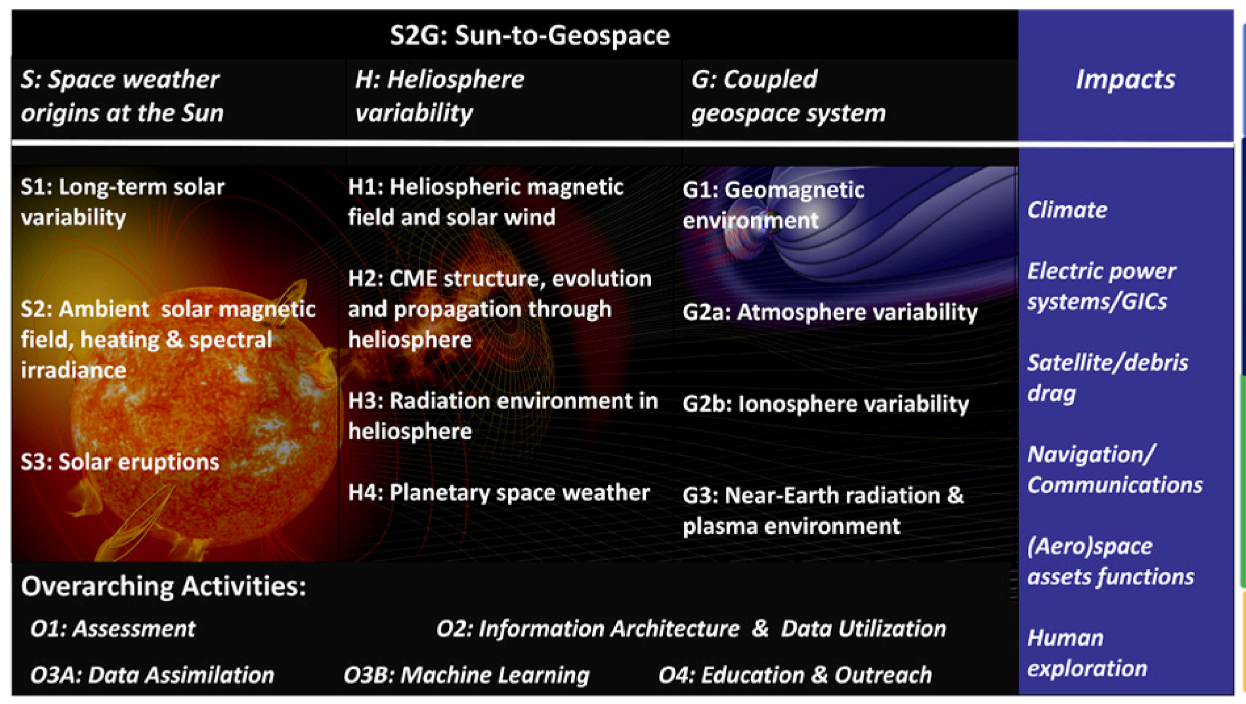
2. Introduction

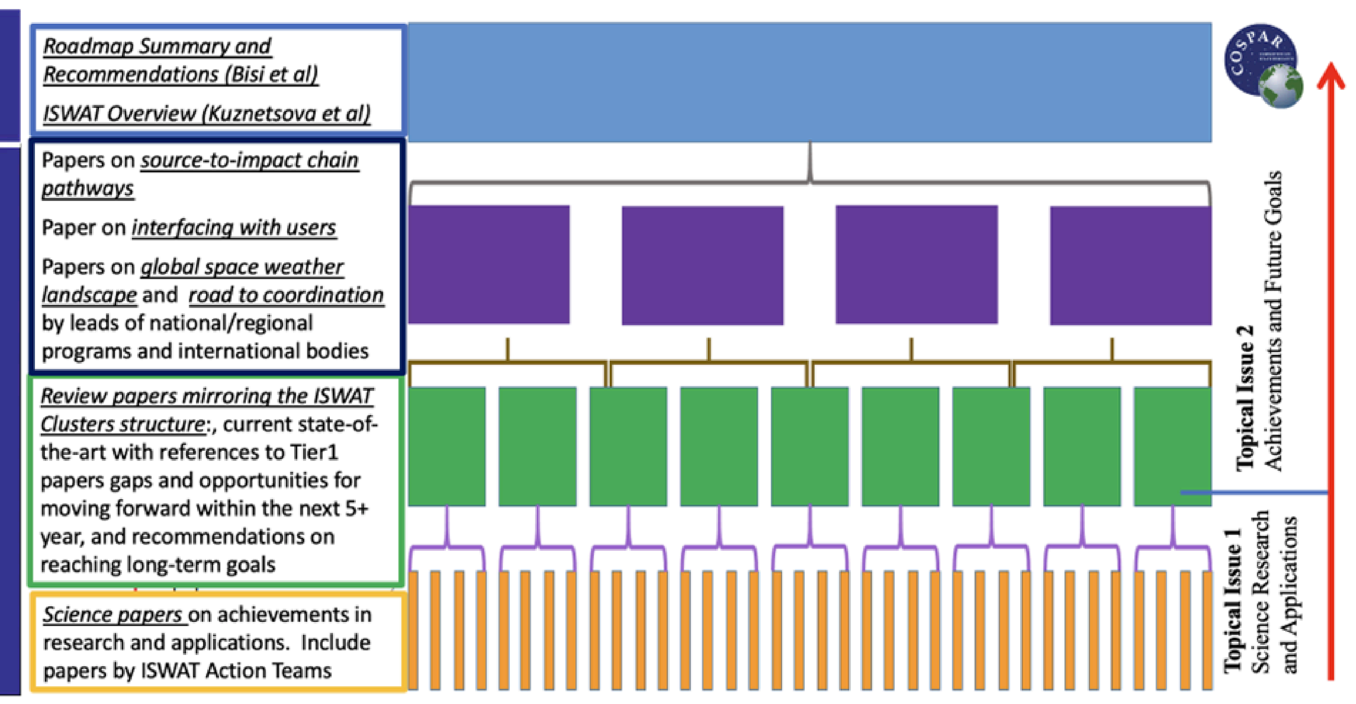
Our modern society is highly reliant on technologies susceptible to the effects of space weather. Satellites for navigation, communication, timing, and Earth observation, as well as terrestrial infrastructures such as power grids, pipelines, and the aviation sector, are all vulnerable. This roadmap underscores our growing reliance on these systems with the societal and economic risks. We need to move beyond individual national/regional efforts to a more-unified global approach.

3. A Novel Approach to the Roadmap [2]

The roadmap is made up of many papers across two special issues in the COSPAR Advances in Space Research journal, with the first being research driven (December 2023) and the second bringing together interdisciplinary aspects of space weather as well as looking at impacts, current and future needs, and reviewing national/international capabilities (in-press 2024-2025). In addition, the COSPAR International Space Weather Action Teams (ISWAT) initiative (https://iswat-cospar.org/) was used alongside the COSPAR Panel on Space Weather (PSW) to drive the roadmap forward, which commenced just before the COVID-19 pandemic in February 2020.

The below-left figure shows the make-up of the ISWAT Initiative and the below-right figure shows the make-up of the roadmap double special issue.





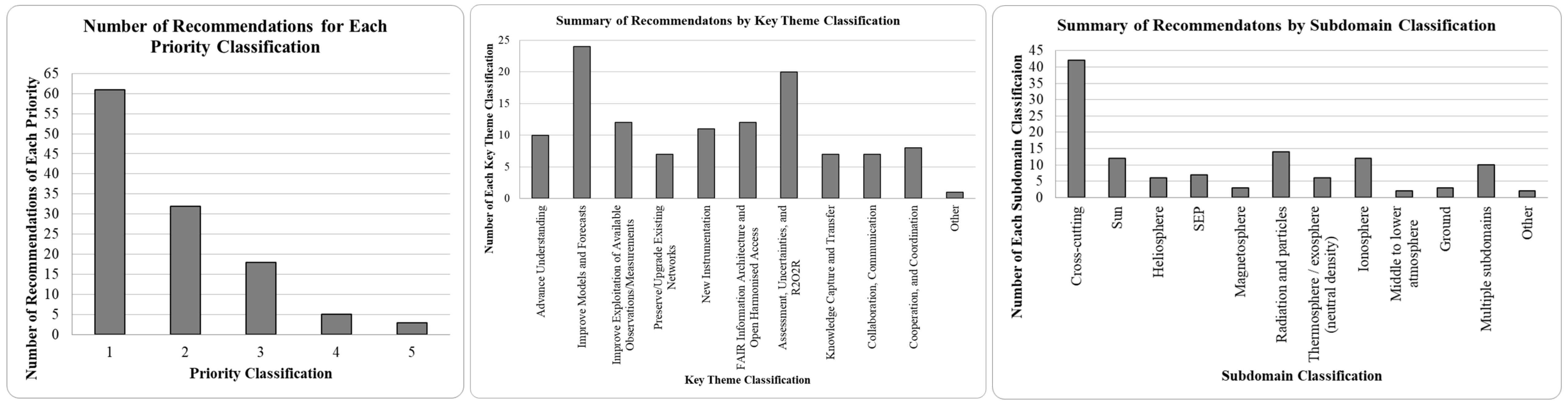
4. Recommendations

In all, there are 119 recommendations made across all areas of space weather research, monitoring, operations, modelling, forecasting, data standards, infrastructures, and missions/instrumentation – going beyond the Schrijver *et al*. paper which was predominantly research focussed and future opportunities. We overview and summarise a selection of these recommendations in the following subsections along with showing a breakdown of distribution of recommendations and their priority.

4.1. Breakdown of Recommendations… [3]

Space weather is a rapidly evolving field, so this roadmap is designed as a living document. An online database of the 119 rationalised recommendations will be maintained to allow for frequent updates, ensuring the community is guided by the most current information. As it stands, the 119 recommendations of the paper have bee broken down into difference types and space-weather sub-domains.

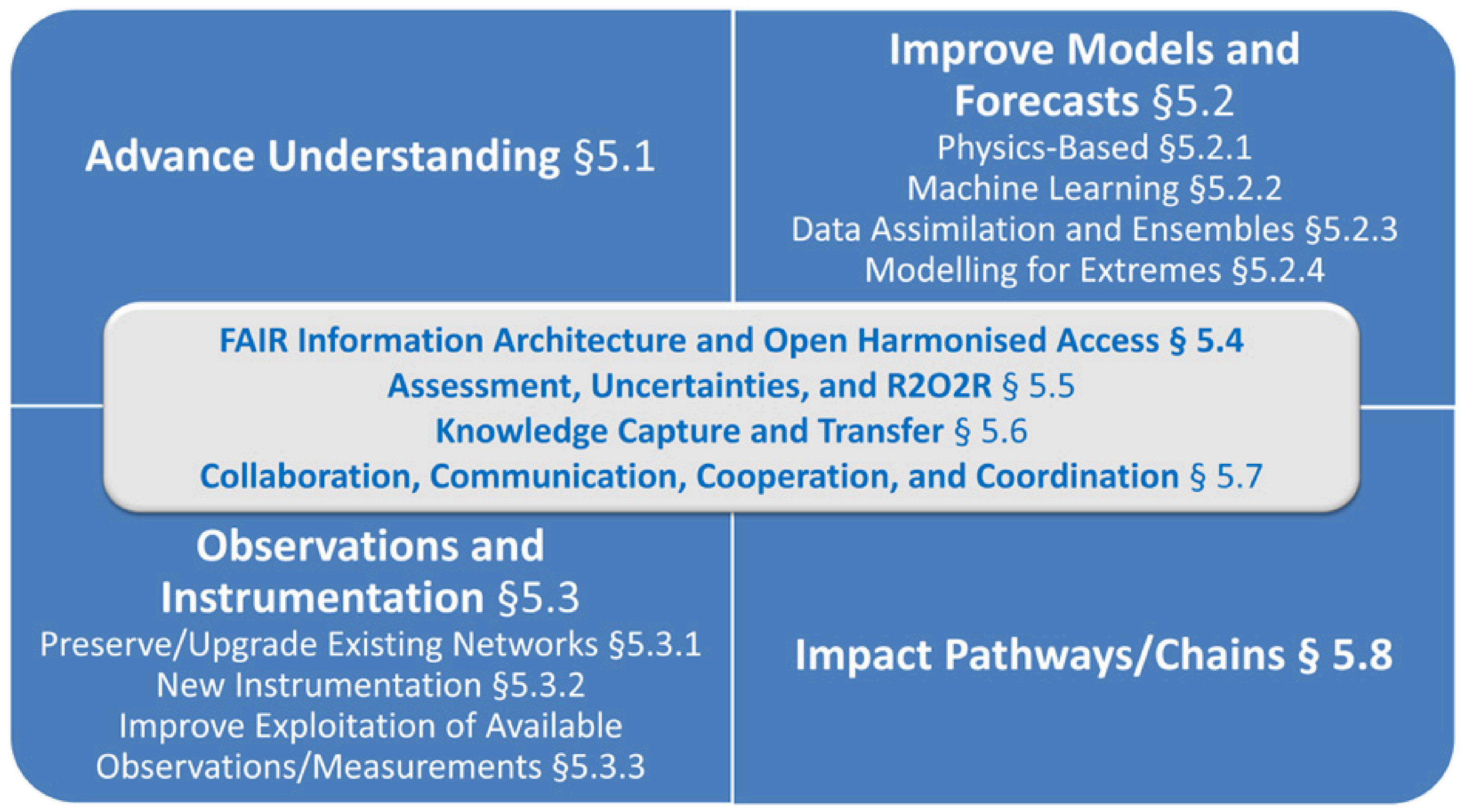
This overall approach fosters alignment among diverse stakeholders—researchers, forecasters, engineers, and policymakers—and provides clear milestones for tracking progress into the future.

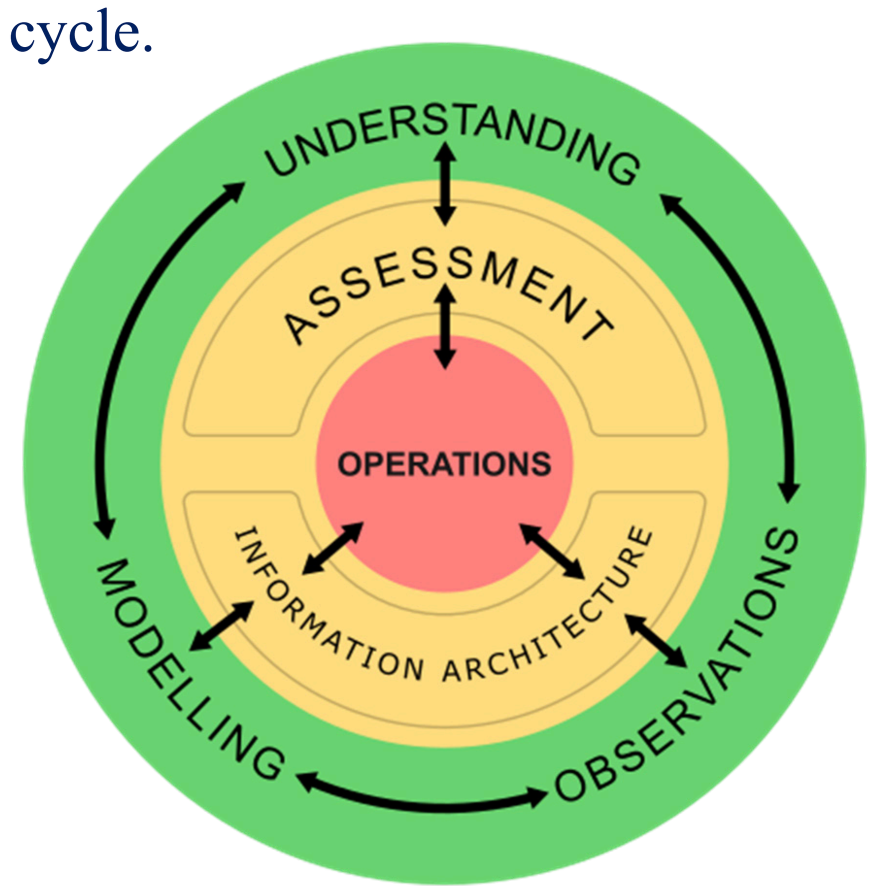


The above bar charts show a breakdown of the recommendations by priority (left), type (middle), and space-weather sub-domain (right) as used in the roadmap.

4.2. Cross-Cutting Themes and the Importance of R2O2R…

A key requirement for the space weather enterprise is establishing collaborative Research-to-Operations-to-Research (R2O2R) pipelines. This feedback loop accelerates the process of transitioning promising research, datasets, and modelling-advancements into practical, operational forecasting capabilities that can be used by civil and military forecasting centres worldwide. The below-left figure shows a visual breakdown of the key recommendation areas as alluded to in Section 4.1. The section references on the figure refer to those in the paper and not on this poster. The central, cross-cutting themes of information architecture, assessment, knowledge transfer, and collaboration are essential for connecting progress in the four main quadrants. The below-right figure shows a "target" signifying the importance of the R2O2R cycle.





4.3. Advance Understanding and Assessment and Validation… [4]

These categories focus on improving our fundamental scientific knowledge of space weather phenomena and in ensuring that space weather models and predictions are accurate and reliable.

- Conducting focussed studies to understand the limitations of using magnetic indices in models.
- Improving understanding of processes that lead to the initiation of Solar Energetic Particles (SEPs) to enhance operational models.
- Advancing solar eruption prediction capabilities from active regions and improving forecasts for coronal mass ejections (CMEs).
- Exploring the propagation of CMEs and solar wind disturbances to improve their forecasting.
- Gaining a better grasp of the physics behind ionospheric and magnetospheric variability, particularly during quiet times.
- Improving our knowledge of solar wind variability and its effects on Earth's magnetosphere.
- Establishing standardised, quantitative, and objective model validation procedures, including the use of automated tools and community scoreboards.
- Developing and assessing end-to-end, physics-based risk analysis models.
- Developing next-generation, coupled geospace modelling systems for comprehensive analysis.
- Establishing a community-wide process for the validation and verification of operational products and models.

4.4. Observations and Instrumentation…

These recommendations summarise current and future capabilities to be maintained and developed.

- Securing the long-term preservation and upgrading of existing networks for both ground-based and space-based observations.
- Maintaining the measurement of solar proxies that are widely used for operational purposes.
- Continuing synoptic observations of the Sun at radio and optical wavelengths.
- Upgrading ground-based facilities to improve the accuracy and spatial resolution of data.
- Developing a constellation of satellites for global, continuous monitoring of the auroral oval.
- Building a dedicated global ionospheric monitoring system.
- Deploying new instruments to measure solar wind properties at the L1 point and also at other locations throughout the heliosphere (prioritising L5).
- Enhancing capabilities to measure solar irradiance and energetic particles.
- Developing new ground-based instruments to complement existing networks as well as upgrading those to space-weather capabilities (*e.g.* LOFAR across Europe)..

5. Summary

The roadmap identifies several key scientific and technical challenges that currently limit our ability to predict space weather with the necessary accuracy and timeliness. The roadmap highlights that our fundamental physical understanding of key processes is incomplete. The roadmap outlines a path to enhance our ability to predict and mitigate the risks posed by space weather by addressing the critical scientific and technical challenges. It underscores that this is a global effort requiring sustained investment in research, infrastructure, and international partnerships. By implementing the recommendations, we can significantly improve the resilience and security of our technology-dependent world against the impacts of space weather, ensuring a safer future for all.

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