

## Metadata for Ionospheric and Space Weather Observations (MISO)

Modern space weather research relies on large volumes of heterogeneous data collected by satellite missions operated by different space agencies and scientific communities. However, differences in data formats, metadata standards, and documentation practices significantly limit the interoperability, reproducibility, and long-term reusability of these datasets. This challenge affects key domains such as radiation belt physics, ionospheric science, and atmospheric particle precipitation, despite the high scientific and societal relevance of space weather research.

The MISO project addressed these limitations by developing harmonized metadata standards for space weather and space physics observations. The project brought together expertise from GFZ Potsdam, the German Aerospace Center (DLR), and the Karlsruhe Institute of Technology (KIT), focusing on improving data interoperability across satellite missions and scientific disciplines. The overarching objective was to enable FAIR (Findable, Accessible, Interoperable, Reusable) data practices for space weather data products used in research, modeling, and operational applications.

During the project, existing data formats and metadata practices were systematically reviewed across multiple space weather domains. For radiation belt observations, ionospheric measurements, and atmospheric particle precipitation data, domain-specific metadata requirements were identified and consolidated. Based on this analysis, standardized metadata recommendations and metadata profiles were developed for each domain. These efforts resulted in a coherent framework that captures essential information on data provenance, processing workflows, versioning, uncertainty estimates, and physical interpretation.

A central outcome of the project was the establishment of a common metadata vocabulary for space weather research. Building on earlier community efforts, the project updated the Standard File Format Guidelines for Particle Fluxes (Version 1.2) originally developed by the COSPAR Panel on Radiation Belt Environment Modeling (PRBEM). The revised guidelines incorporate improvements such as consistent variable naming conventions, explicit uncertainty fields, classification flags for different particle populations, and provisions for inter-calibration coefficients. These updates were informed by practical application to contemporary datasets, including the ELFIN-L Level 3 Electron Particle Detector data product.

Dissemination and community engagement were integral components of the project. The developed standards were presented and discussed at international scientific meetings, including COSPAR assemblies, URSI conferences, and ISO technical committee meetings on space systems and operations. Through these activities, the project contributed directly to ongoing international standardization efforts and fostered dialogue between space weather

scientists, data providers, and metadata experts.

Overall, the MISO project delivers a significant contribution to the standardization of space weather metadata. By improving data interoperability and documentation, the project enhances the scientific value and reuse potential of space-based observations collected over decades of satellite missions. The results provide a robust foundation for future integration with international frameworks such as SPASE and HAPI and support the long-term sustainability of space weather data infrastructures for both research and operational use.