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Advancing Data Use by Leveraging the Synergy of FDOs and the InterPlanetary File System

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Abstract.

Climate science relies on managing, sharing, and analyzing vast, diverse datasets. Ensuring FAIR principles is critical, particularly for enabling machine-to-machine (M2M) actionability in AI-assisted workflows. This work proposes combining the Fair Digital Object (FDO) standard with the InterPlanetary File System (IPFS) protocol to improve interdisciplinary reuse of climate model outputs and observational data. The IPFS provides a decentralized, peer-to-peer network for storing and sharing files via unique content identifiers, supporting immutability, and redundancy. Using IPFS as the access layer enhances data integrity, while FDOs ensure structured semantics for M2M actionability. A conceptual use case was tested with data from the ORCESTRA measurement campaign, which comprises data from satellites, aircraft, ground systems, and models. Selected datasets were aggregated in an FDO-compliant catalog and shared via IPFS, demonstrating practical benefits. Together, IPFS and FDOs create an ecosystem which can enhance reproducibility and cross-disciplinary collaboration in weather and climate research and beyond.

Keywords: IPFS, Data Integrity, Cross-Disciplinary

1. Introduction

Climate science relies heavily on the effective creation, management, sharing, and analysis of massive and diverse datasets. As the digital landscape evolves, there is a growing need to establish a framework that ensures FAIRness in handling climate science digital objects. In particular, the M2M actionability of digital objects will be a crucial step towards future AI-assisted research workflows. This conference contribution illustrates, through a conceptual implementation, how adopting the Fair Digital Object (**FDO**) standard in synergy with the InterPlanetary File System (**IPFS**) protocol can address challenges associated with the interdisciplinary reuse of climate data.[1]

2. Background and Motivation

The increasing complexity and scale of climate data make traditional data management systems insufficient for ensuring interoperability, long-term accessibility, and reproducibility. FAIR Digital Objects and IPFS present complementary approaches to these challenges. FDOs

introduce a standardized, M2M actionable framework for representing digital assets and their metadata as cohesive, persistent, and traceable entities. IPFS provides a decentralized, content-addressable infrastructure for reliable and tamper-resistant file storage and distribution. Together, these technologies offer a pathway toward a more resilient and transparent data ecosystem.

2.1. InterPlanetary File System (IPFS)

The IPFS is a peer-to-peer network protocol designed for decentralized file storage and sharing. Each file in IPFS is assigned a unique content identifier (CID), derived from the file's contents. This technology ensures: distributed storage, built-in data immutability, and enhanced resilience against data loss or corruption.[2] By employing IPFS as the access and transport layer for FDOs, data management frameworks can gain scalability, security, and redundancy, while the FDO standard itself contributes semantic structure and interoperability.

3. Use Case: The ORCESTRA Campaign

To demonstrate the combined potential of FDOs and IPFS, a conceptual use case was developed handling data from the ORCESTRA (Organized Convection and EarthCARE Studies over the Tropical Atlantic) campaign. Conducted in August–September 2024, this campaign collected data from multiple sources such as satellite observations, airborne instruments, ground-based systems, and climate model simulations. From a data management perspective, ORCESTRA provided an ideal testbed for handling large, heterogeneous datasets. Selected datasets were ingested into the IPFS and catalogued following the FDO standard. The implementation showcased improved interoperability, provenance tracking, and streamlined access across data types and platforms.

4. Conclusion

The integration of IPFS into FDOs demonstrates how decentralized systems and FAIR principles can enhance data management in climate science. Beyond improving accessibility and transparency, this approach can support automation in research workflows, facilitating reproducibility and long-term usability. The lessons learned from the ORCESTRA use case highlight how such frameworks can scale to broader interdisciplinary applications. FDOs and IPFS together establish a decentralized, verifiable, and interoperable ecosystem for digital objects. This can effectively address the requirements of interdisciplinary scientific data sharing and management. By enhancing the reproducibility and consolidation of scientific results, these innovations can significantly strengthen the societal and economic impact of research.

Data availability statement

The present work examines digital objects from the ORCESTRA campaign database, openly available through the ORCESTRA data browser. [3]

Underlying and related material

As the conference date approaches, a Git repository containing all related materials will be made publicly available via Zenodo, and this section will be updated accordingly.

Author contributions

According to the CreDIT guidelines all authors (M.K., K.PvG., and I.A.) conceptualized this contribution and developed a methodology. M.K. wrote the original draft, which was reviewed and edited by K.PvG and I.A.

Competing interests

The authors declare that they have no competing interests.

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