Transferability of Earth Foundation Model Embeddings for Spatially Implicit Infrastructure Mapping

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Spatially implicit infrastructure, those engineered features like culverts, small bridges, and buried drainage crossings whose presence cannot be directly observed from overhead imagery, are important for hydrography mapping, flood modeling, and transportation planning. Because their spectral signatures are often subtle, fine-scaled, and geographically variable, these road-embedded structures are notoriously difficult to map as their locations must be inferred from spatial context, terrain continuity, network relationships, or land-surface patterns.

Recent geospatial foundation models provide global satellite embeddings that encode broad Earth-surface context from multisource observation data. However, their reliability remains uncertain for out-of-distribution mapping targets that are spatially implicit, fine-scale, and dependent on terrain or network relationships rather than direct spectral appearance. This study evaluates AlphaEarth as a representative global satellite embedding product for cross-region spatially implicit infrastructure mapping.

Using labeled drainage crossing data, we compare four model feature settings, including DEM-derived terrain variables (e.g., slope, topographic position index, and local relief), AlphaEarth embeddings that are used as frozen contextual features, fused AlphaEarth and DEM-derived features, and a previously published deep learning detector that is used as a visual-appearance baseline. Models are trained on Nebraska drainage crossing data and evaluated on independent test regions in Illinois, North Dakota, and California to assess geographic transferability under out-of-distribution conditions. Model performance is assessed using precision, recall, F1 score, and cross-region degradation, as well as a qualitative analysis of representative success and failure cases. The study examines whether global satellite embeddings provide transferable landscape context, if high-resolution DEM-derived terrain variables remain necessary, and to what extent feature fusion can reduce transfer failure.

This work contributes to an empirical understanding of the performance and transferability of using global satellite embeddings for spatially implicit infrastructure detection. Moving beyond the assumption of universal transferability, this research characterizes the operational limits of foundation-model embeddings, specifying where they provide utility, where transfer degrades, and what complementary ground truth is required for robust deployment.

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