Deutsches Zentrum für Luft- und Raumfahrt

Remote Sensing Technology Institute

Exploiting A Synthesis-based Representation Learning Pre-Training Task To Repair Hyperspectral Satellite Image Cubes

Maximilian Langheinrich – maximilian.langheinrich@dlr.de
Department Imaging Spectroscopy

In a previous publication, a bottom-of-atmosphere (BOA) reflectance approach was evaluated and demonstrated remarkable accuracy for reconstructing degraded hyperspectral satellite images [1]. However, the atmospheric correction required before reconstruction is computationally and time intensive.

A masked-reconstruction encoder pre-training task involves training a transformer encoder to learn generalized spectral representations by reconstructing masked spectral vectors from hyperspectral satellite measurements. During pre-training, synthetic training data is generated using radiative transfer simulations, which physically model electromagnetic radiation propagation through the atmosphere to create realistic hyperspectral observations. While the purpose of generalized spectral representations is to act as unified input to a variety of down-stream tasks, the framework introduced for a pre-training task of this kind facilitates the reconstruction of damaged and defective hyperspectral satellite data without any additional training required.

The transformer encoder leverages self-attention mechanisms to capture long-range dependencies across spectral bands, forcing the model to understand the relationships between different wavelengths and learn comprehensive representations of plausible spectral signatures. By reconstructing randomly masked spectral vectors, the model develops an understanding of spectral continuity and physical plausibility that transcends individual sensor specifications. This approach enables cross-sensor generalization, allowing the trained model to reconstruct data from previously unseen sensors with different configurations—including varying spectral resolutions, band counts, and wavelength coverages—without requiring additional fine-tuning or sensor-specific adaptation.

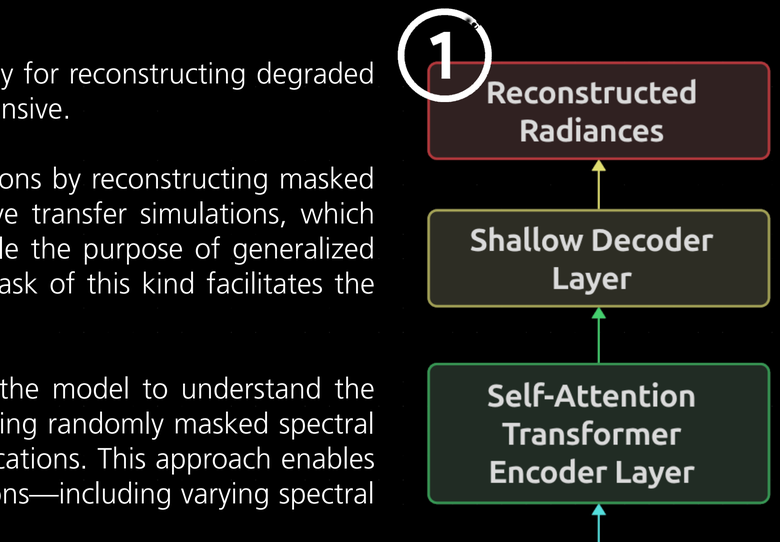
Traditional reconstruction methods require sensor-specific tuning for spectral band pass functions, spatial resolutions, and signal-to-noise ratios or are not able to reconstruct specific atmospheric features i.e. absorption regions. In contrast, the pre-training framework learns representations transcending individual sensor specifications by exposure to synthetic data simulating multiple sensor configurations and is able to reconstruct missing atmospheric features from remaining healthy data. This enables processing data from previously unseen sensors without additional fine-tuning.

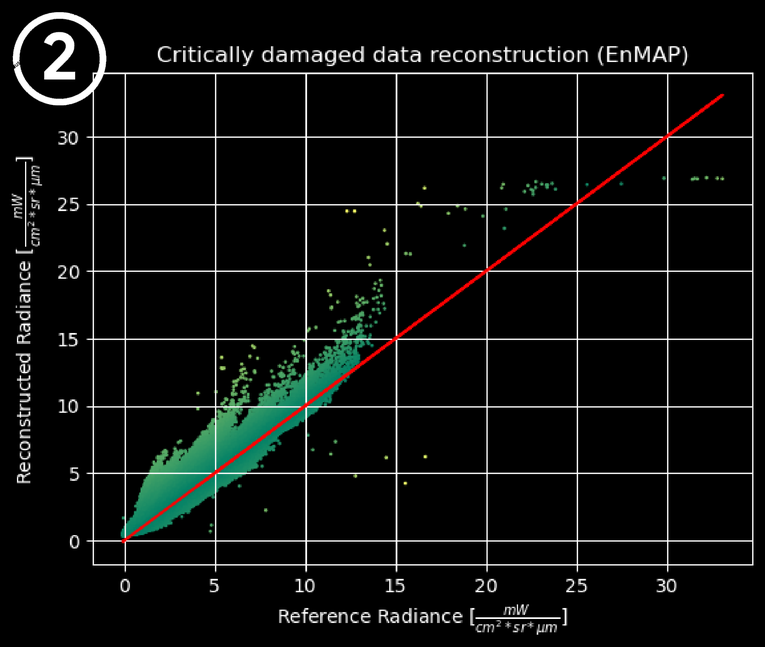
The transformer encoder pre-training approach addresses critical limitations of traditional BOA reflectance methods. While BOA techniques offer physical interpretability and accuracy, their computational intensity constrains deployment regarding large datasets (i.e. HySpex) or time-critical applications. By leveraging radiative transfer simulations, the method achieves competitive reconstruction quality while enabling efficient processing and cross-sensor generalization, establishing a foundation for scalable, sensor-agnostic reconstruction pipelines.

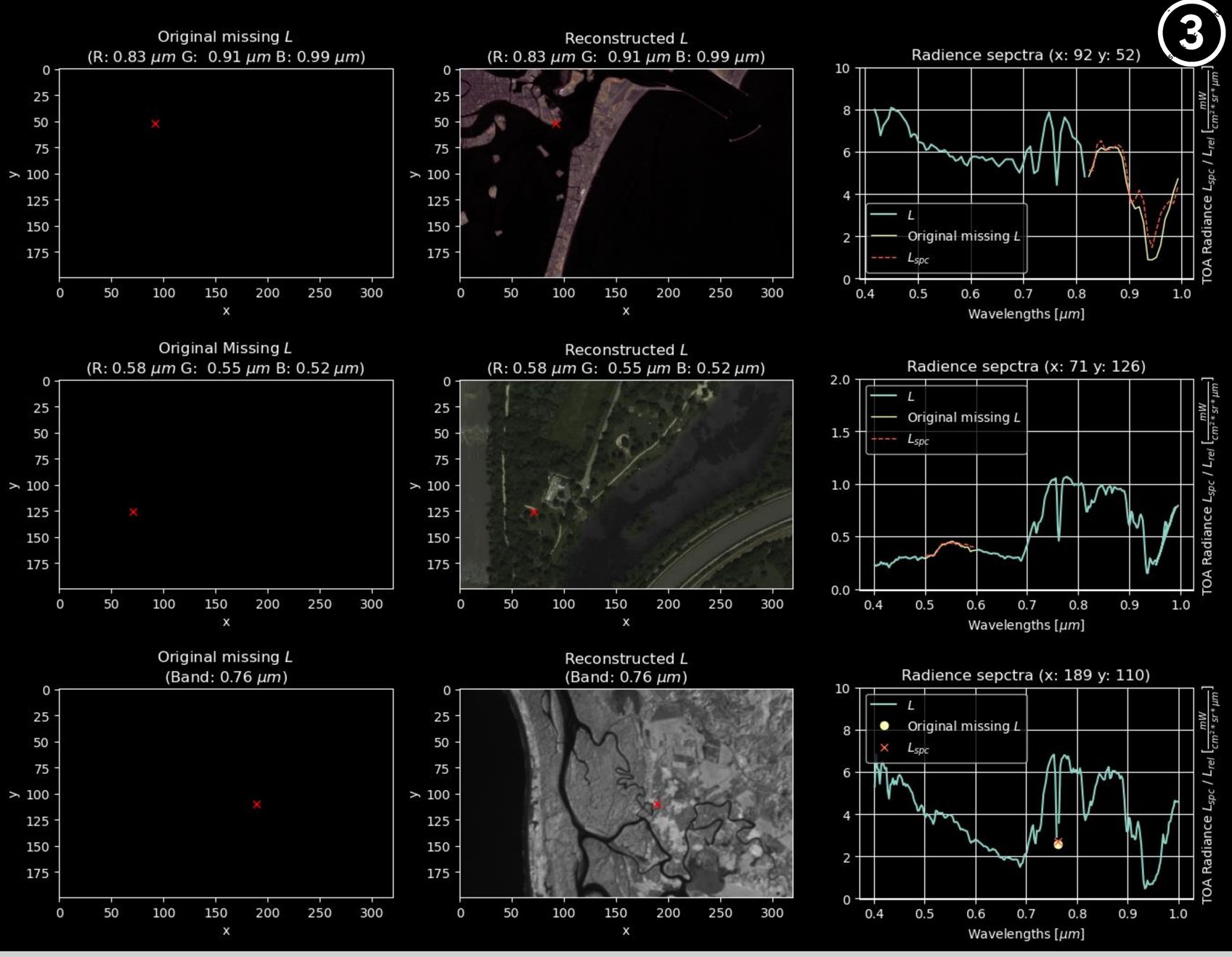
Results are presented as follows:

(1) Simple Transformer Encoder-Decoder Reconstruction Architecture used in the study
(2) Scatter plots of all damaged pixel and their reconstruction for a critically damaged EnMAP dataset (**top**), a corrupted HySpex dataset (**middle**) and a DESIS dataset with missing atmospheric feature band (**bottom**)
(3) Reconstructed image data of damaged bands and exemplary reconstructed spectra for EnMAP (**top**), HySpex (**middle**) and DESIS (**bottom**) datasets

The **same** network was used on all three **unseen** satellite data trained only on the synthetic dataset.







References: [1] Langheinrich, Maximilian, David Marshall, and Raquel De Los Reyes. "BOA Reflectance Based Dead and Defective Pixel Interpolation in the ENMAP Ground Segment Processing Chain." *IGARSS 2023-2023 IEEE International Geoscience and Remote Sensing Symposium*. IEEE, 2023.