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HyperEst: Advancing Biogeochemical Parameters Estimation through Self-Supervised Pretraining with Hyperspectral Imagery

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Introduction

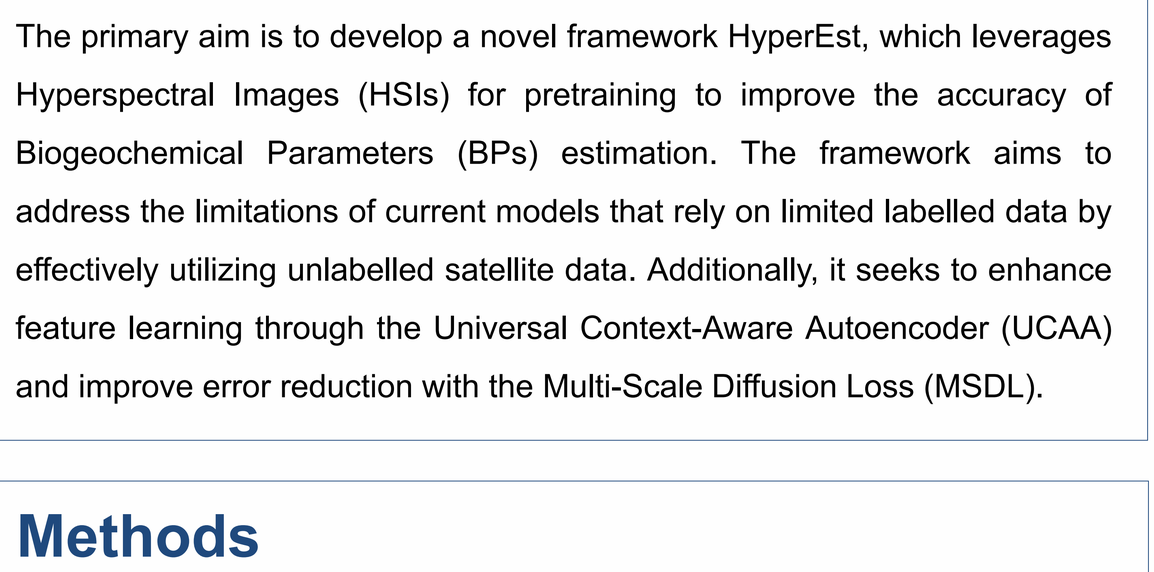
The state-of-the-art models for estimating Biogeochemical Parameters (BPs) rely solely on limited labelled in-situ measurement data and do not fully utilize the abundant unlabelled satellite data, which contain valuable prior knowledge. This paper proposes an adaptive Self-Supervised Learning (SSL) framework using Hyperspectral Images (HSIs) as pretraining data, adaptable for both low-dimensional multispectral and high-dimensional hyperspectral data. This approach captures complex spectral and spatial variations, addressing the challenges of limited labelled data and reducing BPs estimation errors. Experimental evaluations were conducted on two public in-situ datasets with HICO and Landsat 8 bands. HyperEst outperforms state-of-the-art model by overall weighted mean of 3% in $\log R^2$.

Aims

The primary aim is to develop a novel framework HyperEst, which leverages Hyperspectral Images (HSIs) for pretraining to improve the accuracy of Biogeochemical Parameters (BPs) estimation. The framework aims to address the limitations of current models that rely on limited labelled data by effectively utilizing unlabelled satellite data. Additionally, it seeks to enhance feature learning through the Universal Context-Aware Autoencoder (UCAA) and improve error reduction with the Multi-Scale Diffusion Loss (MSDL).

Methods

The HyperEst framework employs a two-stage approach for estimating BPs from HSI data with minimal annotations. Initially, it extracts spectral information from R_{rs} image tiles in the HICO Level 2 dataset, processing them into 5x5 patches for the UCAA. The encoder weights from UCAA are transferred to the second stage, applied to both HICO and Landsat 8 bands. During training, backpropagation of gradients enables learning task-specific features. HyperEst comprises the UCAA and the Water Quality Multi-parameter Estimator.



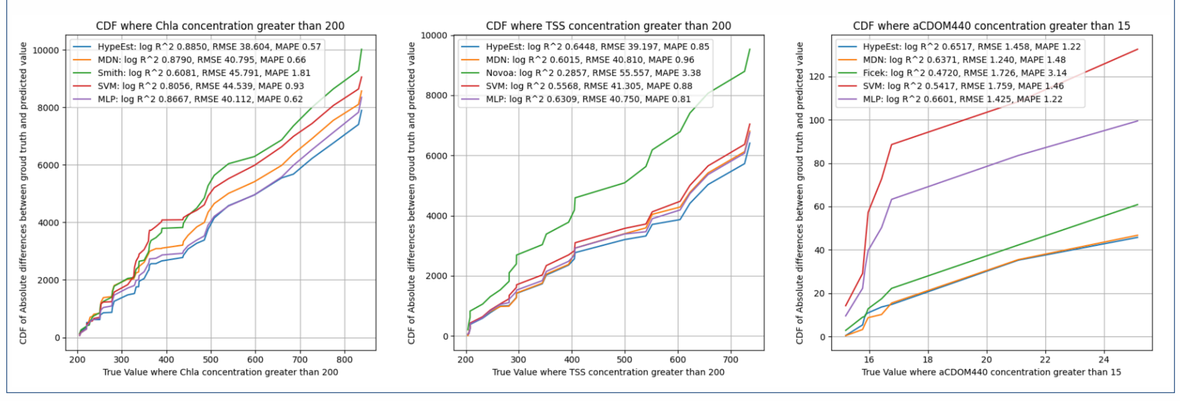
Two – Stage HyperEst Framework

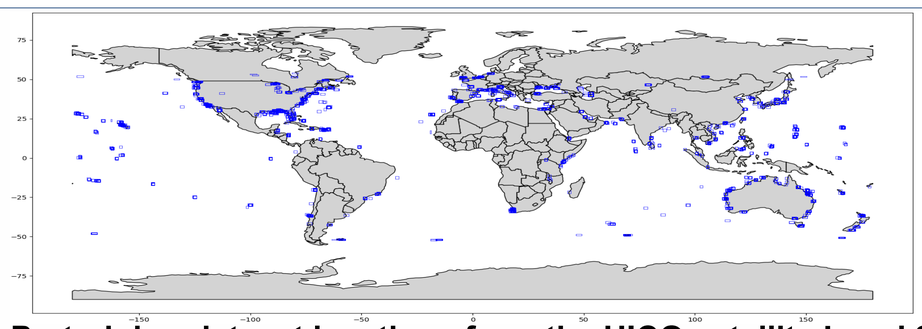
Results

PERFORMANCE OF DIFFERENT METHODS WHERE ESTIMATED BPS CONCENTRATION LESS THAN $1000\ mg \cdot m^{-3}$

BPs	Methods	HICO			Landsat 8		
		$\log R^2 \uparrow$	RMSE ↓	MAPE ↓	$\log R^2 \uparrow$	RMSE ↓	MAPE ↓
Chla	Blend/OCx, 2018/2019 [6]/[25]	0.62	46.9931	1.6390	0.43	218.2563	1.2682
	SVR, 2021 [27]	0.81	44.5385	0.9311	0.71	55.3687	1.1507
	MDN, 2023 [14]	**0.88**	41.0824	0.6786	0.75	54.6169	1.3267
	HyperEst	**0.88**	**40.8780**	**0.6021**	**0.77**	**52.4723**	**0.9684**
TSS	Novoa, 2017 [11]	0.29	50.9251	3.4511	0.29	54.7341	3.9759
	SVR, 2021 [27]	0.57	35.2104	0.9263	0.53	38.4504	1.1338
	MDN, 2023 [14]	0.62	37.7309	0.9372	0.56	36.5863	**0.9077**
	HyperEst	**0.64**	**33.3712**	**0.9065**	**0.58**	**36.3945**	1.0205
$aCDOM_{440}$	Ficek, 2011 [26]	0.46	1.7984	3.5984	0.48	2.0784	4.2917
	SVR, 2021 [27]	0.53	1.5905	1.7559	0.53	1.9054	1.8179
	MDN, 2023 [14]	0.61	**1.2431**	1.7571	0.58	1.5717	**1.4340**
	HyperEst	**0.64**	1.3010	**1.4341**	**0.59**	**1.5304**	1.7989
Weighted Mean	SVR, 2021 [27]	0.64	27.1131	1.2044	0.59	31.9082	1.3675
	MDN, 2023 [14]	0.70	26.6855	1.1243	0.63	30.9250	**1.2228**
	HyperEst	**0.72**	**25.1834**	**0.9809**	**0.65**	**30.1342**	1.2626

Cumulative absolute difference of HICO bands ground truth and predicted values for outlier labels.





Pretraining dataset locations from the HICO satellite Level 2

References

- R. E. O'Shea et al., "A hyperspectral inversion framework for estimating absorbing inherent optical properties and bio-geochemical parameters in inland and coastal waters," Remote Sens. Environ., vol. 295, Sep. 2023.
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