Fine-tuning Foundation Models for Earth Observation Using a Multi-objective Optimization Strategy

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Foundation Models in EO

Prithvi-EO-2.0

TerraMind

Clay Model

EarthPT

Foundation models in EO:

- Large-scale, pretrained AI models designed to extract generalizable features from vast and diverse geospatial data.
- Trained once, they adapt everywhere — powering smarter, faster decisions from space to ground.
- Enable better generalization across different geographic regions, seasons, and sensor types, making them highly effective for downstream tasks.

Multi-Objective Optimization for Fine-tuning

Define Search Space: Search space definition for foundation models involves identifying key architecture, training, and optimization parameters.

Search space type - Categorical: backbone types, Continuous: dropout rate, and Ordinal: number of network layers

Select objective functions: The objective function balances accuracy, robustness and size of the model.

Properties of objective function: Must be differentiable and scalable, should be inversely proportional (or conflicting).

Purpose: Balance accuracy and efficiency while fine-tuning, Handles conflicting performance metrics, Ensures local accuracy with global generalization, Seamless fine-tuning despite noise and sensor variability.

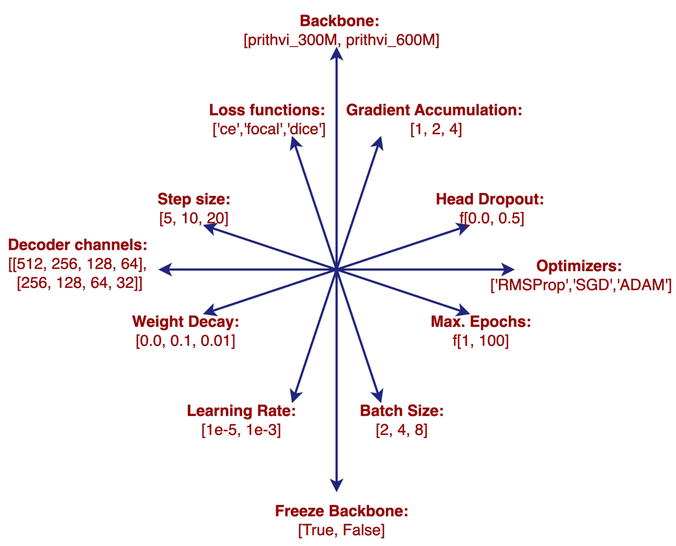

Fig.1 Search space for Foundation Models

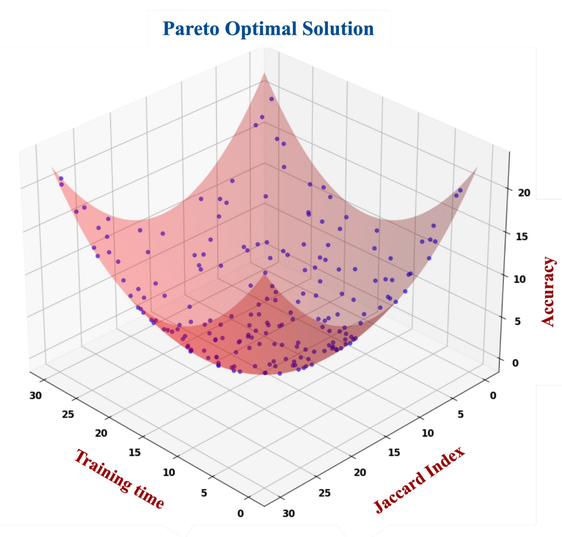

Fig.2 Pareto front (optimal solution

Demonstration of MOO driven Fine-tuning for Prithvi-EO-2.0

Experimental Pre-trained Model

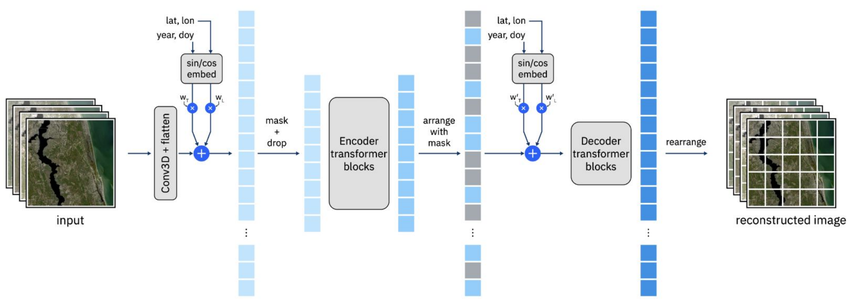

Fig. Model Architecture from Szwarcman, D., et al. (2024)

- Prithvi-EO-2.0-300M
- A pretrained 300M parameter foundation model
- Vision Transformer Architecture
- Pre-trained on 4.2M Global time series HLS data
- Self-supervised with Masked Autoencoder method

Downstream Task

- **Task:** Burn scar segmentation
- **Search space:** decoder channels
- **Objectives:** Jaccard Index, Accuracy and Training time
- **Algorithm:** Non-dominated Sorting Genetic Algo.
- **Fine-tune data:** HLS Burn Scar data
- **Backbone state:** Frozen
- **Trials:** 20

Results

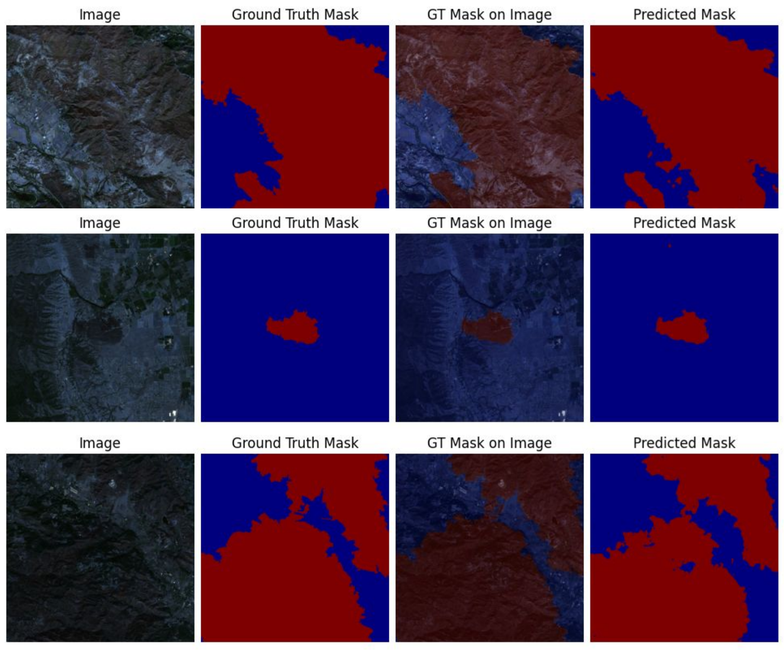

Fig.3 Qualitative results of predicted burn scar masks with optimized fine-tuned model

Pareto-optimal configurations outperformed the baseline fine-tuned model.

More than 50% reduction in number of parameters.

Identified configurations with increased performance and reduced model size

Baseline Fine-tuned Model

Trainable Parameters	20.3 M
Total Parameters	324 M
BurnScar_Accuracy	0.75
BurnScar_Jaccard Index	0.63

Optimized Fine-tuned Model

Trainable Parameters	7.9 M
Total Parameters	94.2 M
BurnScar_Accuracy	0.83
BurnScar_Jaccard Index	0.70

Conclusion

- Multi-objective optimization can effectively fine-tune foundation models like Prithvi for Earth observation tasks.
- More accurate but also computationally efficient foundation models can be delivered.
- Foundation model for EO can be efficiently fine-tuned under resource constraints.

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