

Motivation: incorporate stress buildup in a new way

- We use a range of traditional catalogue-based seismic statistical features (SSFs), some of which, particularly the Gutenberg-Richter b-value, we observe to exhibit high spatial localisation.
- This was confirmed by preliminary SHAP analysis: b-value feature importance improves as the feature computation radius shrinks 24km → 12km → 6km (though very small scales suffer from data sparsity and noise).
- Due to the observed importance of the b-value feature, we seek an additional means to incorporate information about localised stress states based on seismic activity maps rather than catalogue data.

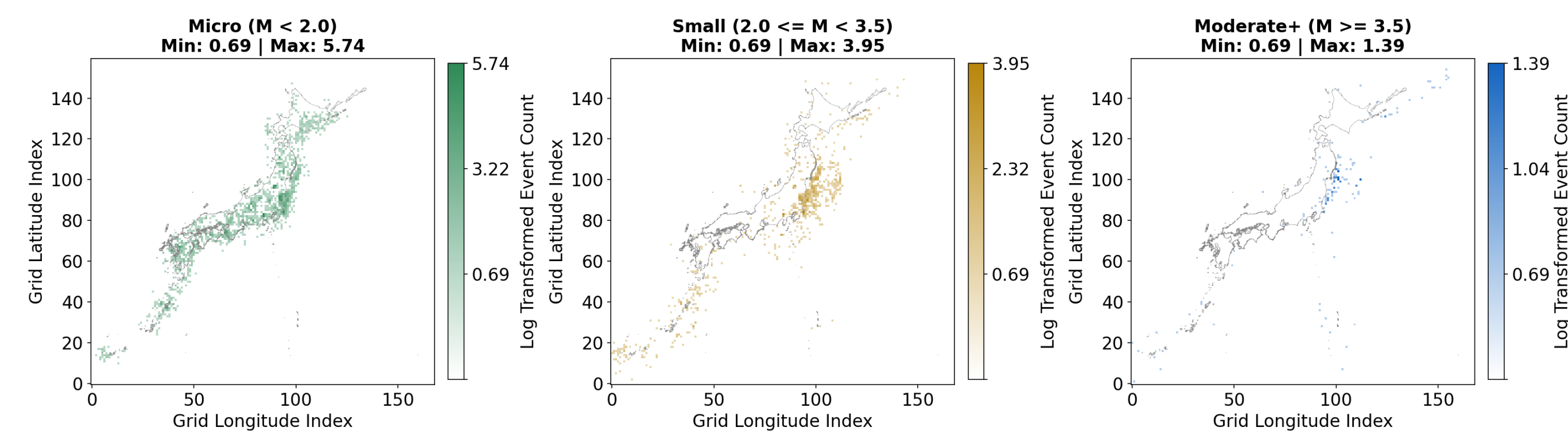


Figure 1. Per-channel magnitude-stratified seismicity for Japan

Green = Micro ($M < 2.0$) | Yellow = Small ($2.0 \leq M < 3.5$) | Blue = Moderate+ ($M \geq 3.5$)

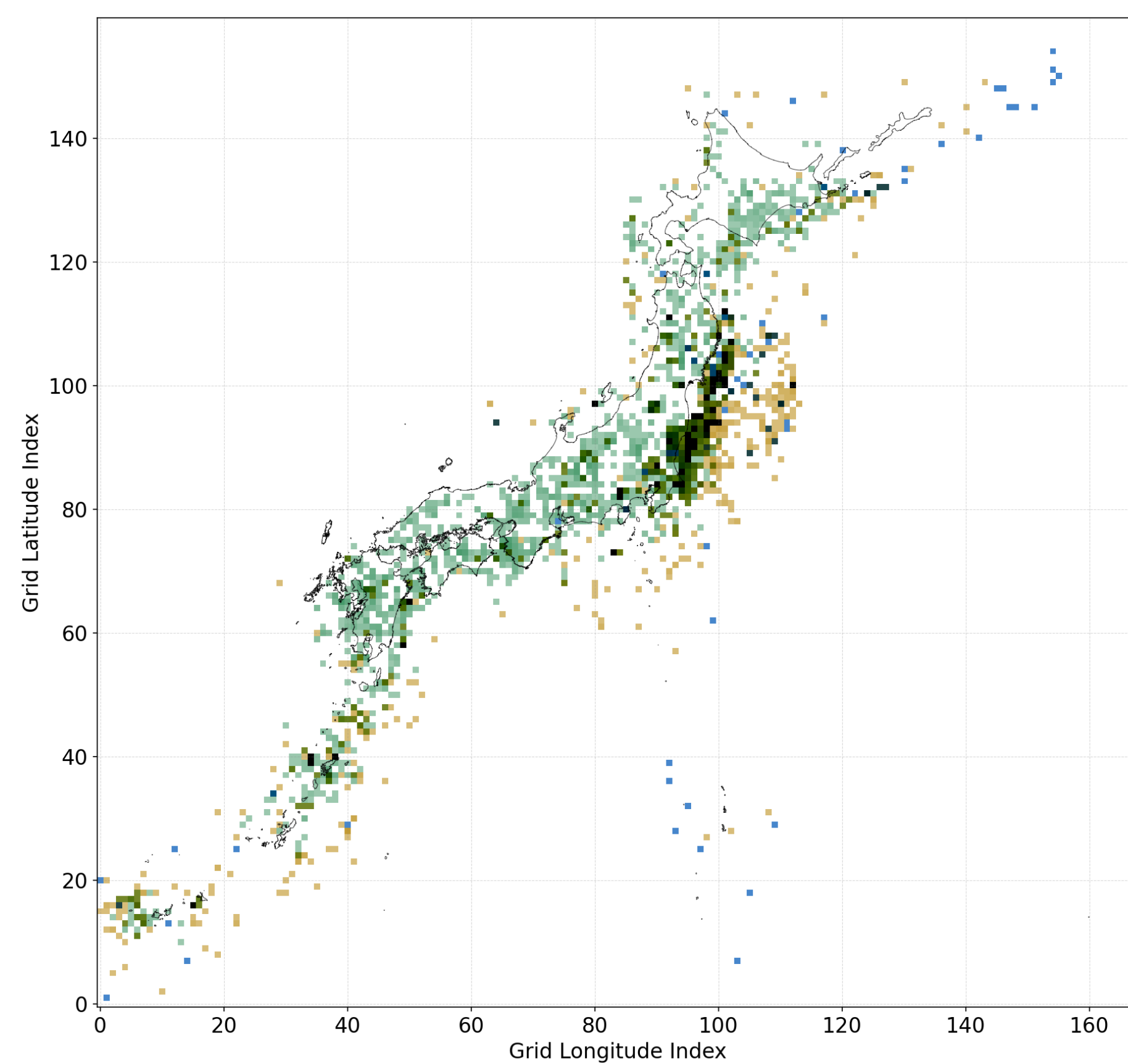


Figure 2. Stacked magnitude-stratified seismicity for Japan

Hypothesis

A VQ-VAE (Vector-Quantised Variational Autoencoder) can dynamically learn localised 'seismic regimes' by reconstructing magnitude-stratified spatiotemporal maps, providing a rolling reconstruction error that acts as a learned proxy for the b-value, representing regional stress macro-states.

Methodology: latent feature learning

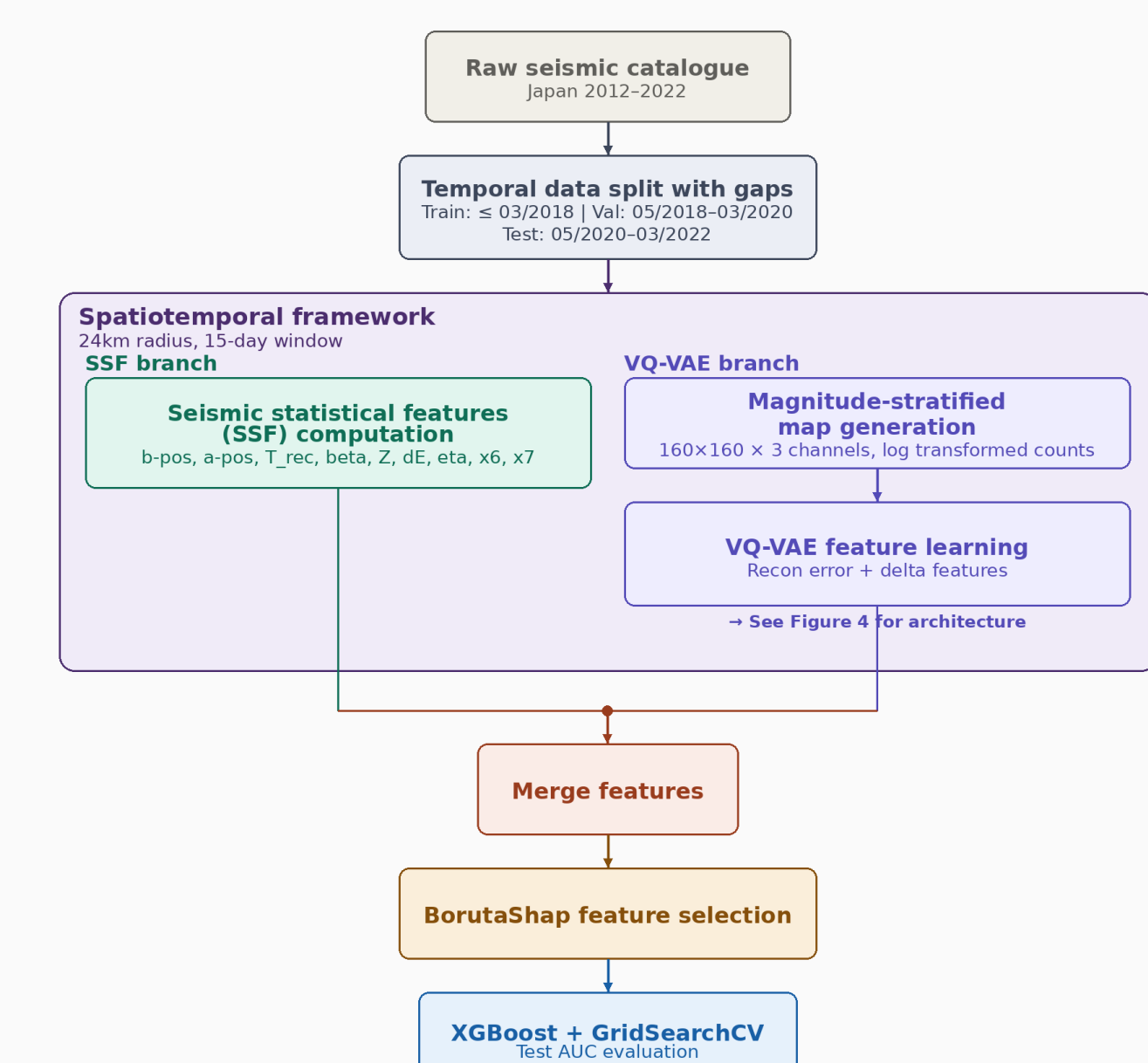


Figure 3. System pipeline

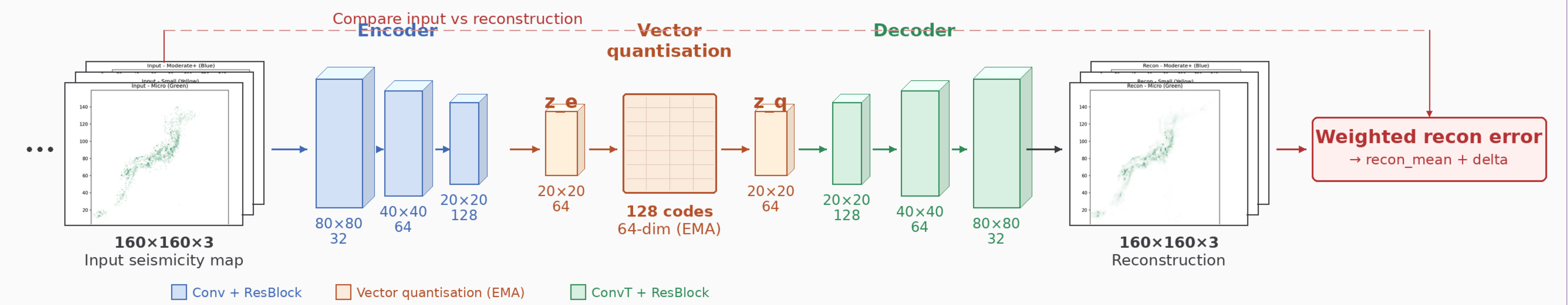


Figure 4. VQ-VAE-b architecture

VQ-VAE Reconstruction: texture

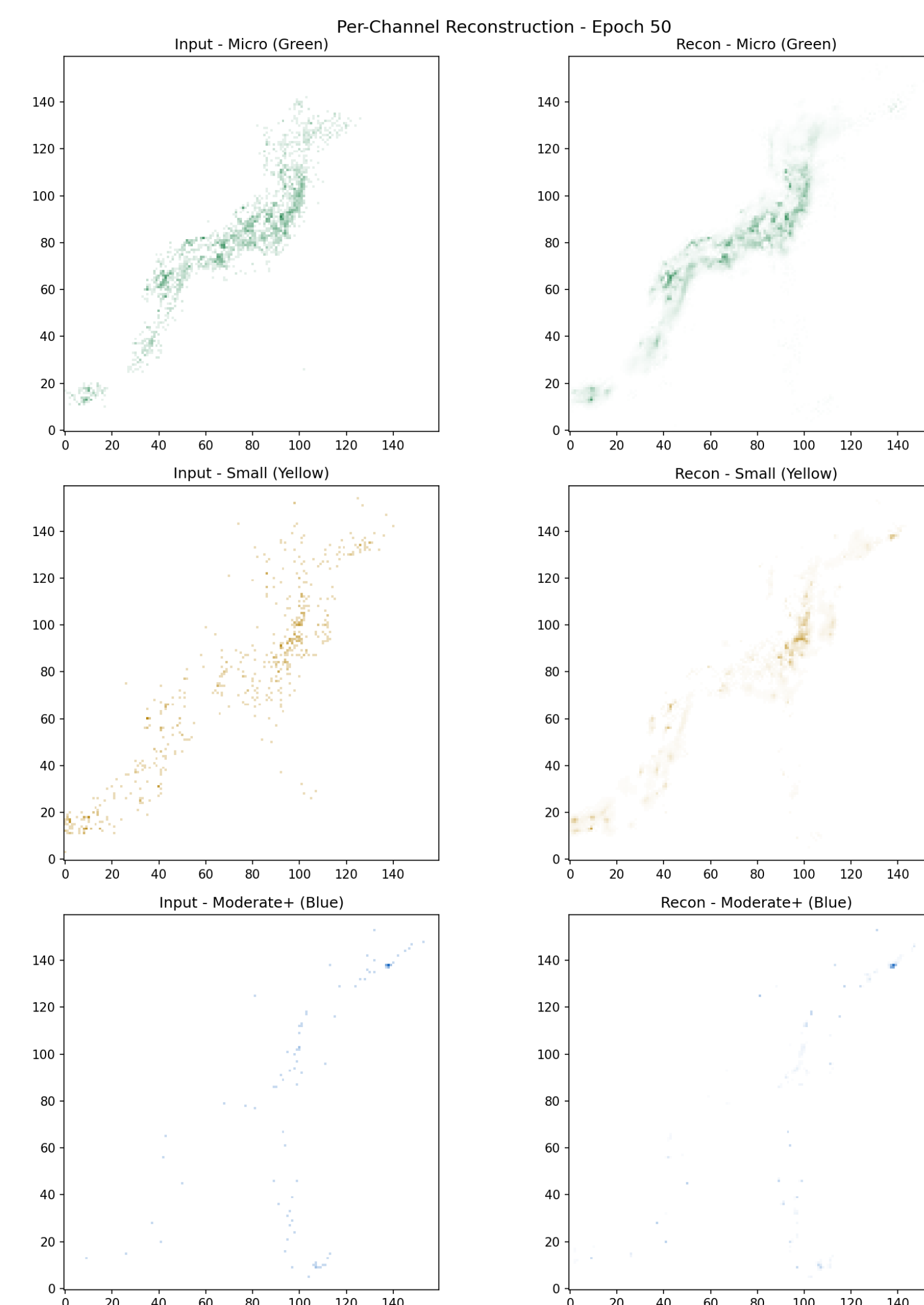


Figure 5. VQ-VAE per-channel reconstruction comparison

Results

Evaluation Metric	SSF Baseline	SSF + VQ-VAE-b (Proposed)
5-Fold Cross-Validation AUC	0.66	0.73
Test Set AUC (Single Period)	0.88	0.90

Performance:

- The inclusion of VQ-VAE-b features provided a substantial performance boost in both validation and test sets.
- SHAP analysis identifies vqvae_recon_mean as the most impactful feature, consistently outperforming traditional SSFs such as energy ($dE/2$) and mean magnitude.

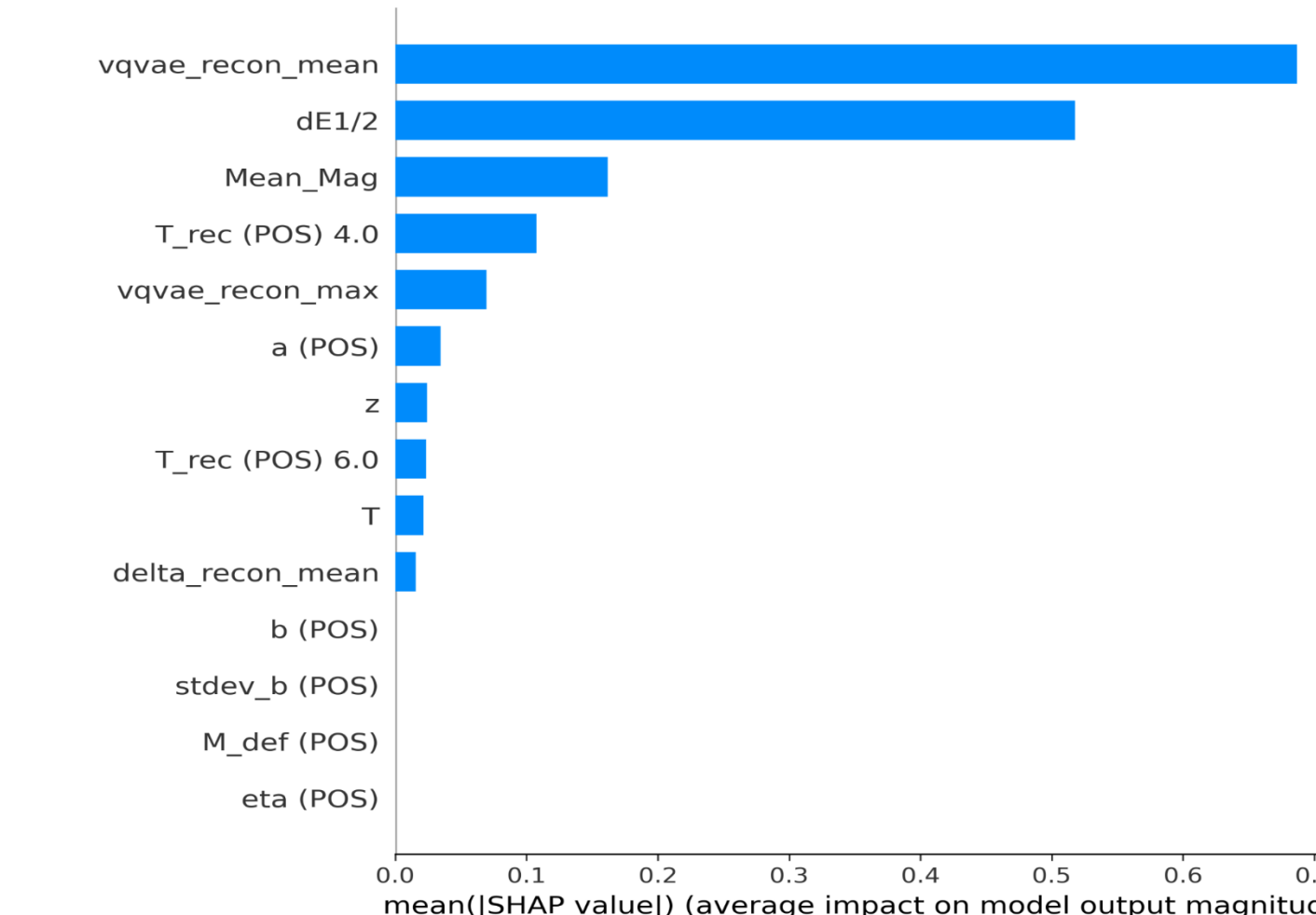


Figure 6. Test set feature ranking

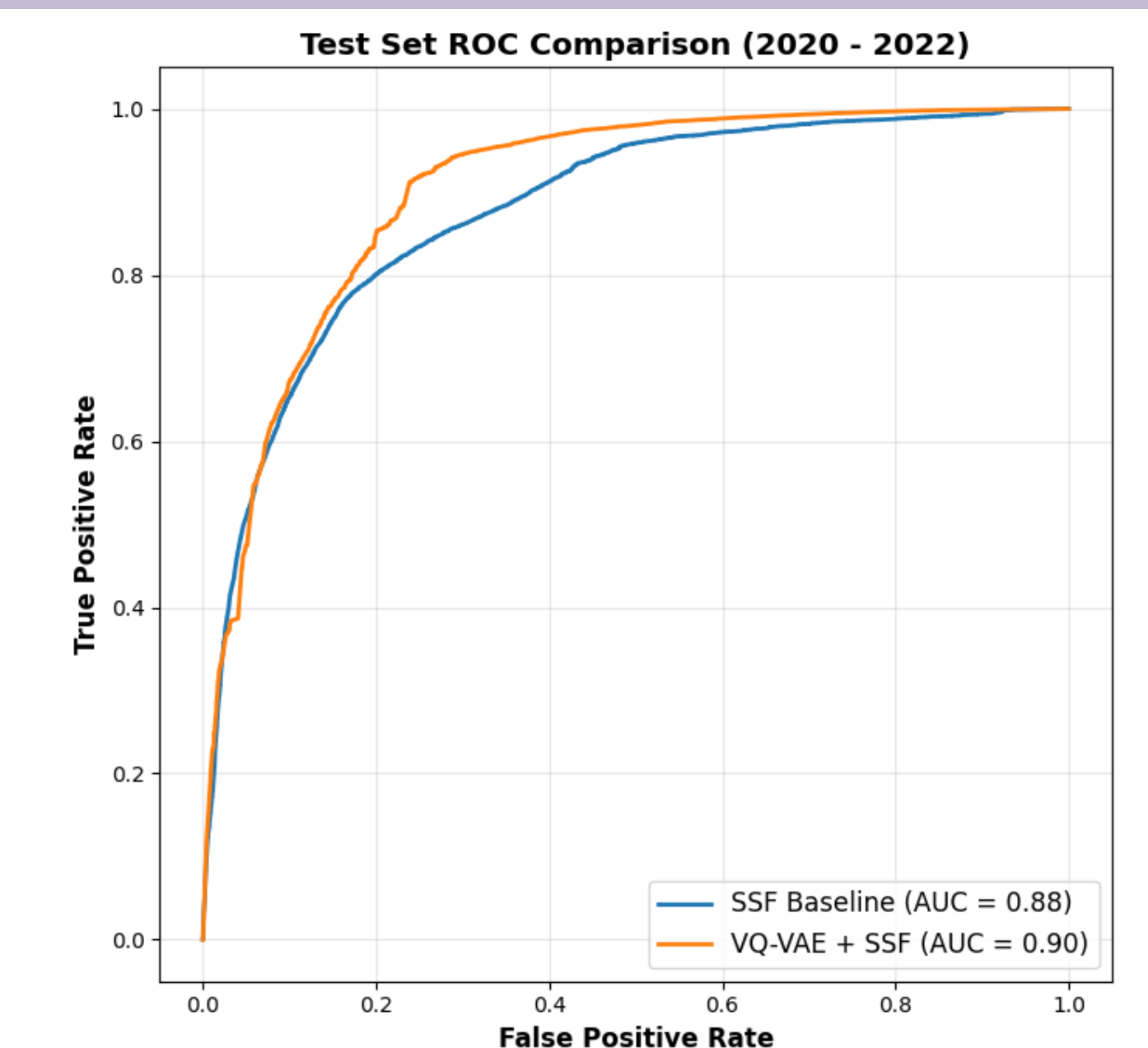


Figure 7. Test set ROC curves

Interpretation:

- The reconstruction error captures how much current seismicity deviates from learned normal patterns.
- High reconstruction error at a given location signals anomalous magnitude-frequency distributions — the type of stress-state change that precedes larger events — precisely what b-value measures.

Conclusion

The VQ-VAE reconstruction error serves as an effective learned macro-regime proxy for b-value, capturing localised stress-state patterns that fine-scale analytical b-value calculations often miss due to data sparsity.

Future work: extend to multi-modal approach (e.g., geodetic) to complement VQ-VAE-b and SSF feature set

