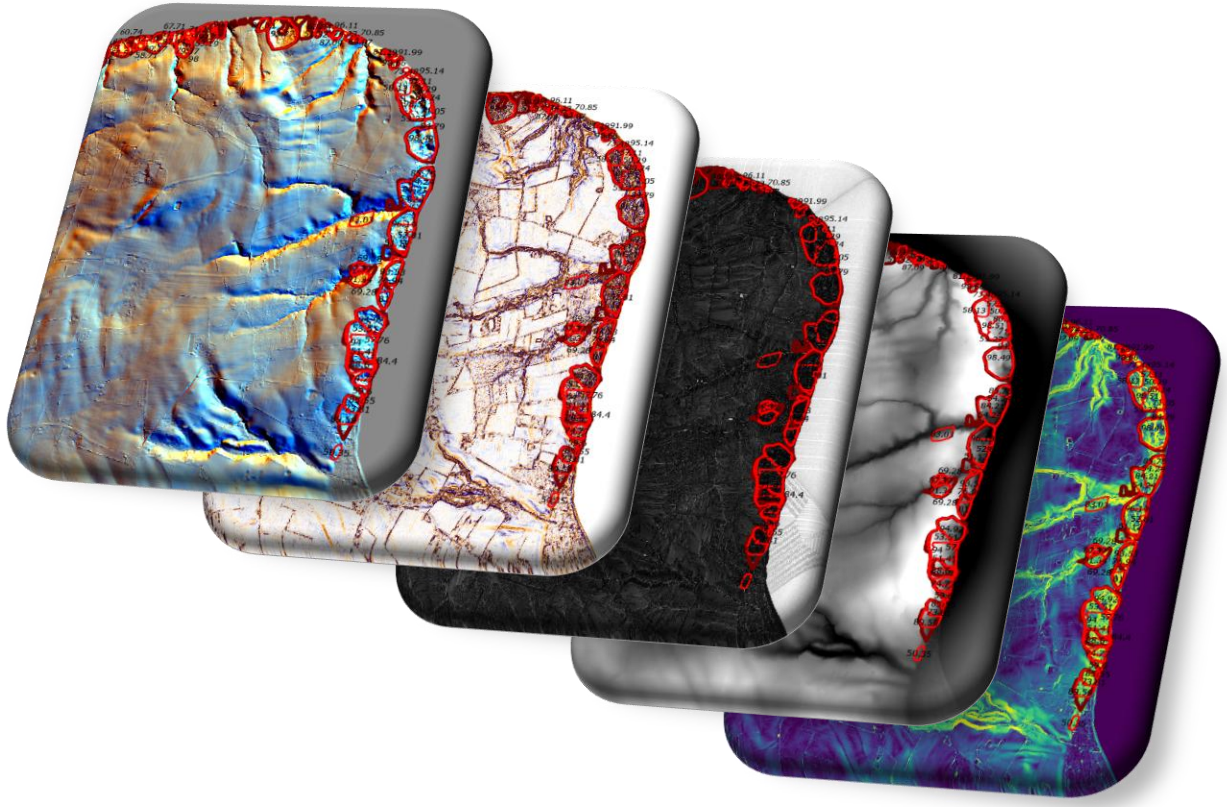
Multi-Band Geomorphic Feature Design for Landslide Detection Using Mask R-CNN



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GEUS

CARLSBERG FOUNDATION

Problem

- Manual landslide mapping is slow.
- Results can vary between mappers.

Solution

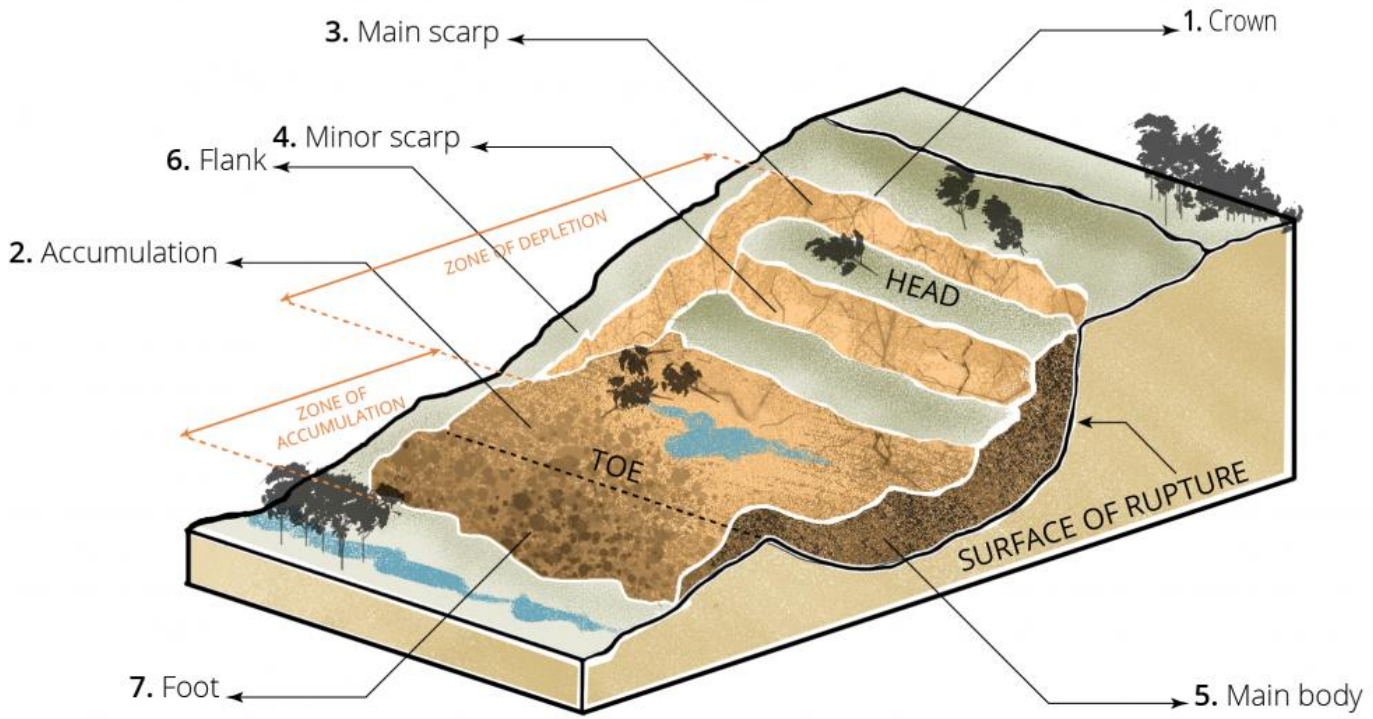
- Mask R-CNN automates landslide detection.
- Performance depends on the input feature stack.
- Feature stack design is iterative and time consuming.

Objective

- Identify the optimal geomorphic feature stack for landslide detection.

What Morphology Defines a Landslide?

1. **Crown** - Undisturbed ground at the top of the landslide
2. **Main Scarp** - Primary headwall marking the upper rupture surface
3. **Minor Scarps** - Secondary scarps formed by internal movement
4. **Main Body** - The bulk of displaced material between the scarp and toe
5. **Flanks** - Undisturbed margins bordering the landslide
6. **Accumulation Zone** - Area where displaced material is deposited
7. **Foot/Toe** - Lowest part of the landslide extending beyond the rupture surface



What Morphology Defines a Landslide for **ML**?

Feature	ML / Geomorphic Signature
Main Scarp	Large arcuate break in slope
Minor Scarps	Internal ridge and scarp features
Hummocky Body	Rough, irregular microtopography
Accumulation Zone / Toe	Lobate convex deposit
Flank Boundaries	Sharp lateral terrain transition

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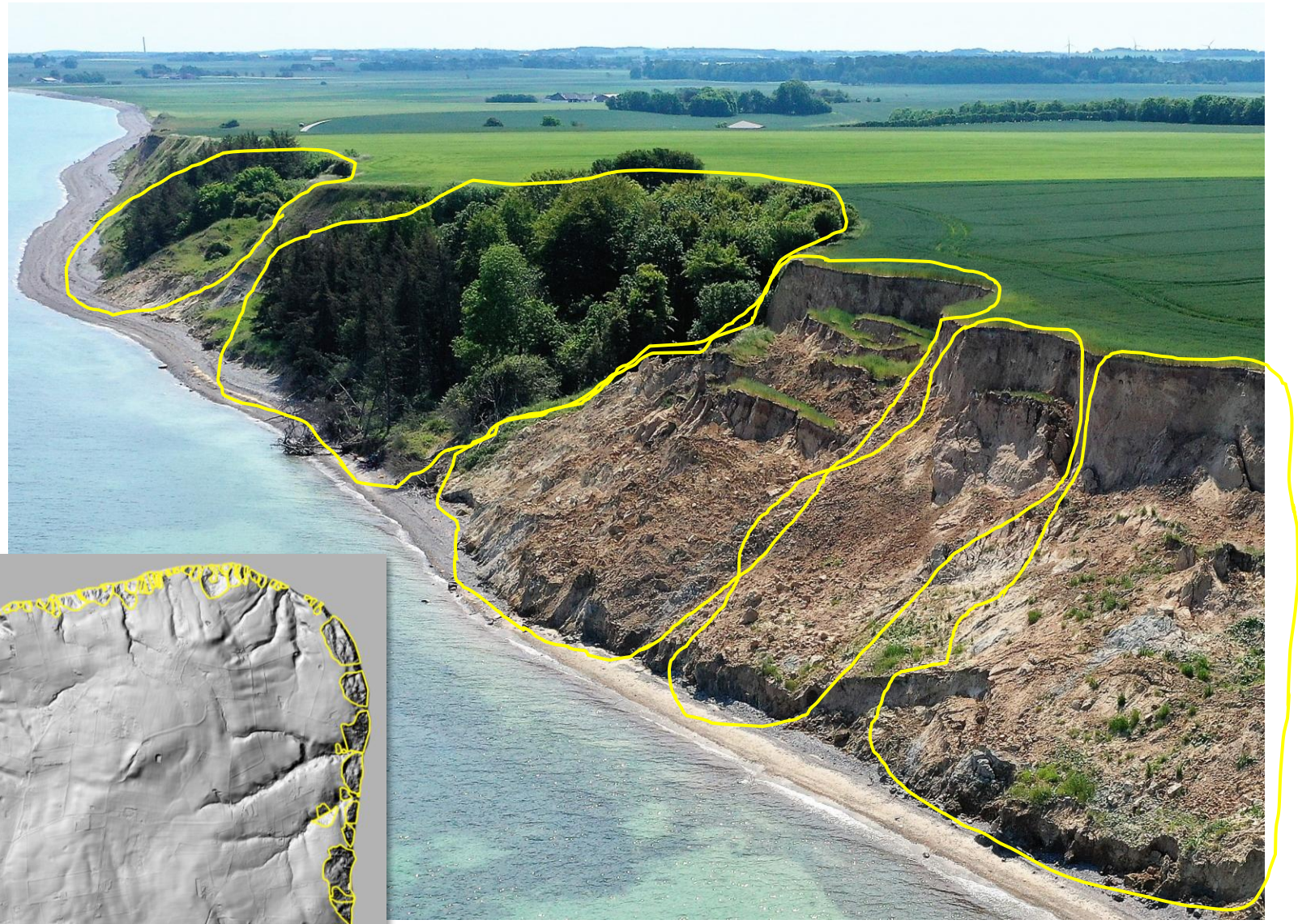
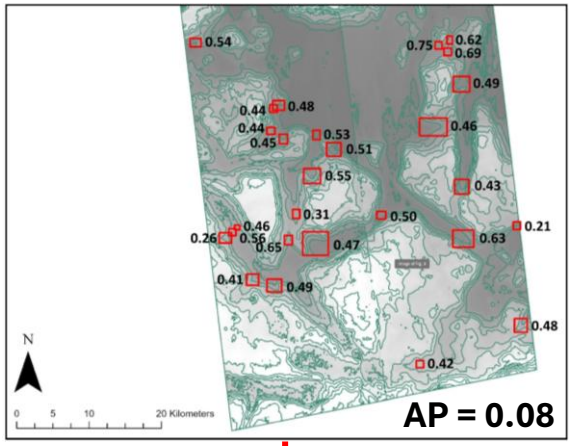


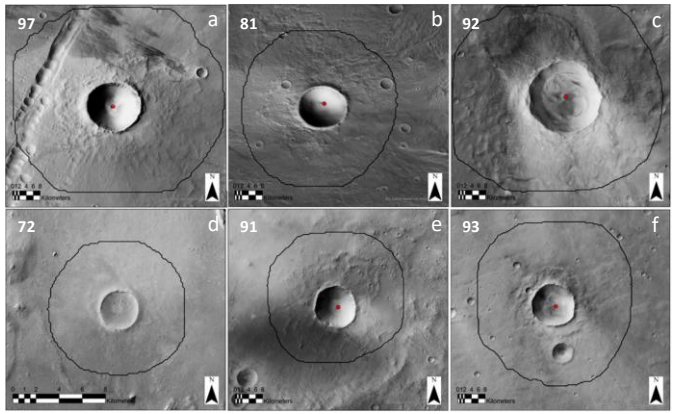
Evolution of Geomorphic Feature Design

Cirques: DEM→RGB (Mars, CNN)



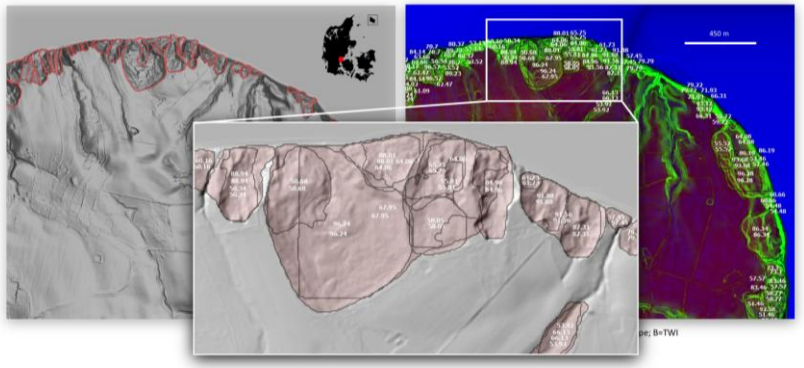
AP = 0.08

Ramparts: Grayscale→RGB (Mars, Mask R-CNN)



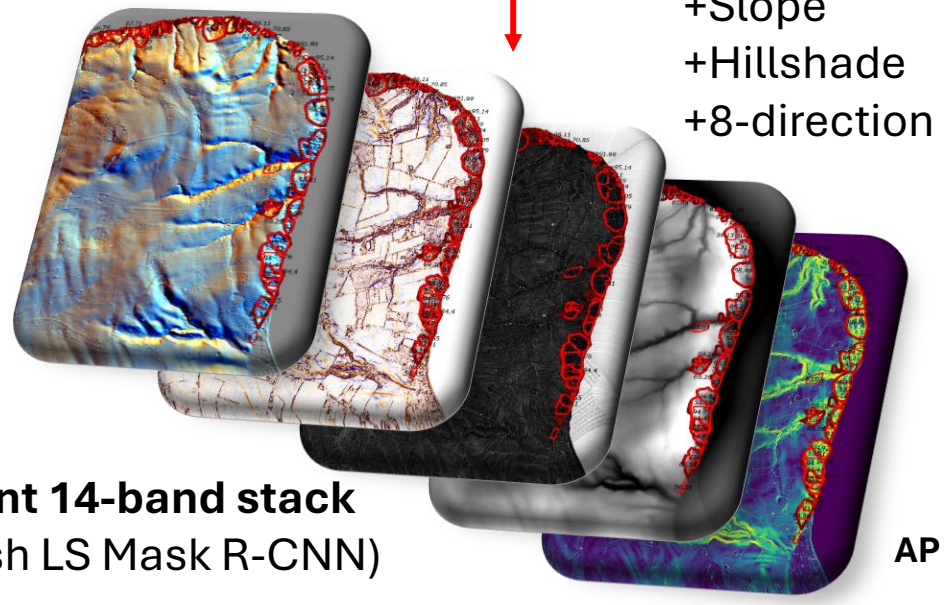
AP = 0.39

Danish Landslides: DEM+TWI+TPI (Danish LS Mask R-CNN)



AP = 0.15

+TPI 50m, TPI 300 m
+Slope
+Hillshade
+8-direction hillshades

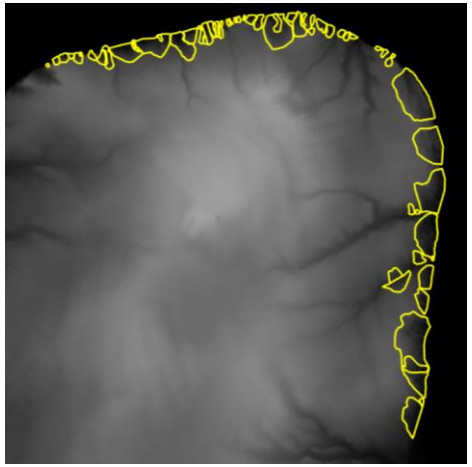


Current 14-band stack
(Danish LS Mask R-CNN)

AP = 0.43

Building the 14-Band Stack

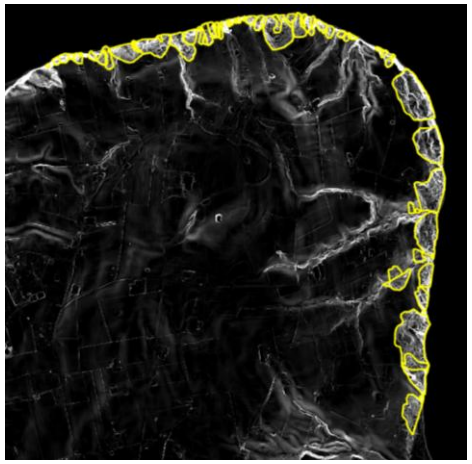
DEM



Absolute terrain elevation and landslide topographic context.

+

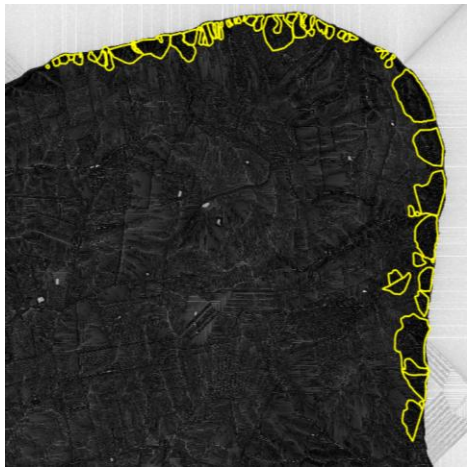
Slope



Steepness and slope breaks associated with failure zones.

+

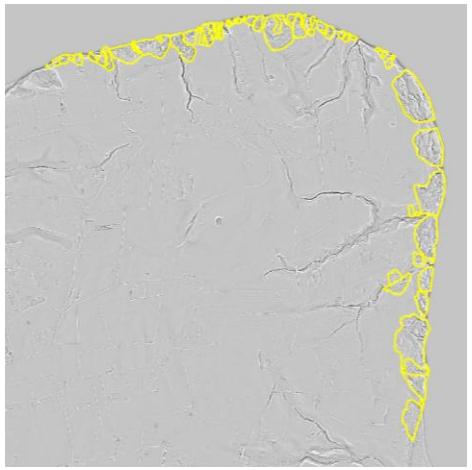
TWI



Potential moisture accumulation and groundwater concentration.

+

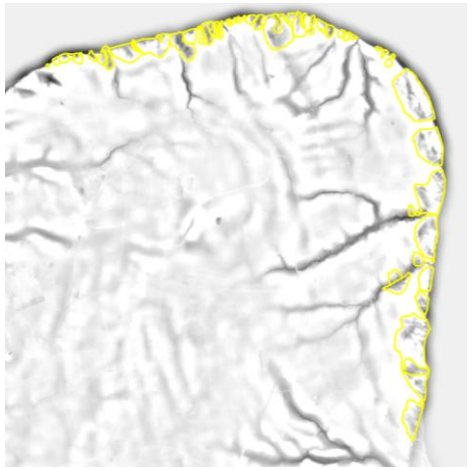
Profile Curvature



Convex scarps, concave hollows, and depositional lobes.

+

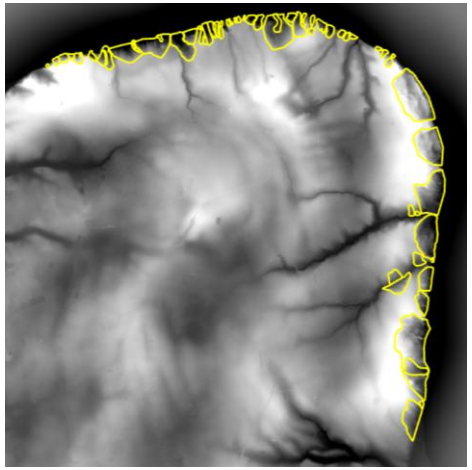
TPI 50 m



Fine-scale ridges, scarps, depressions, and hummocky terrain.

+

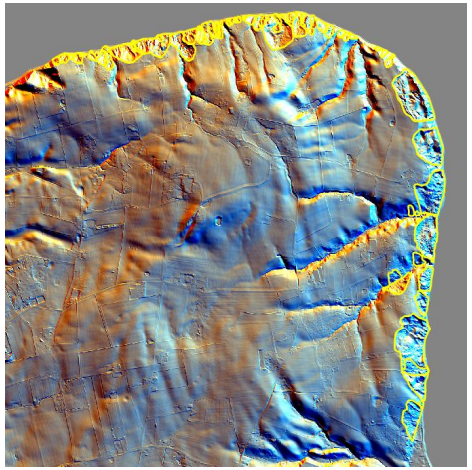
TPI 300 m



Broad landslide morphology and regional terrain position.

+

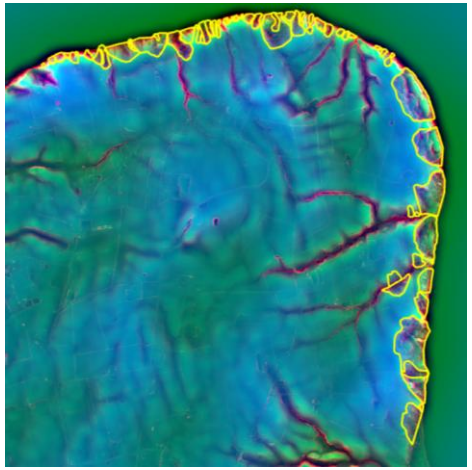
8 Hillshades



Directional relief from **N, NE, E, SE, S, SW, W, NW**.

=

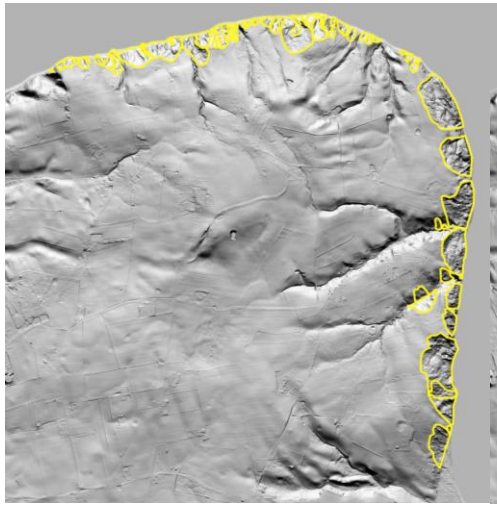
Composite 14 Bands



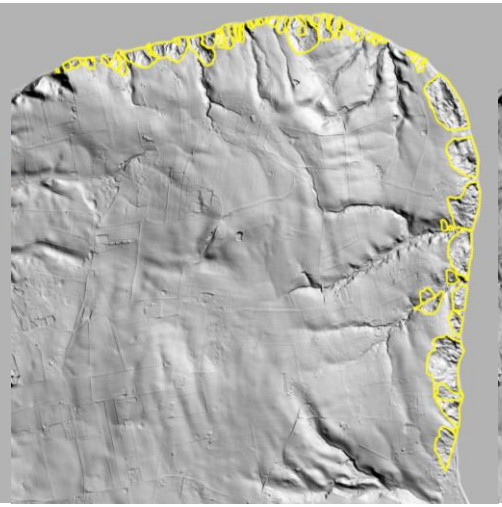
Integrated terrain, hydrologic, and morphometric information.

Why Eight Directional Hillshades?

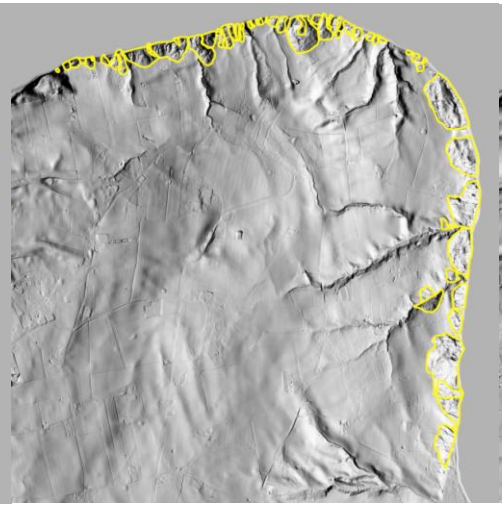
Hillshade 0°



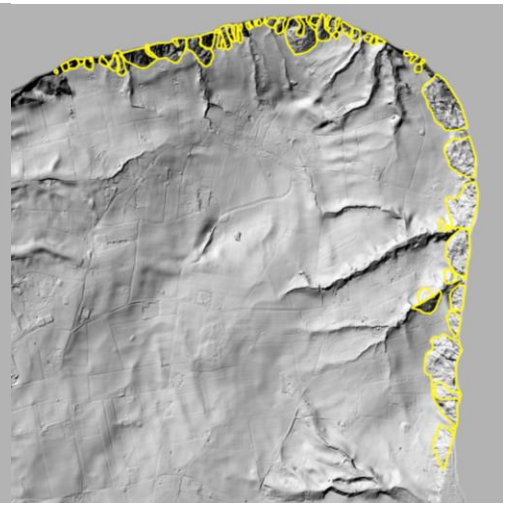
Hillshade 45°



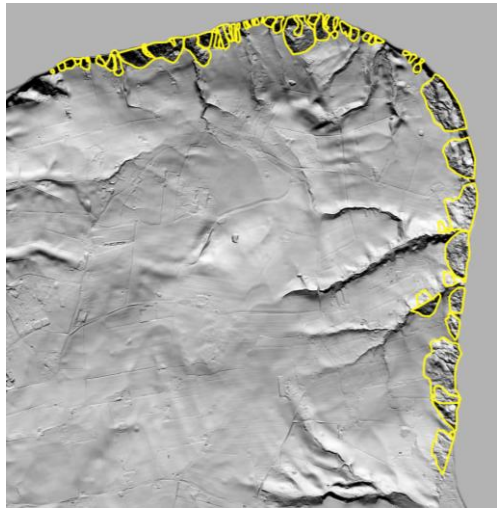
Hillshade 90°



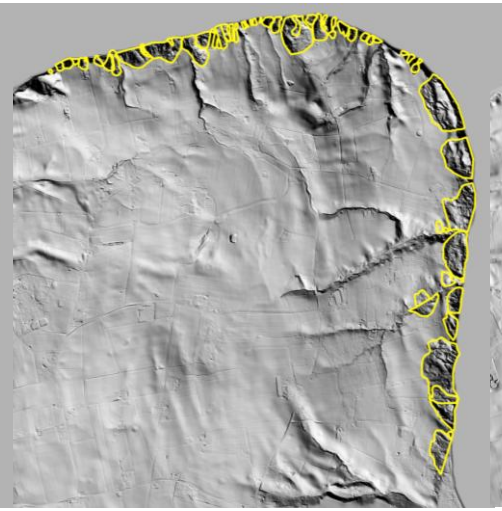
Hillshade 135°



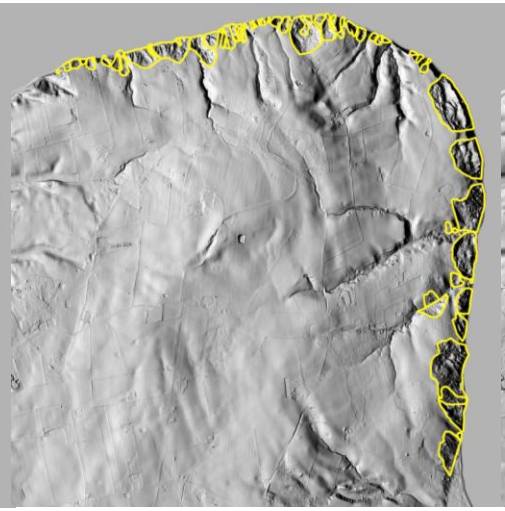
Hillshade 180°



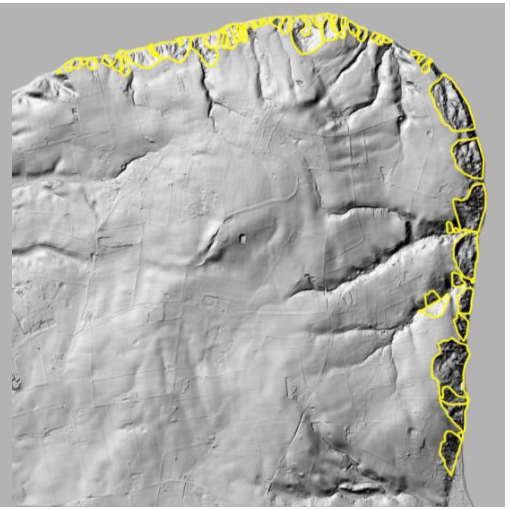
Hillshade 225°



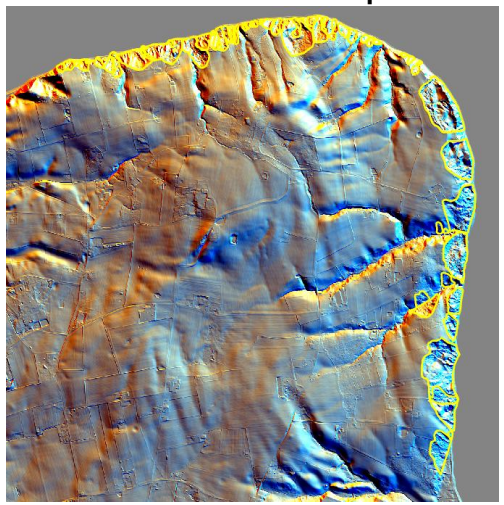
Hillshade 270°



Hillshade 315°

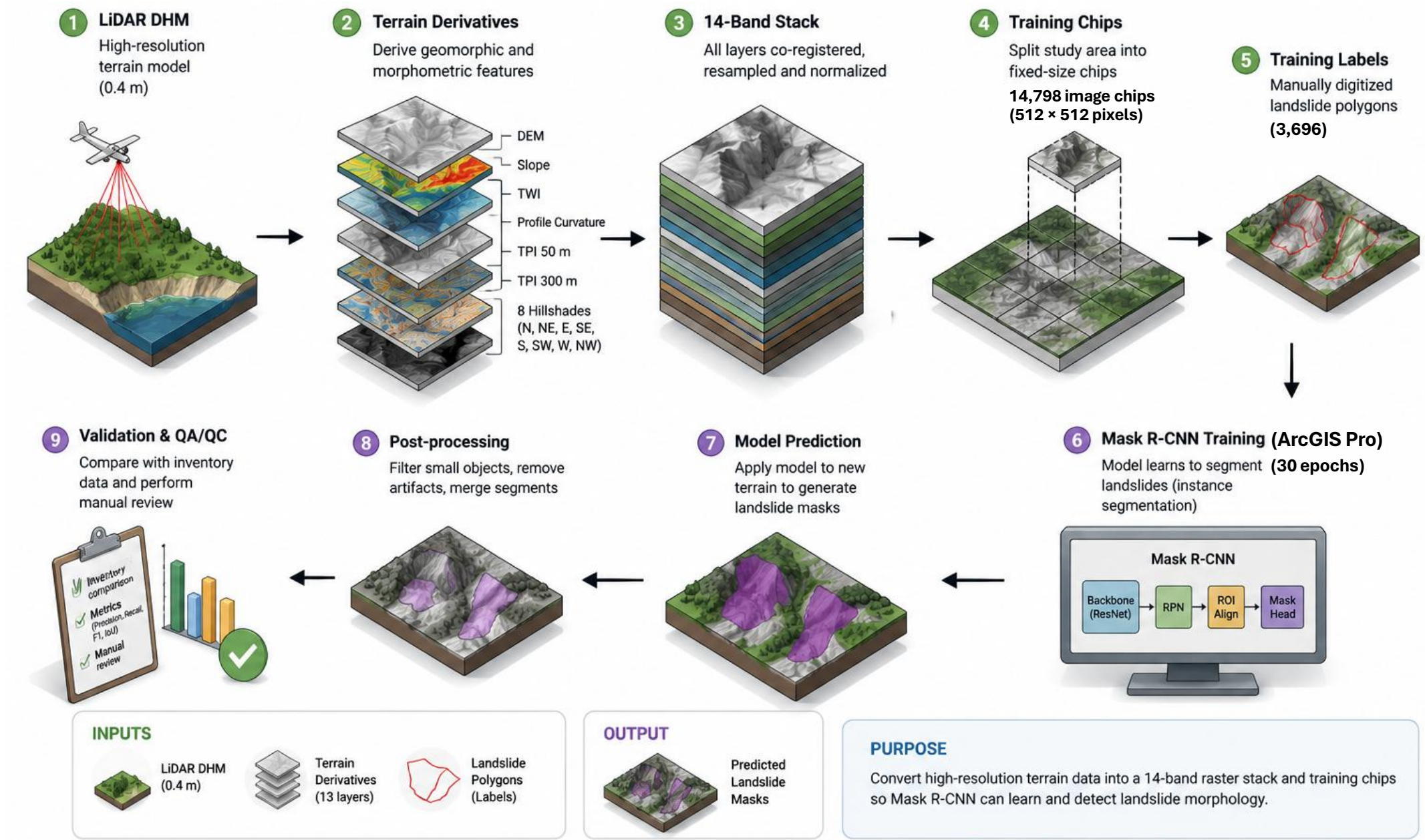


8 Hillshades Composite

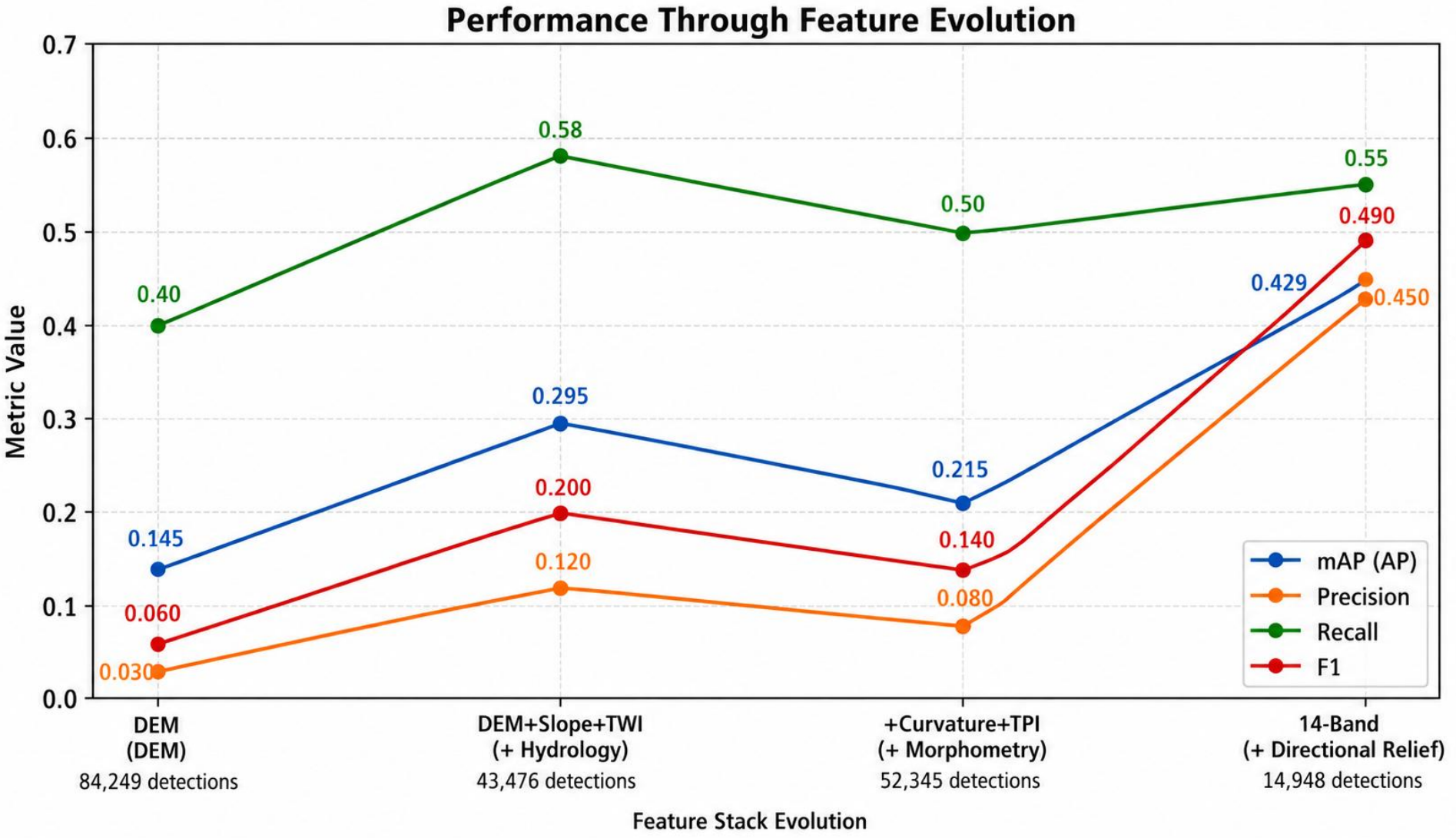


- Avoids illumination bias
- Captures landforms of all orientations
- Improves morphology representation

Mask R-CNN Landslide Detection Workflow



Performance Through Feature Evolution



Recall = 0.550
F1 = 0.490
Precision = 0.450
mAP = 0.429

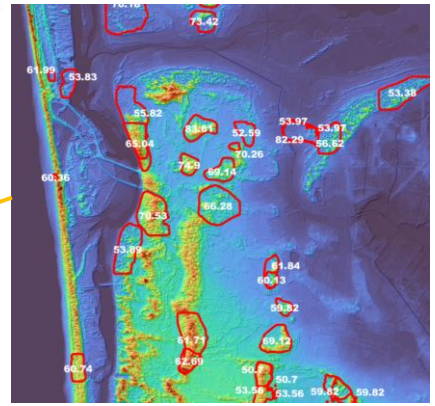
Key Results

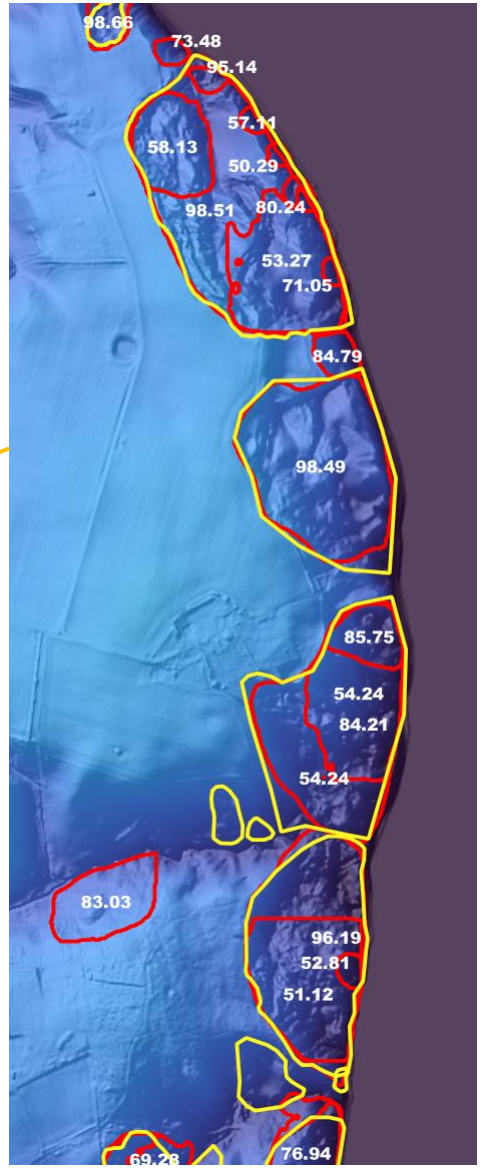
- AP increased from **0.145 → 0.429** (+196%)
- Candidate detections reduced from **84,249 → 14,948** (−82%)
- Best performance achieved using the full **14-band stack**

Denmark-Wide Results

False positives

True positives



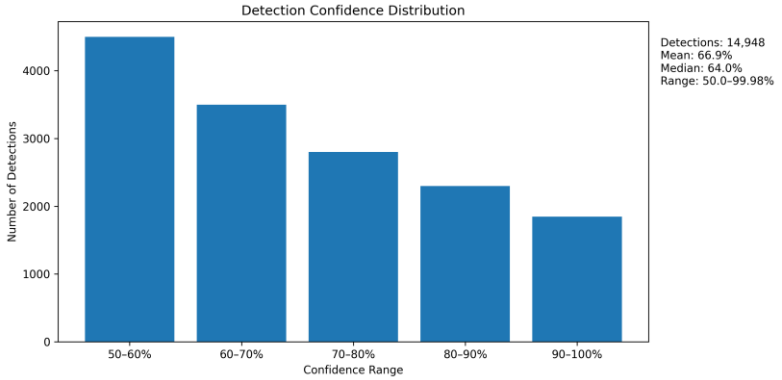


Inventory polygons

Red polygons = New detections (14,948)

Yellow polygons = Mapped Landslides (3,696)

Confidence distribution



100 km

Area = 43,094 km^2

Conclusions

Key Findings

1. Geomorphic feature engineering substantially improved Mask R-CNN performance
2. The 14-band stack produced the highest **AP = 0.429**
3. Candidate detections decreased from **84,249 to 14,948** while improving model performance
4. Multi-scale terrain metrics and directional relief information provided the greatest performance gains

Scientific Implications

- Denmark-scale automated landslide mapping is feasible using LiDAR-derived geomorphic features
- Model performance depends strongly on the geomorphic representation provided to the network
- Automated inventories can accelerate national-scale landslide identification and prioritization

Future Work

- Quantify the contribution of individual terrain layers to model performance
- Identify which geomorphic features drive landslide detections
- False-positive reduction
- Automated confidence ranking
- Manual validation and inventory refinement
- Transferability to other glaciated landscapes