Comparative Analysis of YOLOv8 and YOLOv11 for Cold Spots Detection on the Lunar Surface

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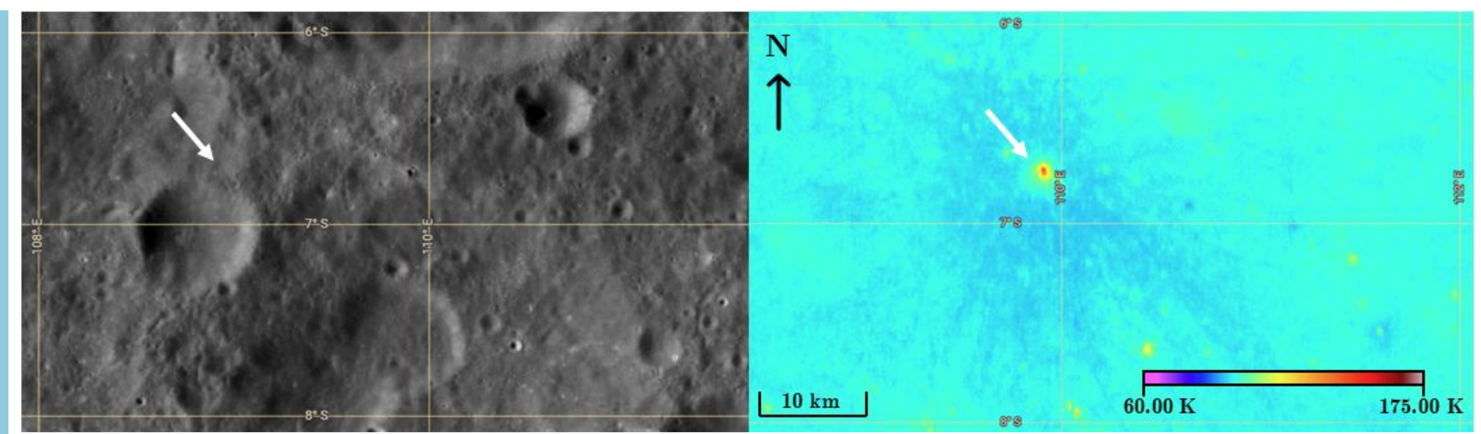
Introduction

- Distinctive thermal features with cooler nighttime temperatures compared to surrounding regolith [1].
- Associated with fresh impact craters and extended ejecta rays.
- Manually Identified using the Diviner radiometer on the Lunar Reconnaissance Orbiter (LRO) [2].
- A catalog of 2,282 identified cold spots provided by Bandfield et al. (2011).



This image shows a cold spot (blue) near a crater (white arrow) on the Moon at 6.74°S, 109.91°E. On the left is a high-resolution camera view and on the right is a temperature nighttime map (https://quickmap.lroc.asu.edu/).

Objectives

Detect Lunar Cold Spots Efficiently
- Automate the identification of thermal anomalies to replace labor-intensive manual methods.

Leverage Advanced Object Detection Models
- Evaluate and compare the performance of YOLOv8 and YOLOv11 in identifying lunar cold spots.

Expand Lunar Cold Spot Catalog
- Identify previously undetected or overlooked cold spots.

Improve Detection Accuracy and Scalability
- Address the limitations of manual methods.

Facilitate Future Lunar Science Research
- Thermophysical properties, impact processes of the lunar regolith.

Challenges in Detection

- **Manual Identification:** Labor-intensive and inconsistent, limited by Diviner's 240-meter spatial resolution.
- **High-Latitude Variability:** Temperature changes due to shadows hinder accuracy.
- **Need for Automation:** Manual methods are time-consuming and prone to errors.

Methodology

Training

Regolith Temperatures Map 2011
Source: 128-pixel-per-degree (ppd) rock-free nighttime regolith temperature maps.
Coverage: Extends to ±60° latitude.
Derived From: Gridded brightness temperatures based on Diviner's thermal infrared spectral observations.

Divide into 384 sub-images (focusing on regions with craters larger than 250 meters to align with the Diviner radiometer's resolution of 240 meters per pixel).

Annotate 652 cold spots using roboflow

Hyperparameter Optimization

Hyperparameters	Set 1	Set 2	Set 3
Optimizer	AdamW	SGD	AdamW
IoU	0.5	0.6	0.7
Augmentation	Fliplr 0.5	Fliplr 0.5 Rotation 10.0	Flipud 0.5
Learning rate	0.001	0.01	0.0001
Batch size	16	16	20

Training YOLO Models
- Without K-fold: 70% training, 20% validation, 10% testing.
- With K-fold: 5-fold cross-validation.

ultralytics
YOLOv8 YOLOv11

Model Evaluation – Measure models' performance
Precision (minimize false positives), Recall (maximize detection sensitivity), F1 Score (balance precision and recall), Mean Average Precision (mAP, evaluate detection accuracy)

Testing

High-Resolution Nighttime Temperature 2023 [3]
Improved Resolution: ~3.5× longitudinally and ~1.3× latitudinally.
Coverage: Extends to ±70° latitude, gridded at 128 ppd.
Data Span: 13 years of Diviner nighttime brightness temperature measurements.

- Crop dataset into 512×512-pixel sub-images with 20% overlap.
- Generate 4,816 sub-images for testing

Testing the Models
Evaluate both YOLO models on unseen data

Comparison of YOLOv8 and YOLOv11 for Cold Spot Detection

Results & Conclusions

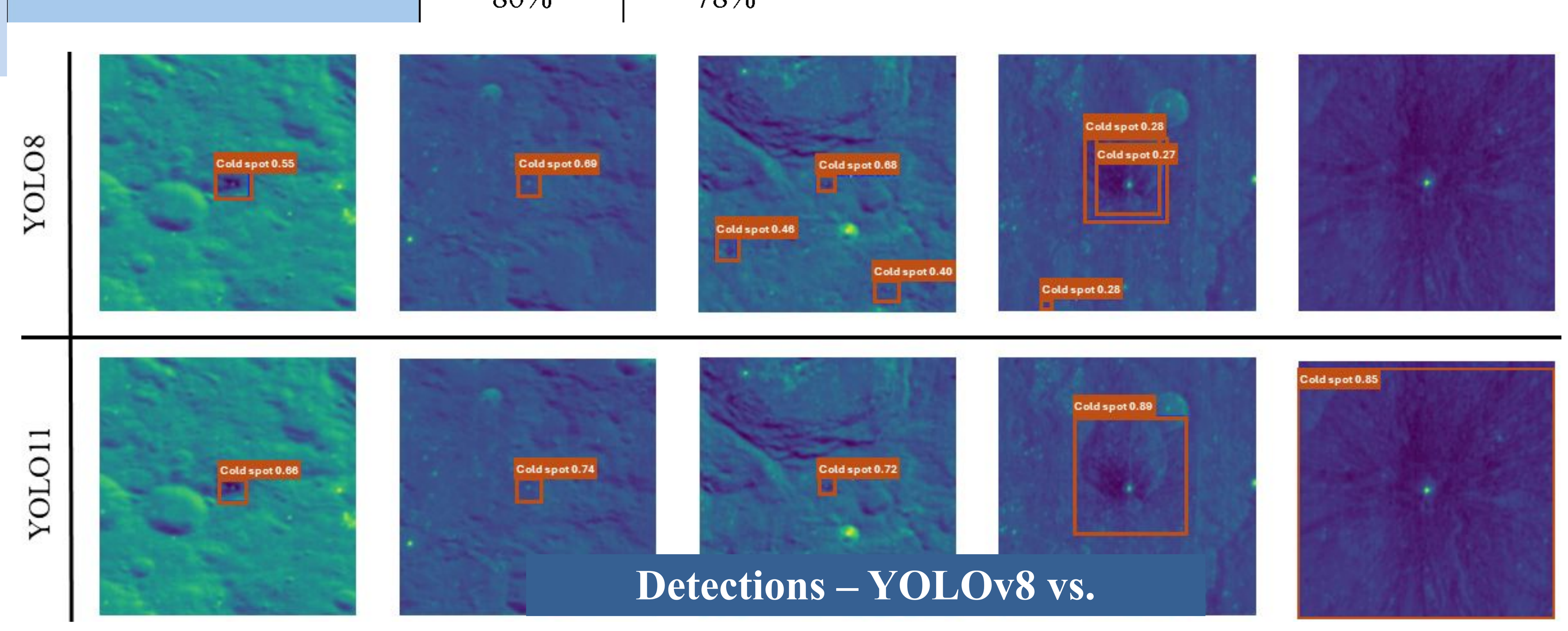
Without K-fold Cross Validation

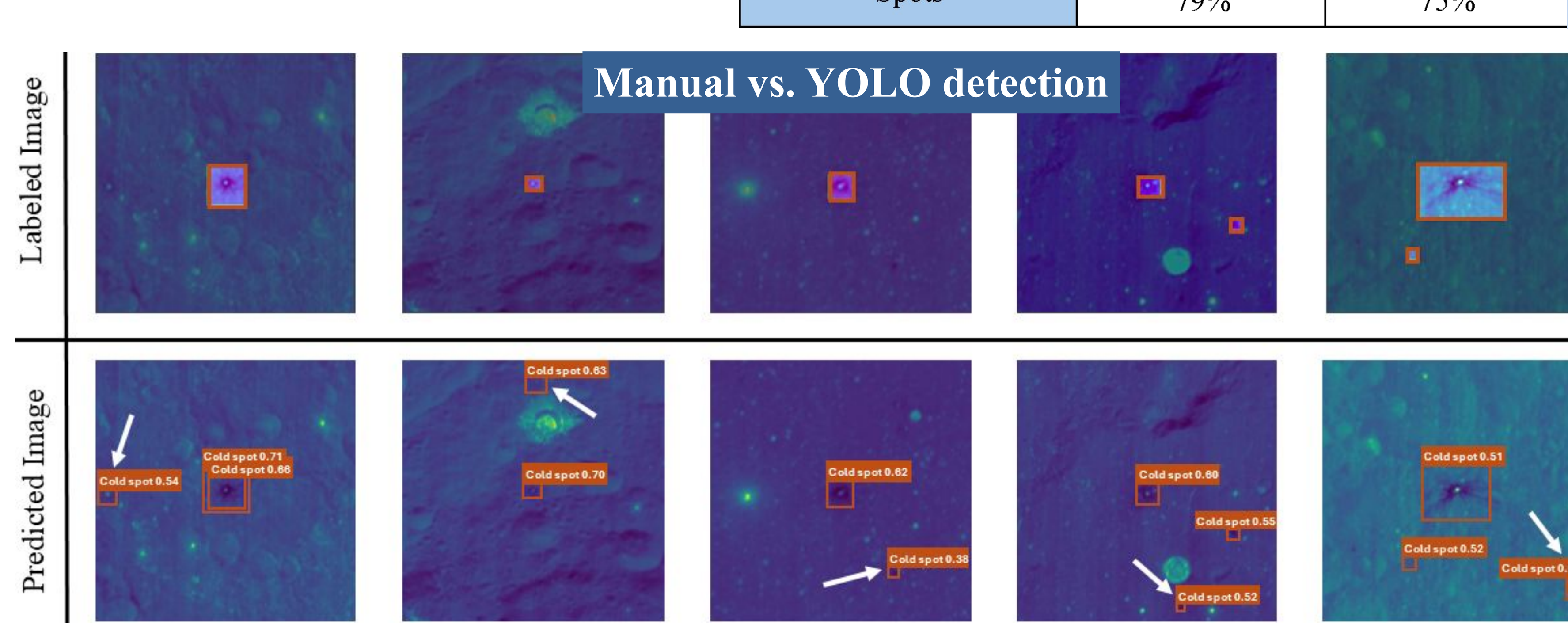
Performance metrics	YOLO8	YOLO11
MAP-50	0.75	0.94
Precision	0.78	0.89
Recall	0.65	0.92
F1	0.71	0.9
Detected Cold Spots	8970	7296
Detected Known Cold Spots	1840	1768
	80%	78%

- Both YOLOv8 and YOLOv11 significantly improve lunar cold spot identification compared to traditional manual methods.
- YOLOv11 demonstrated higher precision, recall, F1 score, and mAP, making it the most reliable model for accurate detection.
- Automated detection provides scalable and efficient solution for studying lunar surface.
- The expanded cold spot catalog enables new opportunities for research and exploration.

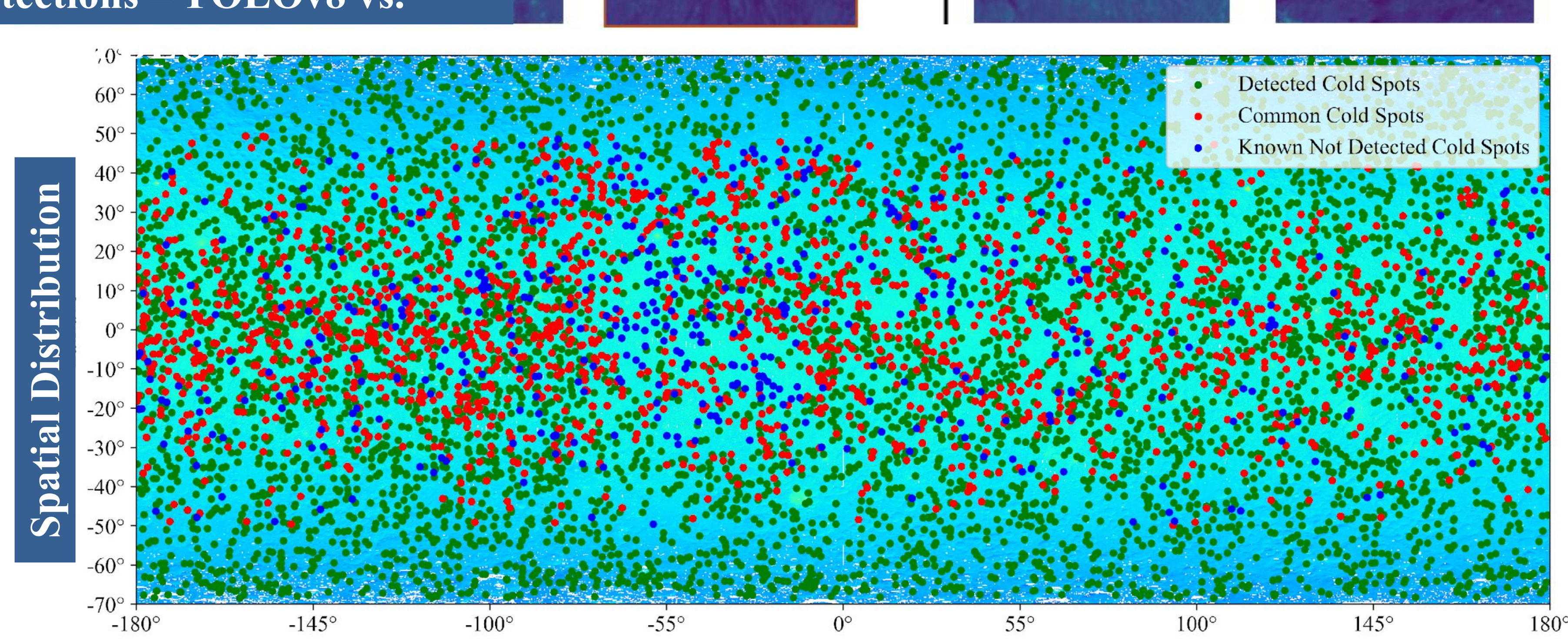
With K-fold Cross Validation

Performance metrics	YOLO8	YOLO11
MAP-50	0.78	0.79
Precision	0.83	0.85
Recall	0.74	0.78
F1	0.78	0.81
Detected Cold Spots	7777	6452
Detected Known Cold Spots	1805	1715
	79%	75%





Diviner Radiometer



References
[1] J. L. Bandfield, R. R. Ghent, A. R. Vasavada, D. A. Paige, S. J. Lawrence, and M. S. Robinson, "Lunar surface rock abundance and regolith fines temperatures derived from LRO Diviner Radiometer data," J Geophys Res Planets, vol. 116, no. 12, pp. 1–18, 2011, doi: 10.1029/2011JE003866.
[2] J. L. Bandfield et al., "Lunar cold spots: Granular flow features and extensive insulating materials surrounding young craters," Icarus, vol. 231, pp. 221–231, 2014, doi: 10.1016/j.icarus.2013.12.017.
[3] T. M. Powell et al., "High-Resolution Nighttime Temperature and Rock Abundance Mapping of the Moon Using the Diviner Lunar Radiometer Experiment With a Model for Topographic Removal," J Geophys Res Planets, vol. 128, no. 2, pp. 1–21, 2023, doi: 10.1029/2022JE007532.