

HelioGuard Technical Whitepaper

Version 2.1 · September 2026

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1. Executive Summary

HelioGuard is a solar flare prediction system that translates NASA's public solar magnetic field data into personalized, actionable risk alerts. It is designed for public safety, professional operations, and scientific transparency.

2. Data Source

- NASA Solar Dynamics Observatory (SDO)**
- Helioseismic and Magnetic Imager (HMI)**
- SHARP (Space-weather HMI Active Region Patches) data product**
- Time span: 2010–2024**
- Total records: ~720,000**
- Data is publicly available via JSOC (Joint Science Operations Center)**

3. Feature Engineering

18 base SHARP parameters:

- Magnetic flux (USFLUX)**

- Current helicity (TOTUSJH)
- Free energy (SAVNCPP)
- Shear angle (SHRGT45)
- Area (AREA_ACR)
- 13 additional magnetogram parameters

Time-evolution features:

- 6-hour and 12-hour differences of key parameters
- Second-order derivatives to capture acceleration of magnetic changes

Total: 33 features.

4. Model Architecture

Algorithm: XGBoost (Gradient Boosted Trees)

Hyperparameters:

- n_estimators: 300
- max_depth: 6
- learning_rate: 0.1
- subsample: 0.8
- colsample_bytree: 0.8
- scale_pos_weight: adjusted for class imbalance (1:1000)

Calibration:

- Platt scaling and Isotonic regression compared

- Isotonic regression selected for 24h model (lower Brier score)

5. Performance Metrics

Evaluation method: Time-split test set (last 10% of data)

- TSS (True Skill Statistic): 0.676
- AUC: 0.912
- Brier Score: 0.015
- Recall (24h): 0.837
- Precision (24h): 0.083
- Specificity (24h): 0.839

Comparison with NOAA operational systems:

- NOAA's current systems have a false alarm rate of approximately 79%.
- HelioGuard provides rigorously calibrated probabilities, enabling decision-makers to act with confidence.

6. Confidence Intervals & Uncertainty

Each prediction includes a 95% confidence interval calculated via Bootstrap resampling (200 iterations).

Example: If probability is 0.70, the 95% CI is [0.58, 0.82].

7. Deployment

- Backend: Flask + Gunicorn + Nginx
- Frontend: HTML/CSS/JS, dark/light theme
- Hosting: Cloud server (2C 4G)
- Domain: helioguardalert.org
- Security: HTTPS (Let's Encrypt)

8. Future Work

- Integration of real-time solar wind data
- Ensemble learning for higher robustness
- Mobile app development
- Collaboration with national space weather agencies

9. Acknowledgments

- NASA SDO/HMI team for open data
- GFZ German Research Centre for Geosciences (Kp index)
- Open-Meteo for cloud cover data
- All beta testers and supporters

10. Contact

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