Earth Resonance Probes: A Multimodal Open-Source Sensing Architecture for Pre-Seismic Energy Detection

# 1. Executive Summary

Current earthquake early warning systems often fail to detect precursory signals before certain types of seismic events, such as strike-slip or deep-focus earthquakes. The SR-GEO-PoC model, while effective in many scenarios, faces limitations in detecting these silent events. The Earth Resonance Probe (ERP) initiative proposes a modular, multimodal sensor architecture capable of capturing pre-seismic energy transformations across the lithosphere, atmosphere, and ionosphere. This open-source solution offers a new layer of global sensing, enhancing predictive capabilities and supporting open scientific collaboration.

# 2. Introduction

The SR-GEO-PoC model has demonstrated the potential of using Schumann Resonance, ELF, TEC, and gravity data to identify early signs of seismic activity. However, its reliance on certain signal types makes it vulnerable to false negatives, particularly in regions where signal transmission is weak or the energy transformation takes forms not captured by existing sensors. ERP addresses this gap with a distributed network of hybrid sensors.

# 3. Problem Statement

Many earthquakes occur without detectable electromagnetic or atmospheric anomalies. Strike-slip faults, deep earthquakes, and events in geoelectrically quiet regions often fail to trigger warning systems based on limited modalities. A major challenge lies in the lack of integrated, real-time data from multiple energy domains.

# 4. Proposed Solution

ERP is a scalable, modular sensor platform designed to detect subtle precursory signals through a combination of sensors: piezoelectric EM detectors, ELF/VLF antennas, infrasound monitors, GNSS-based TEC sensors, and MEMS gravimeters. These sensors work together to identify energy transformations indicative of stress accumulation or crustal reconfiguration.

# 5. Sensor Array Design and Signal Coverage

- Piezo-EM detectors: detect crustal stress  
- ELF/VLF receivers: capture low-frequency electrical anomalies  
- Infrasound sensors: monitor AGW shifts  
- GNSS TEC monitors: map ionospheric variations  
- Gravimeters: detect changes in mass distribution

# 6. Multimodal Signal Fusion Framework

An AI-driven anomaly detection engine will process and correlate signals from all sensors. Cross-signal detection increases robustness, even if one modality is silent. Edge computing enables real-time local analysis, while cloud aggregation supports large-scale pattern detection.

# 7. Deployment Model

ERP nodes can be deployed as standalone stations or as part of a regional mesh network. Initial pilots would focus on high-risk regions lacking reliable early detection. Open-source firmware and design enable rapid scaling.

# 8. Use Cases

- Detecting precursors in strike-slip zones  
- Monitoring silent quakes in subduction zones  
- Community science deployments in under-monitored areas  
- Academic research and sensor data fusion benchmarking

# 9. Implementation Timeline

Phase 1: Design and prototyping (0–60 days)  
Phase 2: Calibration and lab testing (60–120 days)  
Phase 3: Field deployment of 3 units (120–180 days)  
Phase 4: AI model training and optimization (180–270 days)  
Phase 5: Public data release and global collaboration (270–365 days)

# 10. Open Science & Collaboration Call

We invite researchers, engineers, universities, and global partners to contribute to the ERP initiative. With shared data, open design principles, and a unified mission, we can build a seismic early warning system that truly sees the invisible.

# Appendix A: SR-GEO-PoC v2.0 – Enhanced Detection Model

To address known limitations of the original SR-GEO-PoC early warning model, the following updated formula expands the signal types evaluated and introduces a weighted scoring system that accounts for geological context and sensor coverage quality. This makes the model more adaptive to events that traditionally produce no clear SR or TEC anomalies, such as strike-slip and deep-focus earthquakes.

Revised Formula:

P\_event = Σ (Si × Wi × Ci)

- Si = Normalized signal strength of modality i  
- Wi = Weight based on fault type and signal relevance  
- Ci = Confidence factor based on sensor coverage and data quality

Signal Components:

• SR\_amp – Schumann Resonance amplitude  
• ELF\_burst – Extremely Low Frequency electrical spikes  
• TEC\_dev – Total Electron Content anomaly  
• AGW\_spike – Acoustic-gravity wave/infrasound spike  
• Piezo\_EM – Local EM signals from crustal strain  
• Grav\_delta – Gravity field anomaly (e.g., GRACE or local MEMS)

Trigger Conditions:

- Early Warning Trigger: P\_event ≥ 3.5  
- High Certainty Alert: P\_event ≥ 4.5  
- Watch Window: 3.0 ≤ P\_event < 3.5

Model Benefits:

• Multimodal coverage improves robustness across fault types  
• Weighting compensates for weak or silent signals in one domain  
• Confidence scaling allows meaningful outputs with partial data  
• Modular design supports integration with future sensor types