

EARTHQUAKE PREDICTION ENGINE

Seismic Observatory Field Manual — The 3-Layer Guide

Station: AM.R1A3D • Network: Raspberry Shake AM • Location: Berkeley Hills, CA (37.8696° N, 122.2491° W)
Document Version: 2.0 • Focus: What is being shown, progressive scientific disclosure & mathematical derivations.

About the 3-Layer Onion Architecture:

Every section in this manual explains what is being shown across three progressive layers:

- **Layer 1 (Layperson):** Plain-English intuition, practical analogies, and visual identification cues.
- **Layer 2 (Geophysical Science):** Sensor mechanics, wave physics, attenuation, and instrument theory.
- **Layer 3 (Raw Mathematics):** Discrete algorithms, filter transfer functions, and exact mathematical formulations.

1. Multi-Channel Seismograms (The Oscilloscope)

■ Layer 1: The Layperson's Eye (What You Are Seeing)

The Oscilloscope shows 4 continuous squiggly traces gliding from right to left. The green line (EHZ) is an ultra-sensitive geophone listening to soft subterranean murmurs. The blue, amber, and purple lines (ENZ, ENN, ENE) are 3-axis accelerometers measuring violent impacts. The translucent center band is the station's normal 4-minute quiet corridor; when waves break outside this corridor, the station flags an anomaly.

■ Layer 2: Geophysical & Sensor Science

Consists of a 4.5 Hz moving-coil geophone and triaxial MEMS capacitive accelerometers sampled at 100 Hz. The geophone measures velocity via electromagnetic induction (damping factor $h \sim 0.707$). Accelerometers measure differential capacitance from DC to 50 Hz. Bandpass filtering (1-10 Hz) isolates tectonic frequencies while eliminating ocean microseisms (<0.5 Hz) and human acoustic chatter (>15 Hz). A 10-second jitter buffer guarantees stutter-free 60 FPS rendering.

■ Layer 3: Raw Mathematics & DSP Equations

Geophone Transfer Function: $H(s) = G \cdot s^2 / (s^2 + 2 \cdot h \cdot w_0 \cdot s + w_0^2)$, where $G = 388 \text{ V/(m/s)}$, $w_0 = 2 \cdot \pi \cdot (4.5 \text{ Hz})$. Digital 2nd-order Butterworth filter: $y[n] = b_0 \cdot x[n] + b_1 \cdot x[n-1] + b_2 \cdot x[n-2] - a_1 \cdot y[n-1] - a_2 \cdot y[n-2]$. Peak Ground Acceleration: $\text{PGA} = \text{Counts} \cdot (V_{\text{ref}} / (2^{23} - 1)) \cdot (1 / S_a) \cdot 9.80665 \text{ m/s}^2$.

2. High-Definition Spectrogram (STFT Waterfall)

■ Layer 1: The Layperson's Eye (What You Are Seeing)

While the seismogram shows ground movement over time, the spectrogram acts like musical sheet music, displaying vibration pitch (frequency) from deep sub-audible earthquake rumbles at the bottom (0 Hz) up to sharp rattles at the top (50 Hz). A local quake appears as an explosive vertical pillar of bright white/gold light. Roadway traffic appears as a fuzzy horizontal amber stripe.

■ Layer 2: Geophysical & Sensor Science

Visualizes 0-50 Hz Short-Time Fourier Transform (STFT). Earth acts as a low-pass viscoelastic filter: high frequencies (10-45 Hz) attenuate rapidly over distance due to scattering, meaning only nearby events have high-frequency content. Deep teleseismic quakes thousands of miles away appear strictly below 2 Hz.

■ Layer 3: Raw Mathematics & DSP Equations

Discrete STFT with 256-point Hann window: $X[m, k] = \text{Sum}_{\{n=0..N-1\}} x[m \cdot R + n] \cdot w[n] \cdot \exp(-j \cdot 2 \cdot \pi \cdot k \cdot n / N)$, where frequency bin $f_k = k \cdot (f_s / N) = k \cdot 0.390625$ Hz. Power Spectral Density: $S[m, k] = 10 \cdot \log_{10}(|X[m, k]|^2 + \epsilon)$, normalized to the Inferno colormap.

3. 24-Hour Helicorder Drum (The Daily Seismogram)

■ Layer 1: The Layperson's Eye (What You Are Seeing)

The classic spiraling paper drum displaying a complete 24-hour day of seismic history on a single screen. Read like a book from top to bottom; each horizontal line is 30 or 60 minutes. Quiet hours are thin, neat parallel lines. Daytime traffic thickens the lines into a dense fuzzy ribbon. An earthquake creates a jagged burst spilling across rows.

■ Layer 2: Geophysical & Sensor Science

Captures diurnal human cycles and long-period teleseismic events. Around 5:30 AM local time, lines thicken with morning commuter transit. Magnitude 7+ earthquakes occurring thousands of miles away appear as slow, beautiful sinusoidal wave packets lasting 30-45 minutes. Preserves full dynamic range using 1-minute min-max extreme value decimation.

■ Layer 3: Raw Mathematics & DSP Equations

Raster mapping: $\text{Row } r(t) = \text{floor}((t - t_{\text{start}}) / T_{\text{row}})$, $x(t) = ((t - t_{\text{start}}) \bmod T_{\text{row}}) / T_{\text{row}} \cdot W_{\text{canvas}}$. Decimation: $V_{\text{min}} = \min(x_i)$, $V_{\text{max}} = \max(x_i)$ over 6,000 samples/min. Demeaned baseline: $x_{\text{demean}}[n] = x[n] - \text{mean}(x)$.

4. STA/LTA Early Warning Telemetry & RSAM

■ Layer 1: The Layperson's Eye (What You Are Seeing)

The early warning trigger brain. Compares 'Right Now' seismic noise (Short-Term Average, last 0.5s) against 'Background Memory' (Long-Term Average, last 20s). Under quiet conditions, STA / LTA = 1.0x. When a P-wave arrives, STA explodes to 6.5x, 12x, or 30x, instantly sounding the alarm! RSAM tracks overall seismic power minute-by-minute.

■ Layer 2: Geophysical & Sensor Science

Recursive STA/LTA (Allen 1978). Trigger on threshold is 6.5x; trigger off is 2.0x. Automatically adapts to background noise fluctuations during Pacific wind storms so sensitivity remains optimal without false positives. Real-time Seismic Amplitude Measurement (RSAM) calculates 60-second RMS amplitude for tremor tracking.

■ Layer 3: Raw Mathematics & DSP Equations

Recursive exponential filters: $STA[n] = c_sta * CF[n] + (1 - c_sta) * STA[n-1]$, $LTA[n] = c_lta * CF[n] + (1 - c_lta) * LTA[n-1]$, where $c = 1 - \exp(-1 / (T * fs))$. Trigger ratio $R[n] = STA[n] / LTA[n] \geq 6.5$. $RSAM = \sqrt{(1/M) * \sum (x_i - \text{mean}(x))^2}$.

5. 3D Particle Motion Hodogram Orbit

■ Layer 1: The Layperson's Eye (What You Are Seeing)

Imagine watching a single grain of dirt under your house dancing in 3D space during an earthquake. The horizontal display shows whether the ground is shaking in a straight line or swirling. The tilt points straight toward the earthquake! The vertical display shows ground rolls (Rayleigh waves) doing backwards somersaults like ocean waves.

■ Layer 2: Geophysical & Sensor Science

Visualizes 3-component seismic polarization. Primary P-waves are longitudinal (parallel to wave travel). Shear S-waves are transverse (perpendicular). Rayleigh waves produce retrograde elliptical ground rolls in the vertical plane. Eigenvalue analysis of the covariance matrix yields the principal particle motion vector and back-azimuth.

■ Layer 3: Raw Mathematics & DSP Equations

Covariance Tensor $C = (1/N) * \sum (u_i - \text{mean}(u)) * (u_i - \text{mean}(u))^T$. Eigenvalues $\lambda_1 \geq \lambda_2 \geq \lambda_3$ yield Rectilinearity $L = 1 - (\lambda_2 + \lambda_3) / (2 * \lambda_1)$. Back-azimuth $\theta = \text{atan2}(v_E, v_N) \bmod 360 \text{ deg}$.

6. 700-Mile Regional Epicenter Radar & Isochrones

■ Layer 1: The Layperson's Eye (What You Are Seeing)

A tactical radar centered on the Berkeley Hills station with concentric rings at 50, 150, 400, and 700 miles. Major active faults (Hayward, San Andreas, Calaveras) are mapped. When the USGS reports a quake, expanding circular shockwave ripples race across the map toward your house with an exact countdown timer!

■ Layer 2: Geophysical & Sensor Science

Integrates real-time USGS GeoJSON telemetry. P-waves travel at ~6.0 km/s in crust; destructive S-waves travel at ~3.5 km/s. The speed disparity creates a warning lead time window before the destructive shear motion arrives.

■ Layer 3: Raw Mathematics & DSP Equations

Great-circle Haversine distance: $d = 2 * R * \arcsin(\sqrt{\sin^2(dLat/2) + \cos(Lat1) * \cos(Lat2) * \sin^2(dLon/2)})$. Warning lead time: $\Delta t = t_S - t_P = d * (1/V_S - 1/V_P) = d * (V_P - V_S) / (V_P * V_S) \sim d * 0.119 \text{ s/km}$ (e.g. 11.9s at 100 km).

7. 5-Band Urban & Environmental Profiler

■ Layer 1: The Layperson's Eye (What You Are Seeing)

The living heartbeat of the city across 5 channels: Cal Stadium (2-5 Hz fan stomping), Roadway Traffic (8-14 Hz semi-trucks on Hwy 24), Greek Theatre (25-45 Hz concert sub-bass), Human Activity (15-24 Hz footsteps and doors inside the house), and Wind (0.1-0.5 Hz redwood tree sway).

■ Layer 2: Geophysical & Sensor Science

Spectral energy binning across discrete cultural and mechanical resonance bands. Atmospheric sound waves couple into the porous ground surface. Wind pushes tree canopies, acting as mechanical levers transferring torque into the bedrock.

■ Layer 3: Raw Mathematics & DSP Equations

Band energy: $P_{\text{band}} = (1 / (K_2 - K_1 + 1)) * \sum_{k=K_1..K_2} |X[k]|^2$. Anomaly Ratio = $P_{\text{band}} / \text{Ambient}_{4\text{min}}$. Elevated status declared if Ratio ≥ 2.0 ; Anomalous if Ratio ≥ 4.0 .

8. Peterson Noise Model & Instrument Sensitivity

■ Layer 1: The Layperson's Eye (What You Are Seeing)

Compares your station's noise floor against the quietest and loudest places on planet Earth. The lower gray curve (NLNM) is an underground vault in a desert; the upper gray curve (NHNM) is an ocean coast next to a highway. Your station (cyan curve) sits in between—lower is quieter and more sensitive!

■ Layer 2: Geophysical & Sensor Science

Jon Peterson's 1993 USGS New Low Noise Model (NLNM) and New High Noise Model (NHNM). The prominent hump between 5-8 seconds period is the ocean microseismic peak, caused by oceanic storm waves colliding in the Pacific and vibrating the entire continent. High frequencies reflect sensor thermal noise floor.

■ Layer 3: Raw Mathematics & DSP Equations

Peterson piecewise polynomials: $\text{PSD}(T) = A_i + B_i * \log_{10}(T)$ in dB rel 1 (m/s²)²/Hz. Welch's Power Spectral Density: $P_{xx}(f) = (1 / (K * U * N)) * \sum |\sum x[n] * w[n] * \exp(-j * 2 * \pi * f * n)|^2$.

9. AI PhaseNet Neural Phase Probability & Wadati Distance

■ Layer 1: The Layperson's Eye (What You Are Seeing)

An AI neural network inspects incoming squiggles in real time and draws two probability curves: P(P) for P-waves and P(S) for S-waves. The time gap between the two peaks reveals the exact distance to the earthquake from a single station without needing triangulation!

■ Layer 2: Geophysical & Sensor Science

PhaseNet deep convolutional residual U-Net trained on millions of NCEDC waveforms. In 1933, Kiyoo Wadati proved that because $V_p/V_s \sim \sqrt{3}$ is constant in crust, $(t_S - t_P)$ is directly proportional to distance.

■ Layer 3: Raw Mathematics & DSP Equations

Wadati formula: $D = (V_p * V_s / (V_p - V_s)) * (t_S - t_P)$. For California crust ($V_p = 6.0$, $V_s = 3.46$ km/s), $D \sim 8.20 \text{ km} * \Delta t_{S-P} \sim 5.10 \text{ miles} * \Delta t_{S-P}$.

10. Real-Time Magnitude Estimation (M_pd, Tau_c)

■ Layer 1: The Layperson's Eye (What You Are Seeing)

How can we measure earthquake magnitude in the first 3 seconds before the big waves arrive? Small quakes are like high-pitched violin strings; giant quakes are like deep bass drums. By measuring the initial pitch (Tau_c) and height (Pd) of the first P-wave, the engine estimates magnitude instantly!

■ Layer 2: Geophysical & Sensor Science

Pioneered by Kanamori (Caltech) and Allen (UC Berkeley). Characteristic rupture dimension scales with fault length. Tau_c is a frequency parameter independent of distance and attenuation. Pd measures peak initial displacement.

■ Layer 3: Raw Mathematics & DSP Equations

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Tau_c = 2*pi * sqrt( Integral d(t)^2 dt / Integral v(t)^2 dt ). Empirical magnitude: M_tau_c =  
4.0 * log10(Tau_c) + 5.5. Displacement magnitude: M_Pd = 1.05 * log10(Pd) + 1.25 * log10(D) +  
5.22.
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