OPTIMIZATION OF ANALYSIS OF AMBIENT NOISE INSTANTANEOUS POLARIZATION FOR SITE RESPONSE INVESTIGATION

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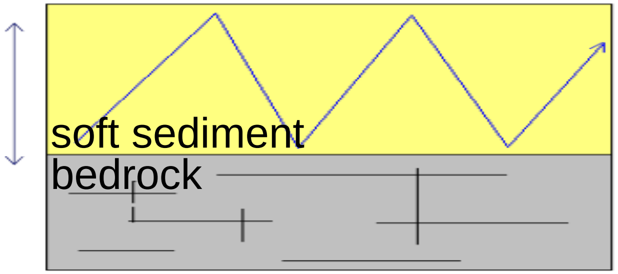
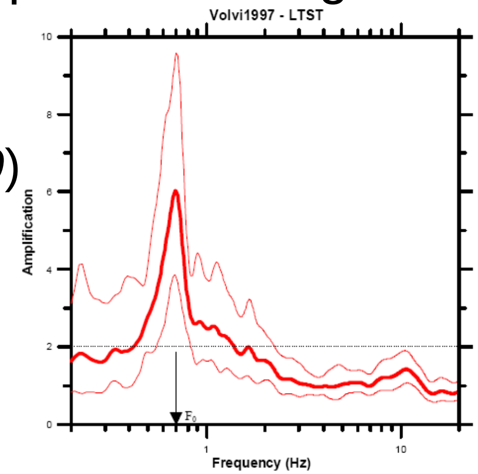
INTRODUCTION

Ambient noise analysis for site response investigation

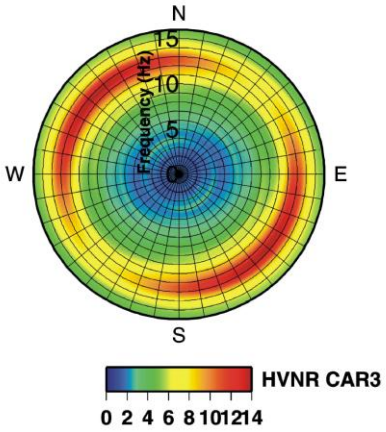
Nakamura (HVNR) outcomes:

- Resonance frequency (*Bard, 1999*)

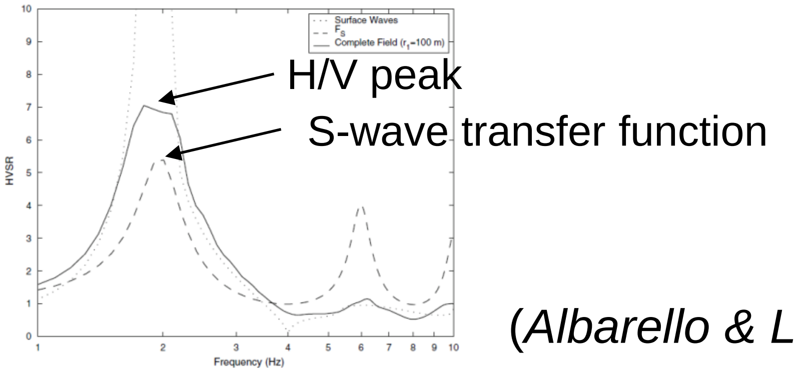




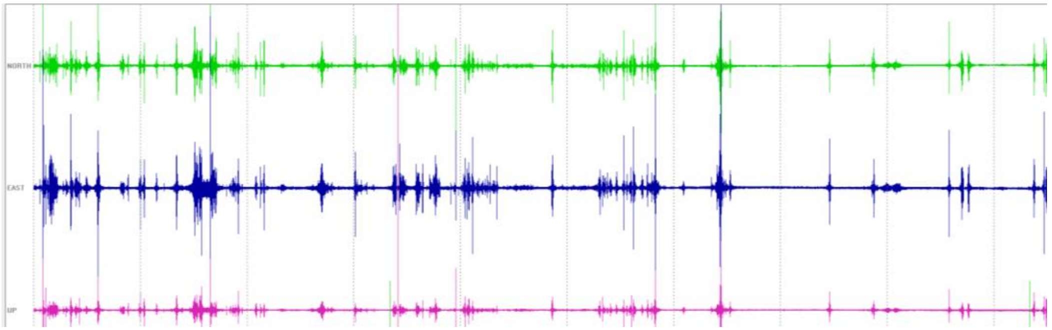
- Site response directivity properties (*Del Gaudio et al., 2008*)



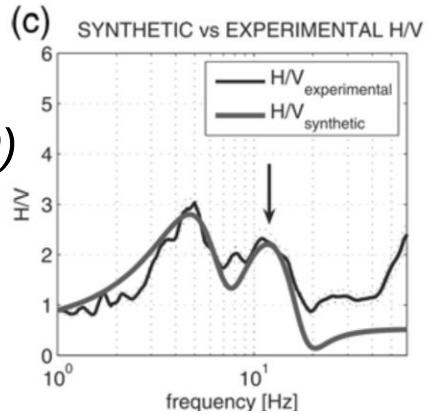
- Amplification factor ?

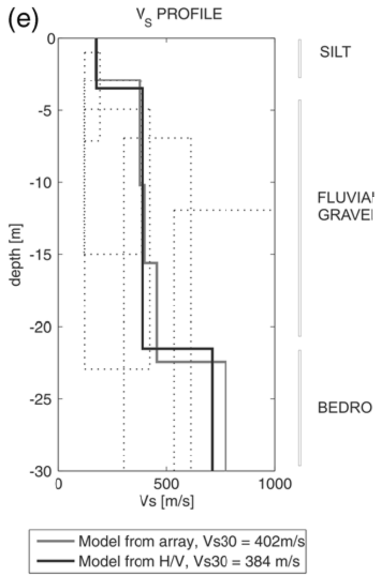


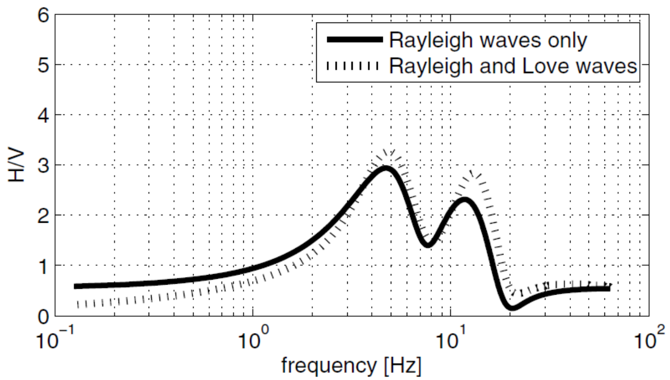
(*Albarello & Lunedei, 2009*)



- Velocity modelling (*Castellaro & Mulargia, 2009*)





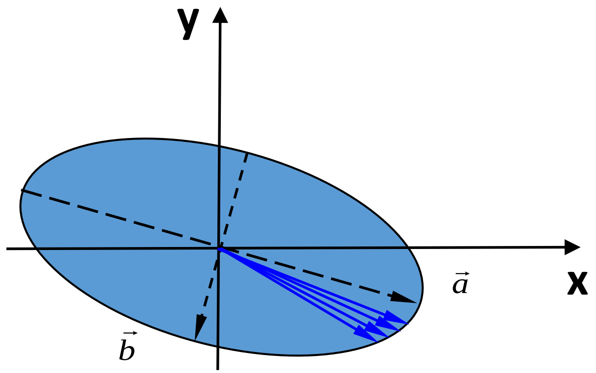


INSTANTANEOUS POLARIZATION ANALYSIS: METHODOLOGY

Analytic transformation

$$u_c(t) = u(t) + j\hat{u}(t) = A(t)e^{j\Phi(t)}$$

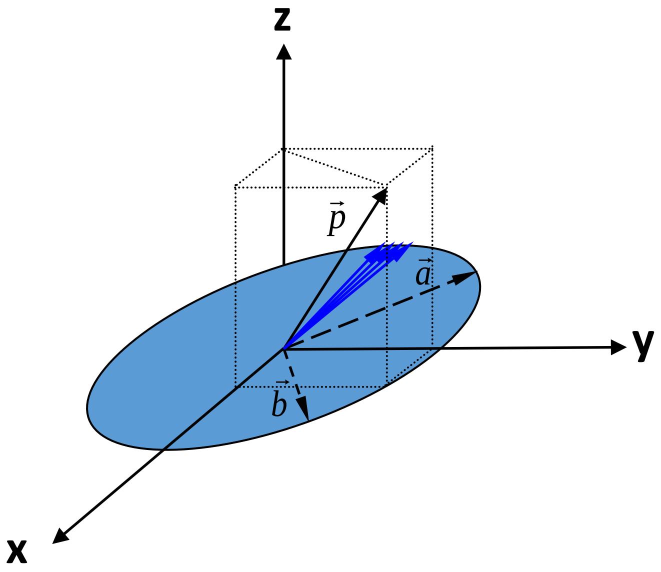
$\hat{u}(t)$ = Hilbert transform of *u(t)*. j = imaginary unit



Elliptical trajectory semi-axes

$$\vec{a}(t) = \mathrm{Re}\left[e^{-j\Phi_o} \cdot \vec{u}_c(t)\right] \qquad \vec{b}(t) = \mathrm{Re}\left[e^{-j\left(\Phi_o + \frac{\pi}{2}\right)} \cdot \vec{u}_c(t)\right]$$

where $\Phi_o = \frac{1}{2}\arg\left[\frac{1}{2}\sum_k (u_k + j\hat{u}_k)^2\right]$ (*Morozov and Smithson, 1996*)



Planarity vector $\vec{p} = \vec{a} \times \vec{b}$

Rectilinearity

(*Schimmel & Gallart, 2003, 2004*)

$$rl = 1 - \frac{|\vec{b}(t)|}{|\vec{a}(t)|}$$

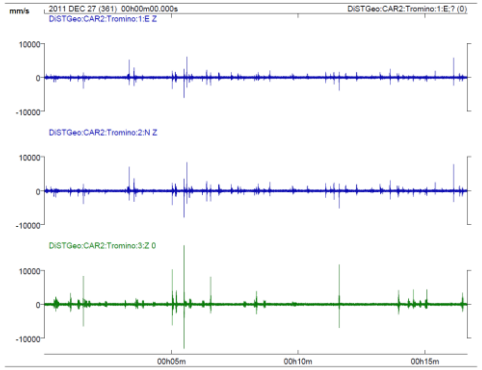
= 0 (circular)

= 1 (linear)

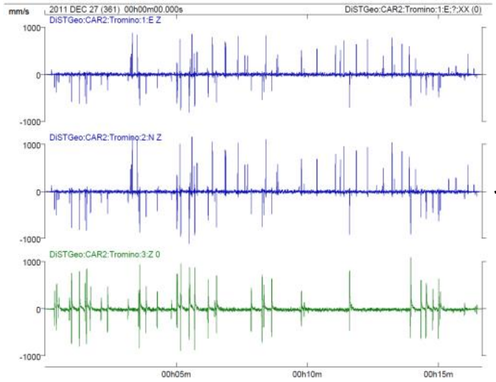
INSTANTANEOUS POLARIZATION ANALYSIS: METHODOLOGY

narrow-band filtering

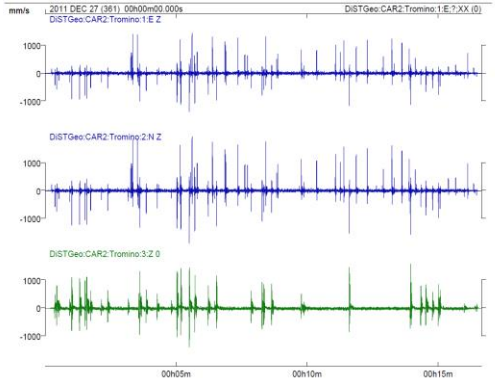
3-component noise recording $\times\, G(\nu) = e^{-\frac{(\nu-\nu_c)^2}{2\beta^2}}$



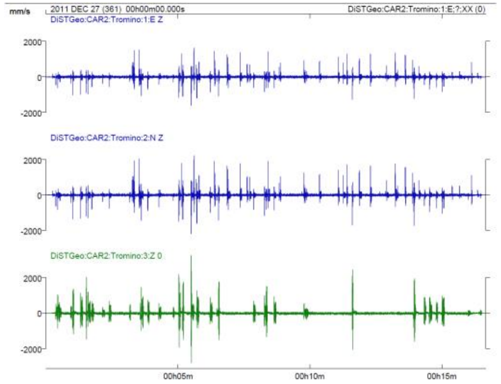
$\nu_c = 0.5$ Hz



$\nu_c = 1.0$ Hz



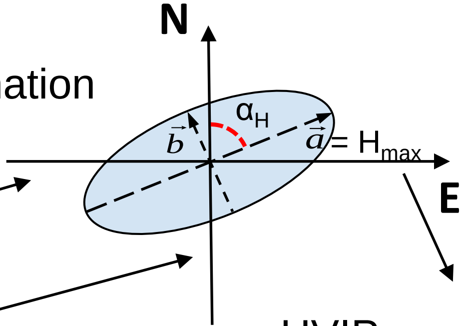
$\nu_c = 1.5$ Hz

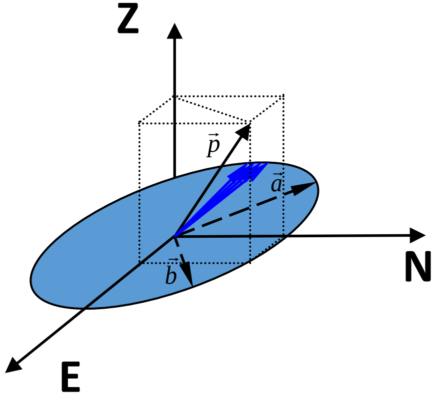


etc.

...

Analytic transformation





$A_Z = V$

$$\text{HVIP} = \frac{H_{max}}{V}$$

$\theta_{\vec{p}}, \theta_{\vec{a}}, \theta_{\vec{b}}$ = inclination of $\vec{p}, \vec{a}, \vec{b}$

Coherent wave packet identification

Minimum number $nmin$ of consecutive samples having

Rayleigh-type

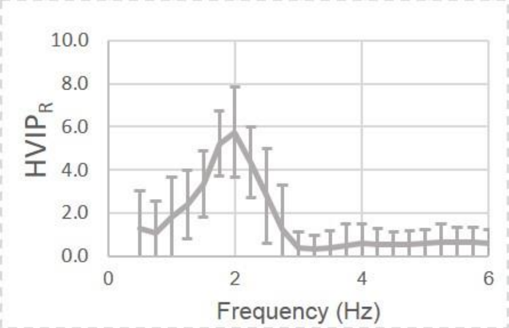
$$\theta_{\vec{p}} < t_p \;\; AND \;\; \left[\begin{array}{c} \left(\theta_{\vec{a}} < t_a \;\; AND \;\; \theta_{\vec{b}} > 90° - t_a\right) \\ OR \\ \left(\theta_{\vec{b}} < t_a \;\; AND \;\; \theta_{\vec{a}} > 90° - t_a\right) \end{array} \right]$$

t_p , t_a = prefixed thresholds

Love-type

$$\theta_{\vec{a}} < t_L \;\; AND \;\; rl > t_{rl}$$

t_L, t_{rl} = prefixed thresholds



TESTS: SYNTHETIC SIGNAL GENERATION

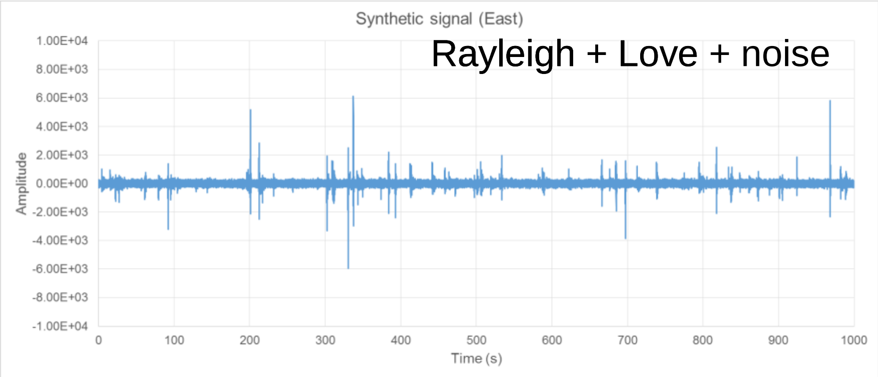
1000 s recording simulation (coherent waves+noise)

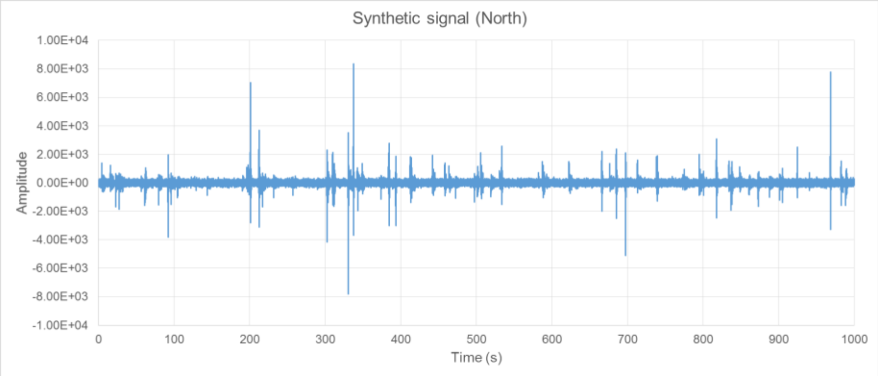
Coherent wave sources

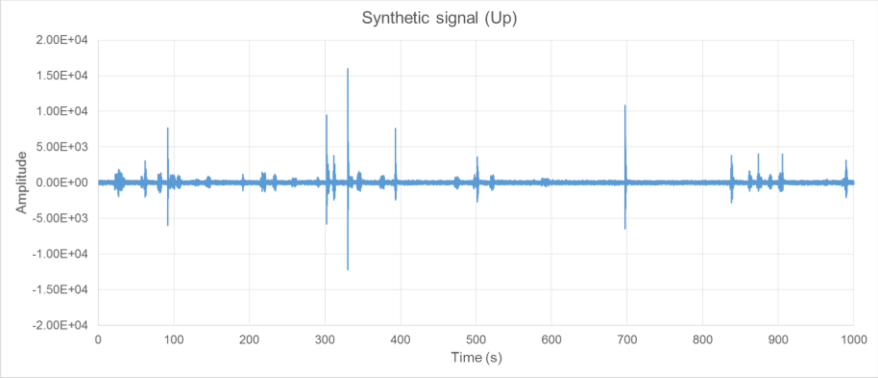
Spectrum 0 – 50 Hz (0.001 Hz step)

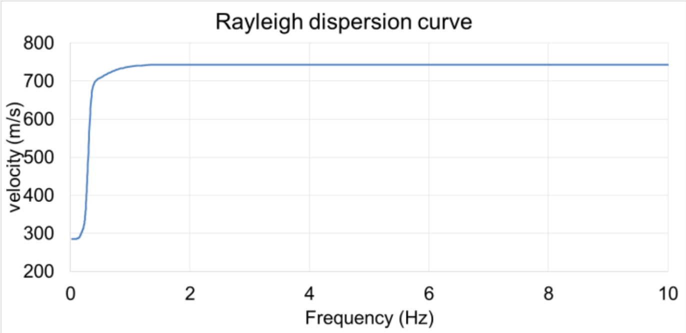
Rayleigh wave sources

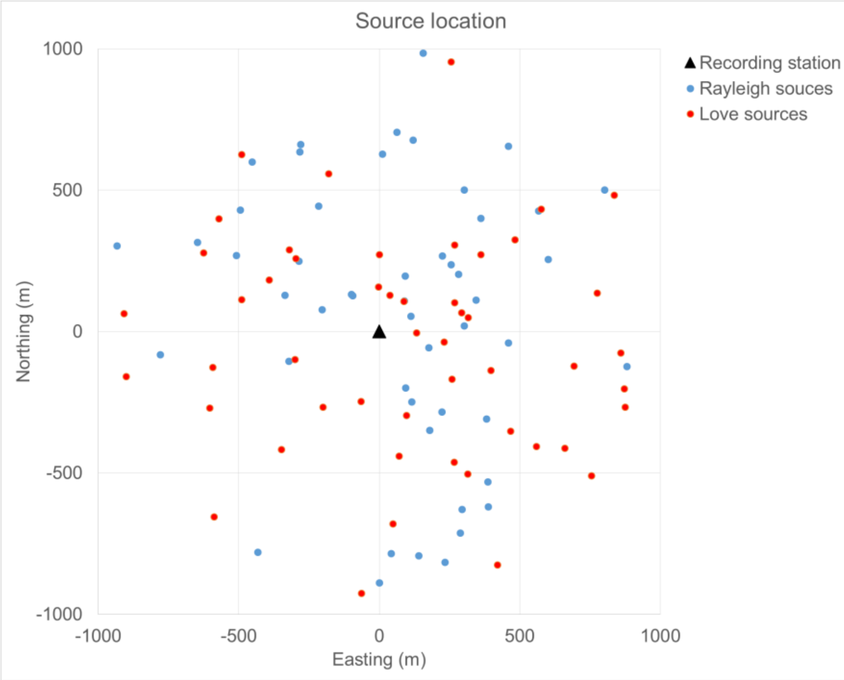
Love wave sources

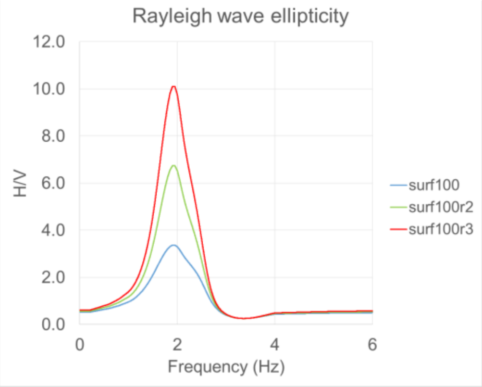


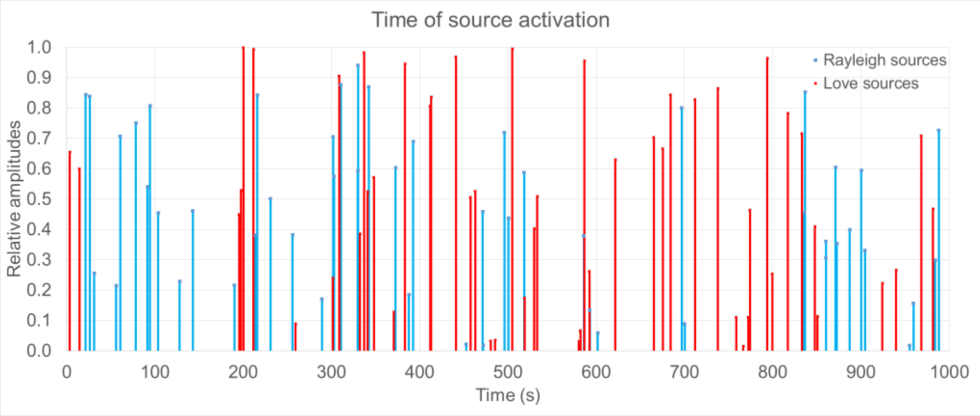








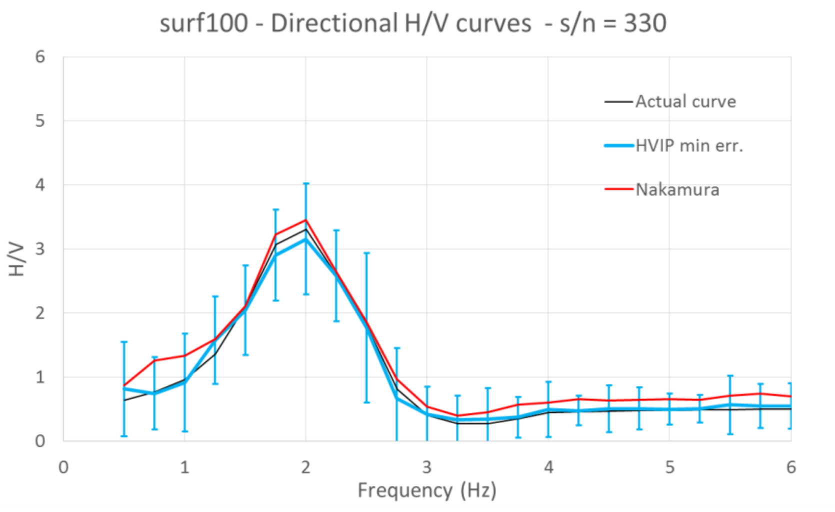




TEST RESULTS

Polarized signals (azimuth = 37°) surf100

β = 0.2 - t_p = 10° - t_{rl} = 0.80 - *nmin* = 20



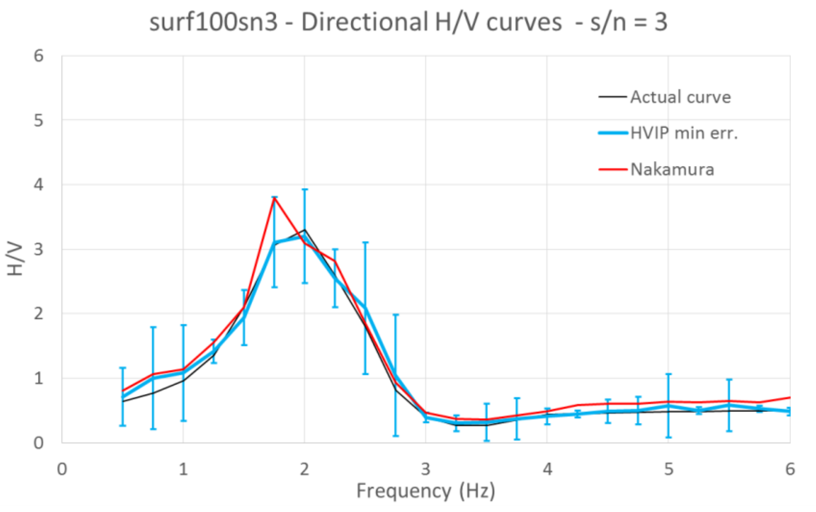
fmax = 2.00 Hz

error rms = 0.090 H/V peak error = 4%

Rayleigh-type samples at fmax = 12.7 %
Mean of Rayleigh-type samples = 10.7 %

Azimuth mode at fmax = 30°- 40° (86.2%)

β = 0.2 - t_p = 5° - t_{rl} = 0.80 - *nmin* = 15



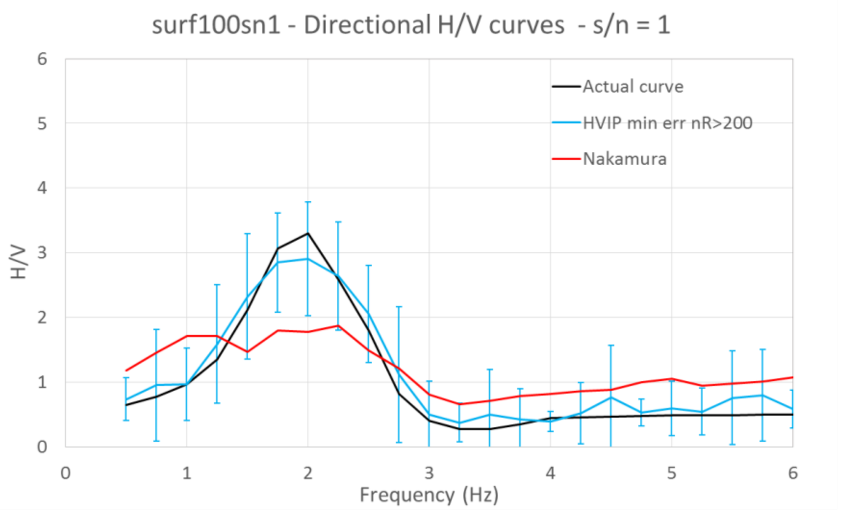
fmax = 2.00 Hz

error rms = 0.110 H/V peak error = 3%

Rayleigh-type samples at fmax = 1.5 %
Mean of Rayleigh-type samples = 2.3 %

Azimuth mode at fmax = 30°- 40° (66.2%)

β = 0.2 - t_p = 10° - t_{rl} = 0.80 - *nmin* = 20



fmax = 2.00 Hz

error rms = 0.193 H/V peak error = 12%

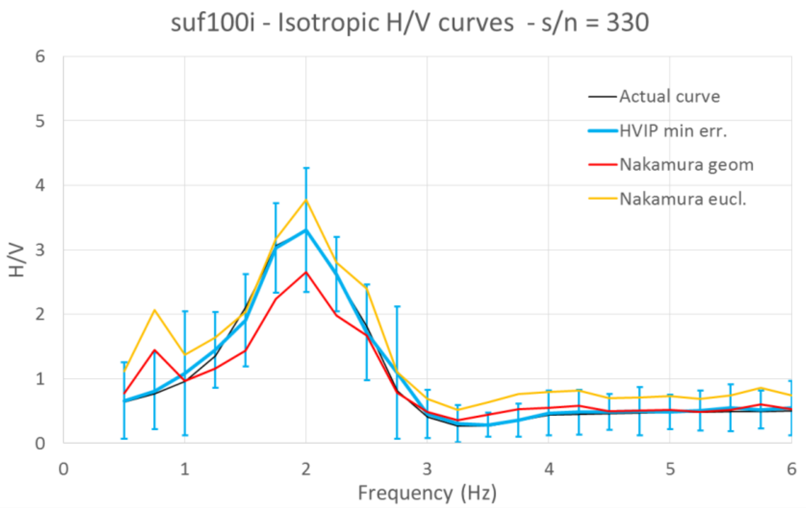
Rayleigh-type samples at fmax = 0.8 %
Mean of Rayleigh-type samples = 1.1 %

Azimuth mode at fmax = 30°- 40° (25.6%)

TEST RESULTS

Isotropic signals surf100

$\beta = 0.1$ - $t_p = 5°$ - $t_{rl} = 0.80$ - $nmin = 20$

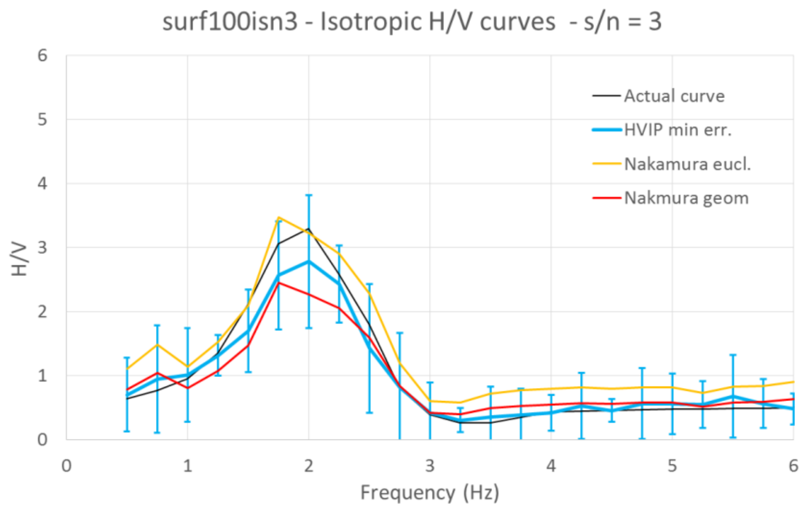


fmax = 2.00 Hz

error rms = 0.086   H/V peak error = 0%

Rayleigh-type samples at fmax = 9.6 %
Mean of Rayleigh-type samples = 14.0 %

$\beta = 0.2$ - $t_p = 5°$ - $t_{rl} = 0.80$ - $nmin = 20$

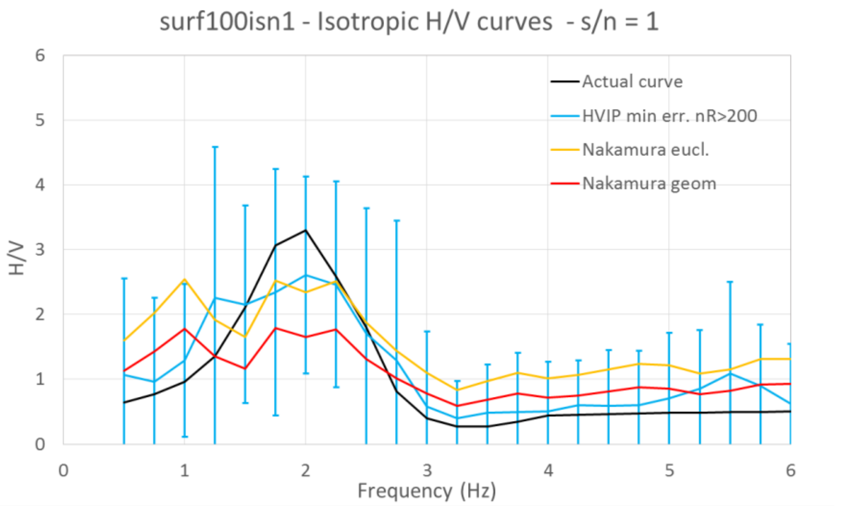


fmax = 2.00 Hz

error rms = 0.205   H/V peak error = 16%

Rayleigh-type samples at fmax = 1.6 %
Mean of Rayleigh-type samples = 3.5 %

$\beta = 0.4$ - $t_p = 5°$ - $t_{rl} = 0.90$ - $nmin = 15$



fmax = 2.00 Hz

error rms = 0.379   H/V peak error = 21%

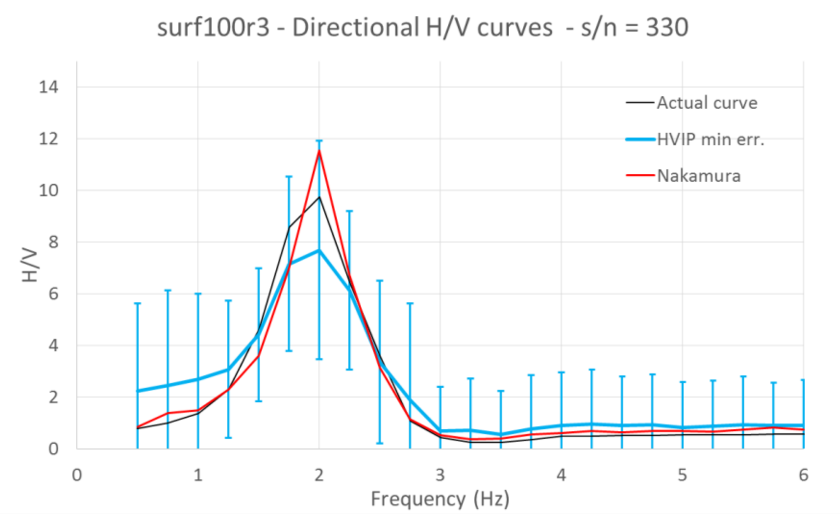
Rayleigh-type samples at fmax = 0.5 %
Mean of Rayleigh-type samples = 1.4 %

TEST RESULTS

34° CONVEGNO TRIESTE 17/19-11-2015

Polarized signals (azimuth = 37°) – surf100r3

β = 0.2 - t_p = 10° - t_{rl} = 0.95 – *nmin* = 20



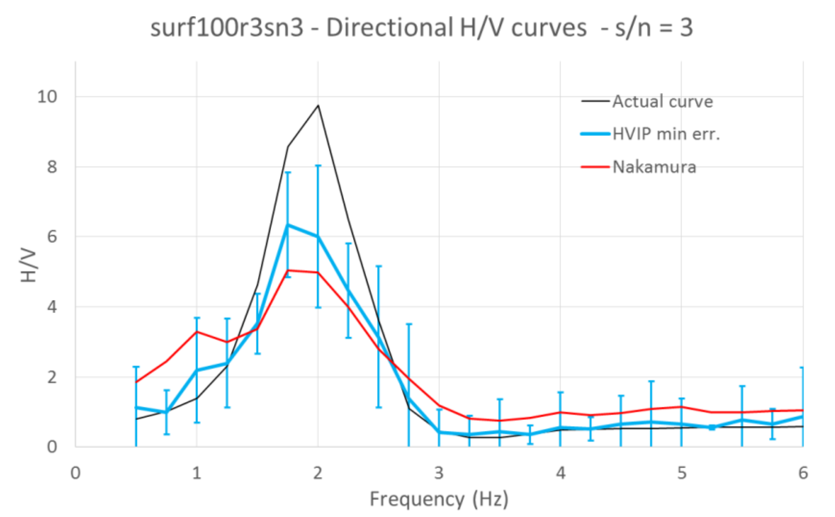
fmax = 2.00 Hz

error rms = 0.819 H/V peak error = 21%

Rayleigh-type samples at fmax = 12.4 %
Mean of Rayleigh-type samples = 14.3 %

Azimuth mode at fmax = 30°- 40° (73.5%)

β = 0.3 - t_p = 5° - t_{rl} = 0.90 – *nmin* = 15



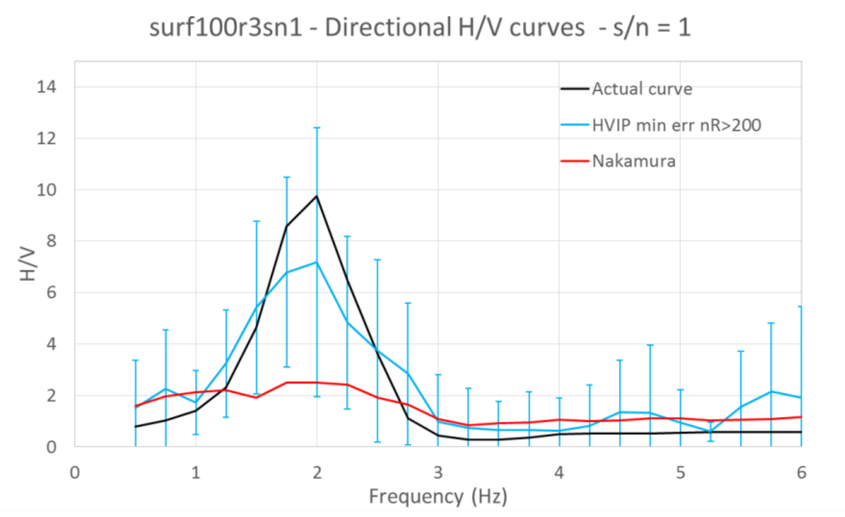
fmax = 1.75 Hz

error rms = 1.053 H/V peak error = 38%

Rayleigh-type samples at fmax = 0.8 %
Mean of Rayleigh-type samples = 1.9 %

Azimuth mode at fmax = 30°- 40° (58.8%)

β = 0.3 - t_p = 10° - t_{rl} = 0.95 – *nmin* = 20



fmax = 2.00 Hz

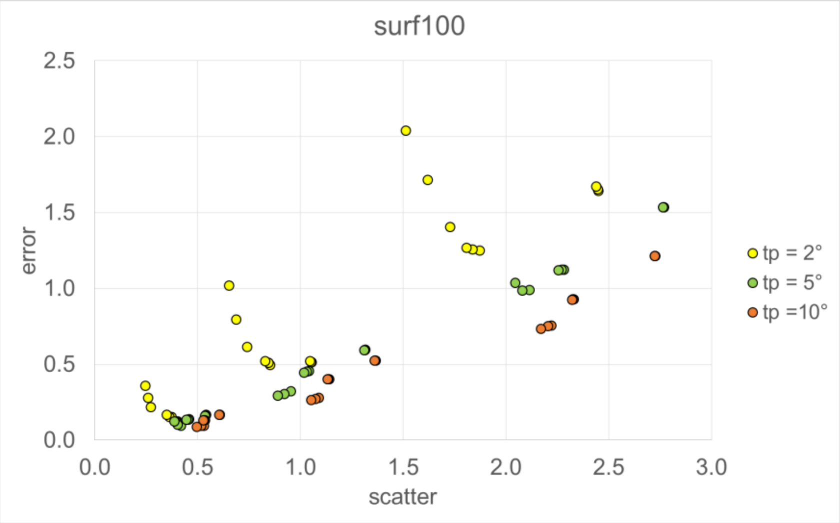
error rms = 1.079 H/V peak error = 26%

Rayleigh-type samples at fmax = 0.8 %
Mean of Rayleigh-type samples = 1.3 %

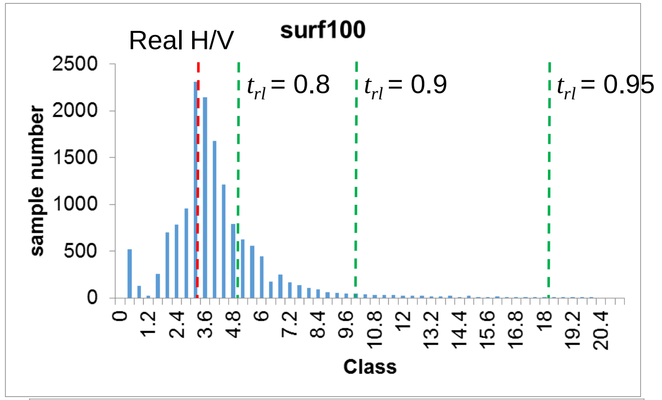
Azimuth mode at fmax = 30°- 40° (26.3%)

PROBLEMS

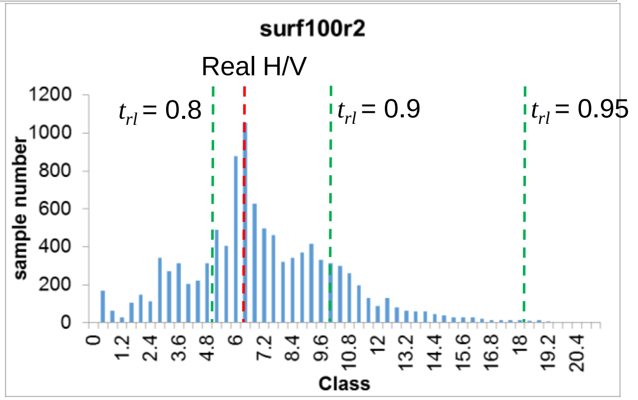
Angular thresholds



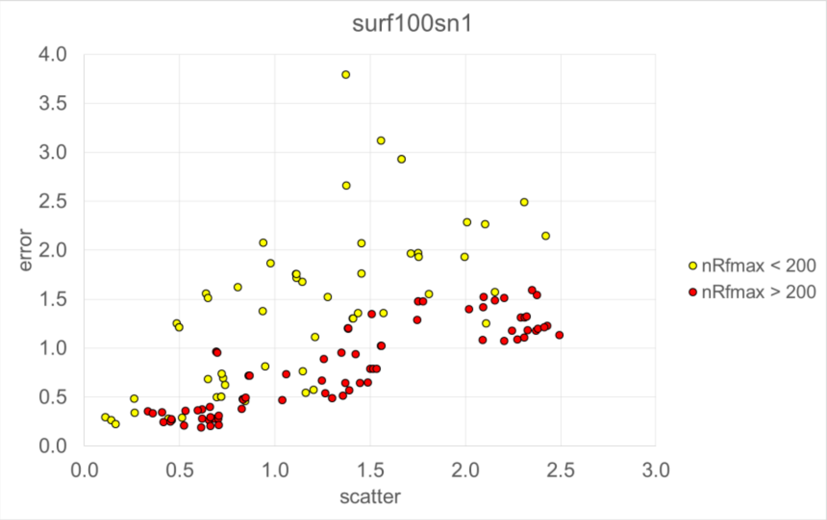
Correlation accuracy-precision

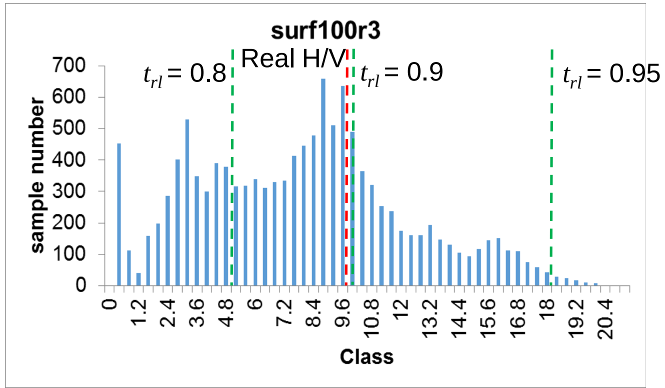


Rectilinearity threshold (to separate Rayleigh from Love)



Number of classified samples





CONCLUSIONS

- Tests on synthetic signals simulating ambient noise demonstrate that instantaneous polarization analysis is very effective in recognizing resonance frequency and orientation (in case of site response directivity).

- Best estimates of Rayleigh wave ellipticity are more accurate than those provided by HVNR, but errors tends to increase as signal/noise ratio decrease and H/V peak values increase.

- The most critical aspect in method implementation is an optimal choice of analysis parameters to have a good correlation between accuracy and precision, so that the parameter selection can be guided by the analysis of the scatter of instantaneous H/V values around the average.

- Analysis parameters should be defined through preliminary trials aimed at obtaining a minimum scatter of instantaneous H/V values within a sufficiently high number of samples classified as of Rayleigh type.