Automatic Seizure Detection

Presentation for the Institute of Neurology, UCL

05-FEB-15

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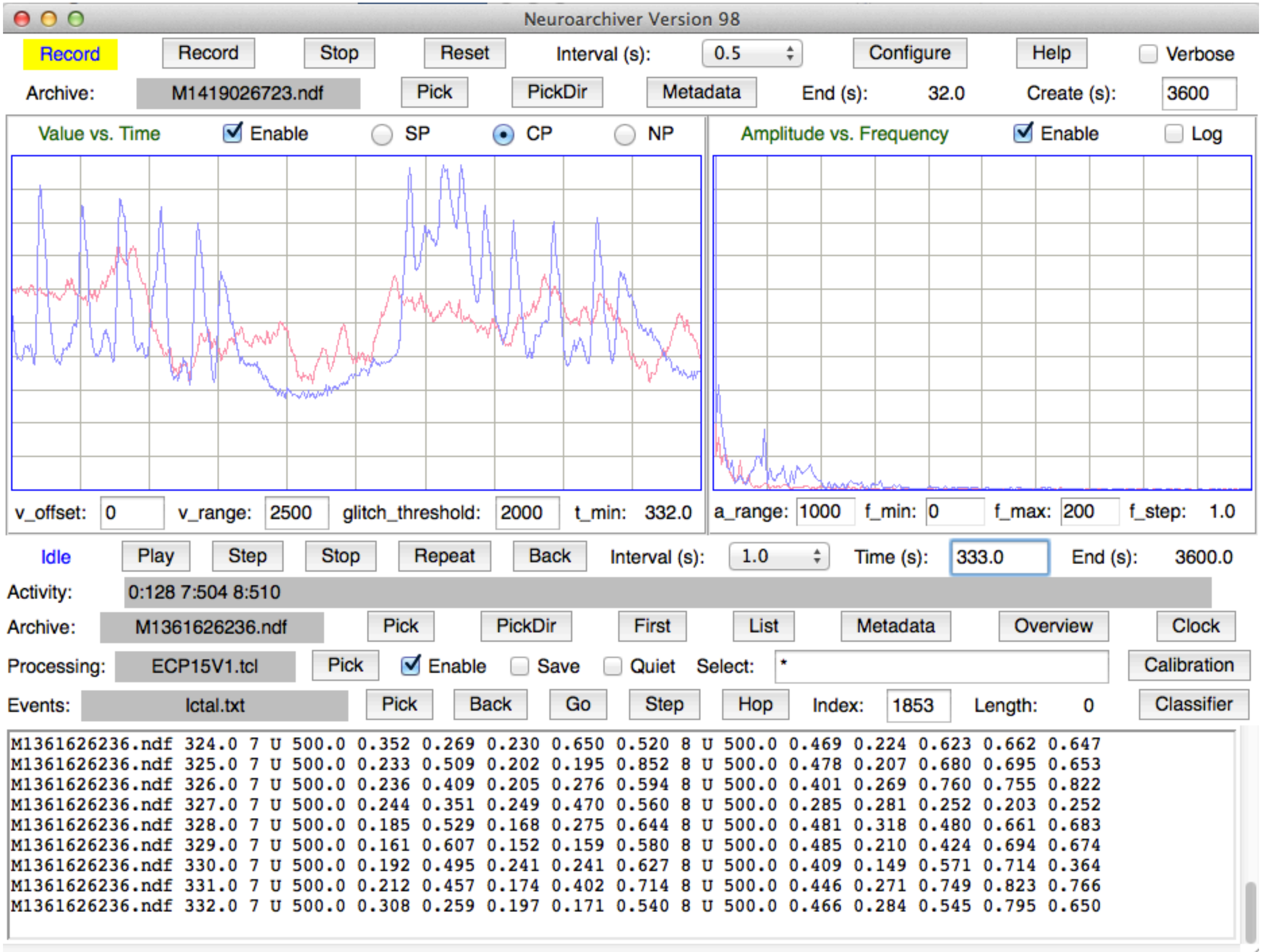
Components

- **NDF Recordings**, from SCTs or imported form another source.
- **LWDAQ Software**, program for Windows, MacOS, or Linux (Version 8.2.10).
- **Neuroarchiver Tool**, program provided by LWDAQ Software (Version 98).
- **Processor Script**, program executed by the Neuroarchiver (Version ECP15V3).
- **Event Classifier**, program provided by the Neuroarchiver (Version 98).
- **Event Library**, example intervals classified by human eye.
- **Characteristics Files**, summary information for each interval.
- **Batch Classifier**, provided by the Event Classifier (Version 98).
- **Classification List**, list of intervals classified as a particular type.

Neuroarchiver 98



Glitch Removal

- Glitches are bad or corrupted messages.
- With latest hardware, glitches occur <1/min/ch.
- Set the *glitch threshold* in the Neuroarchiver.
- Disable glitch filter with threshold 0, the default.
- Signal range is 0 to 65535 (unsigned sixteen-bit sample).
- A sample-to-sample jump greater than the threshold is a glitch
- Glitches removed and replaced by previous sample value.
- Choose threshold to remove jumps larger than physically possible.
- Use 2000 for skull screws on rats.
- Use 4000 for dentate gyrus electrodes in rats.
- Use 500 for skull screws on mice.
- Set it too low: some seizure spikes will be removed.
- Set it too high: glitches may confuse event detection.

Playback Settings

Voltage vs Time: three types of scaling:

- Simple (SP): bottom = offset, top = offset+range.
- Centered (CP): bottom = average-range/2, top = average-range/2.
- Normalized (NP): bottom = minimum, top = maximum (NP).

Playback Interval: should suit the patterns we wish to find:

- Patterns should dominate one interval (upper bound on length).
- Patterns should be established in one interval (lower bound on length).
- Use 1-s for tetanus toxin model in rats (ION).
- Use 1-s for pentylenetetrazol model in mice (Oxon).
- Use 8-s to detect delta waves in mice (Oxon).
- Use 1-s for perforant pathway stimulus model in rats (Philipps).

<u>Metrics</u>

A *metric* is a real-valued characteristic of the interval, bounded 0 to 1.

Our metrics: power, coastline, intermittency, spikiness, asymmetry, periodicity.

With *N* metrics, each interval is a point in the *N*-dimensional unit cube.

With *adequate representation*, intervals are similar if and only if they are close.

Events of a particular type occupy a connected region of the cube.

With adequate representation, different event regions do not overlap.

The *event library* is a list of events classified by human eye.

The event library represents the event regions with points within those regions.

Eg: *baseline* region defined by example baseline patterns.

Eg: *ictal* region defined by example seizure and inter-ictal patterns.

The Curse of Dimensionality

Suppose we have only one metric, $N = 1$.

We find we need $Q = 4$ library events to define baseline and ictal regions.

But find this representation is not adequate, add a metric, now $N = 2$.

We find we need $Q = 16$ library events to define baseline and ictal regions.

But find this representation still not adequate, add a metric, now $N = 3$.

We find we need $Q = 64$ library events to define baseline and ictal regions.

In general, we may need $Q = 4^N$ library events.

For six metrics, $Q = 4096$.

If event regions are small, may need far fewer.

Experience: with six metrics, ION used hundreds of library events.

Power Metric

We begin with a measure of the signal size, which we call *power*.

Possible measures: mean absolute deviation, standard deviation, range.

We choose standard deviation for the emphasis it gives to large excursions.

We specify a *baseline power* for the signal.

We divide the standard deviation by the baseline power.

The result is a dimensionless, calibrated measure of power.

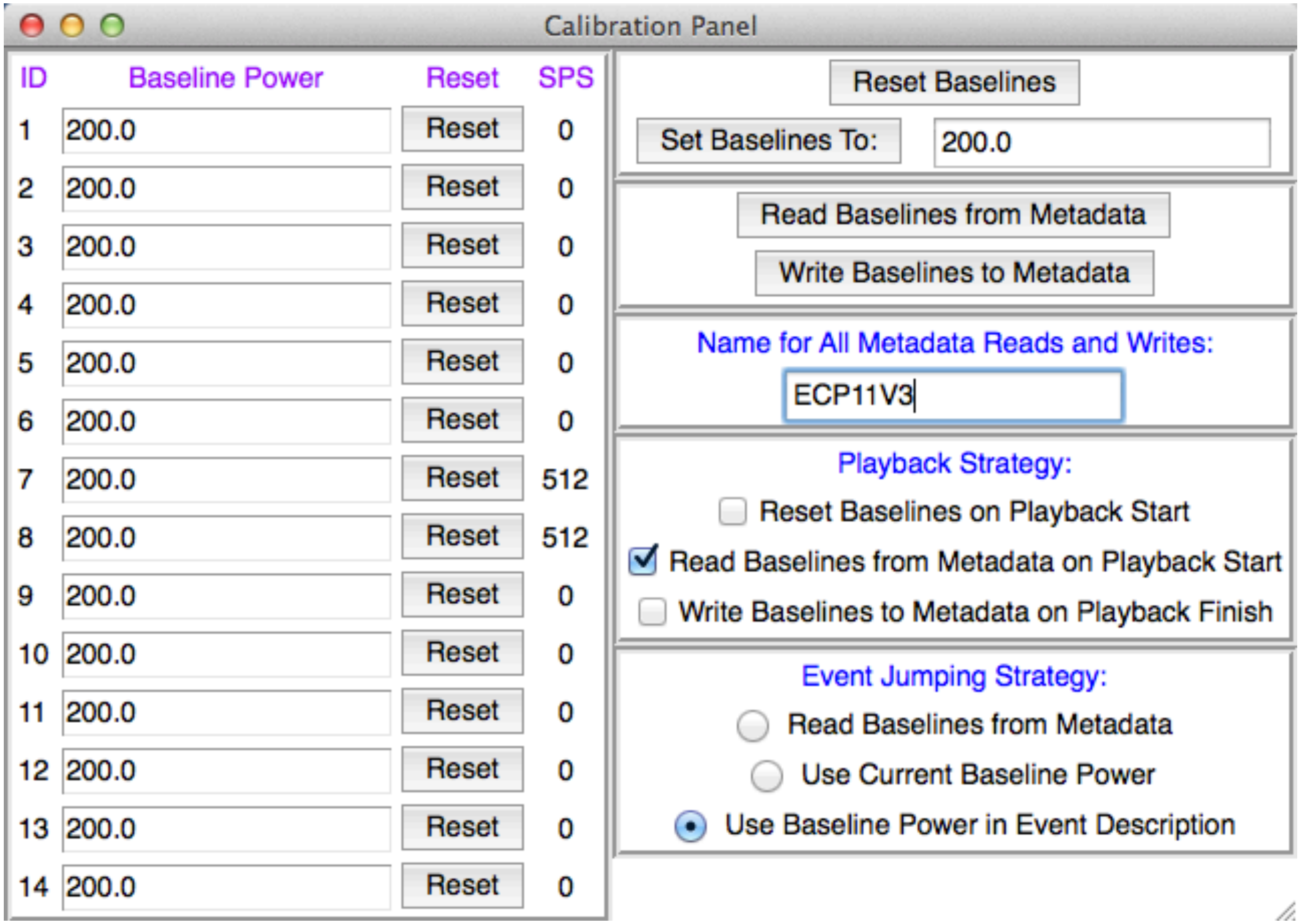
For A3028D, skull screws, rat: baseline = 200 counts = 80 μV rms.

For A3028R, dentate gyrus electrodes, rat: baseline = 500 counts = 200 μV rms.

power_metric = 1 / (1 + (baseline / stdev)), a sigmoidal function of power measure.

power_metric = 0.5 when stdev = baseline.

Calibration



Normalized Metrics

Coastline: the sum of the absolute steps between samples, divided by the mean absolute deviation of the interval, and passed through a sigmoidal function.

Intermittency: the fraction of coastline generated by the 10% largest steps, and passed through a sigmoidal function.

Spikiness: the average separation of medium, and large peaks and valleys, divided by the signal range, and passed through a sigmoidal function.

Asymmetry: the ratio (max-ave)/(ave-min) passed through a sigmoidal function.

Periodicity: the regularity of large peaks and valleys, and passed through a sigmoidal function.

Normalized Metrics: amplify or attenuate the signal, metric remains unchanged.

These Five Metrics: are all normalized.

Processor ECP15

ECP15 is the Event Classification Processor Version 15.

Executed by Neuroarchiver for each channel in each interval.

View and edit with a text editor.

Calls LWDAQ's run-time library to calculate metrics.

Provides a frequency measure also, divide by interval length to get Hertz.

We can omit asymmetry, periodicity, and frequency from characteristics line.

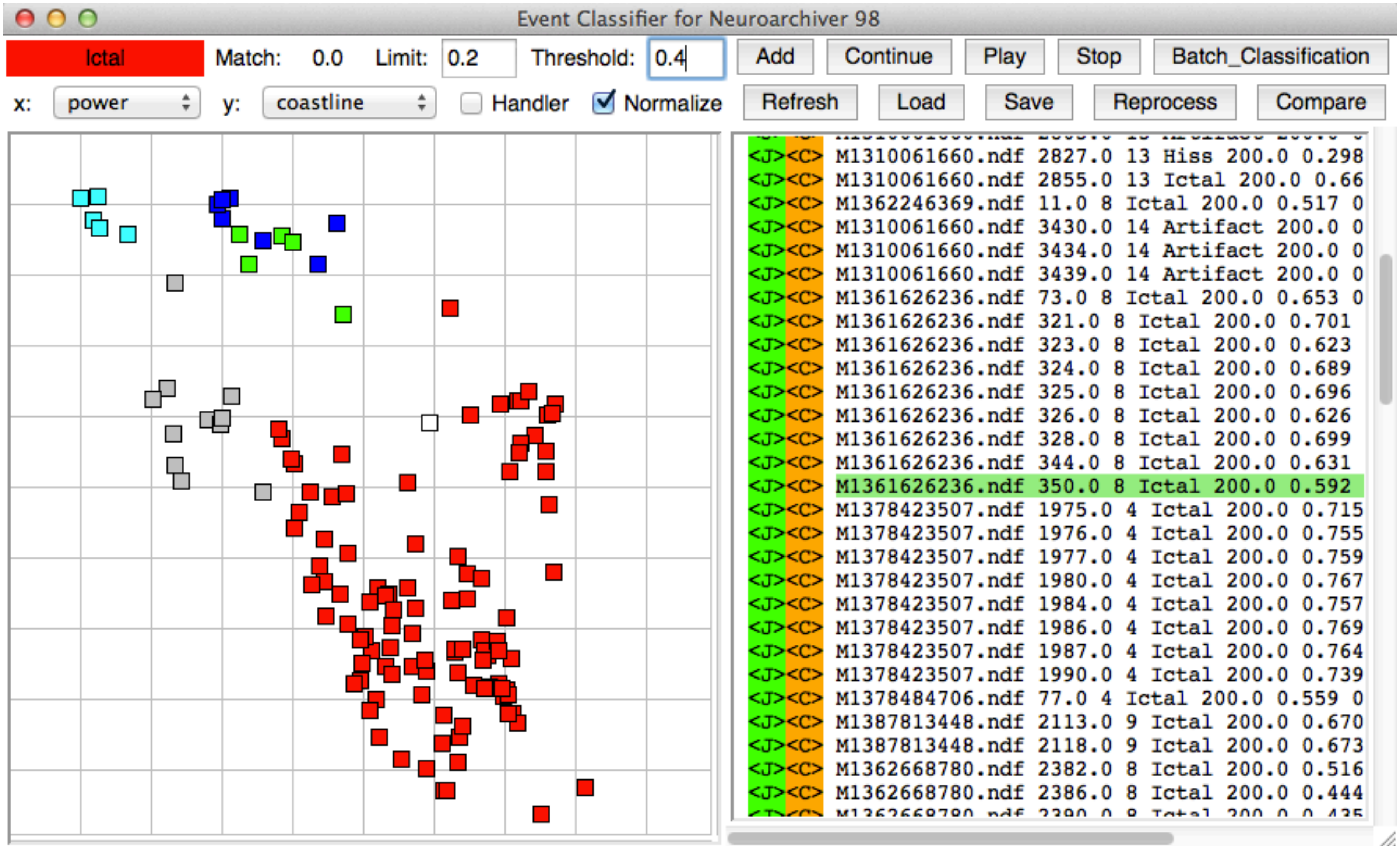
```
set include_asymmetry 0
set include_periodicity 0
set include_frequency 0
```

Turn on and off diagnostic display with configuration variables.

```
set show_intermittency 0
set show_spikiness 0
set show_periodicity 0
set show_frequency 0
set metric_diagnostics 0
```

Uses baseline powers defined in the Calibration Panel.

Event Classifier



Threshold: minimum power for classification, **Limit:** beyond this distance, an event is *Unknown*, **Normalize:** don't use power metric to classify.

Coastline vs Intermittency

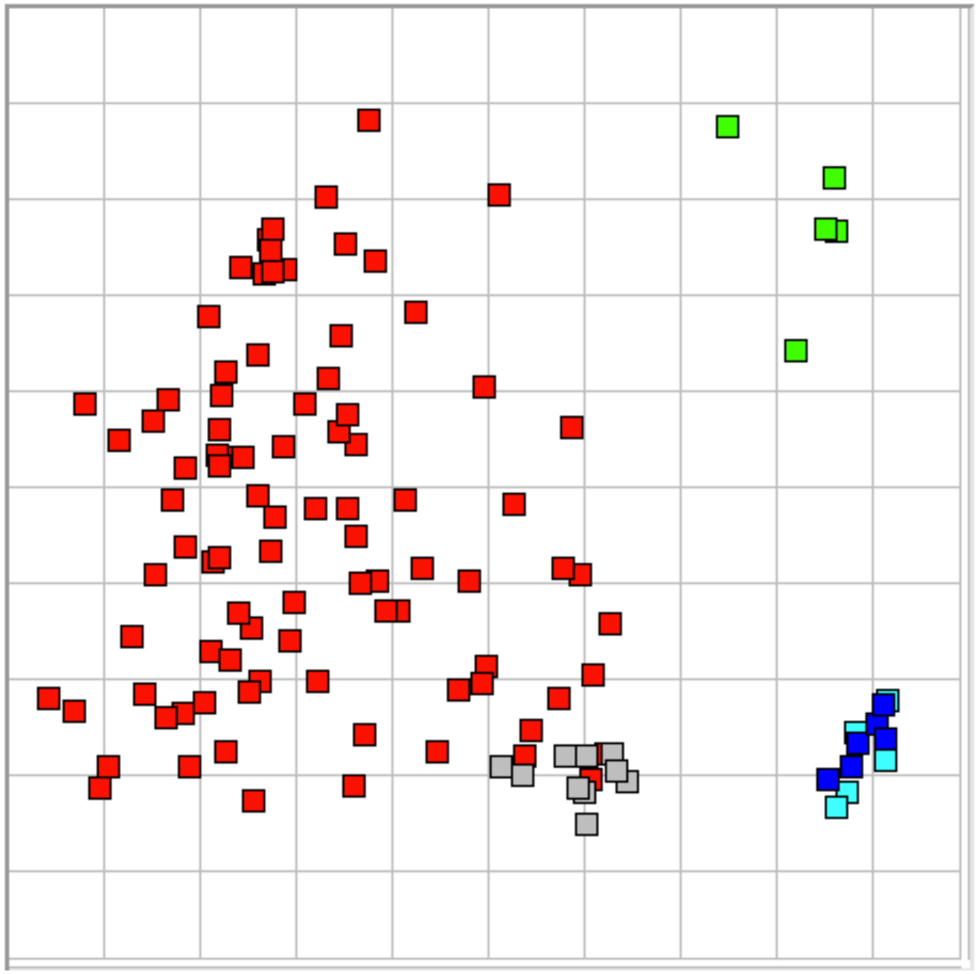


Figure: Coastline (horizontal) versus Intermittency (vertical) in the Event Map.

High Coastline and Low Intermittency

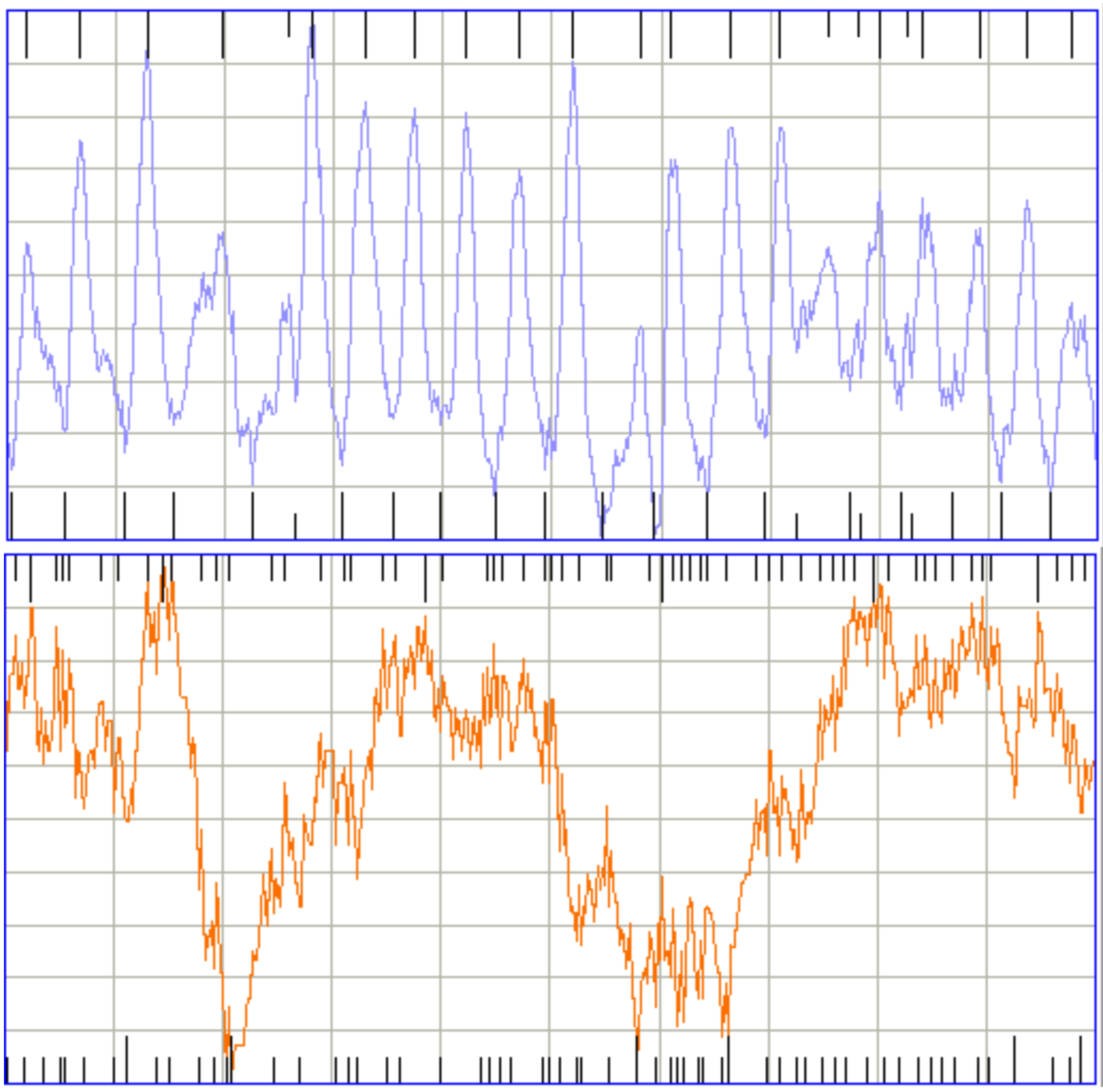
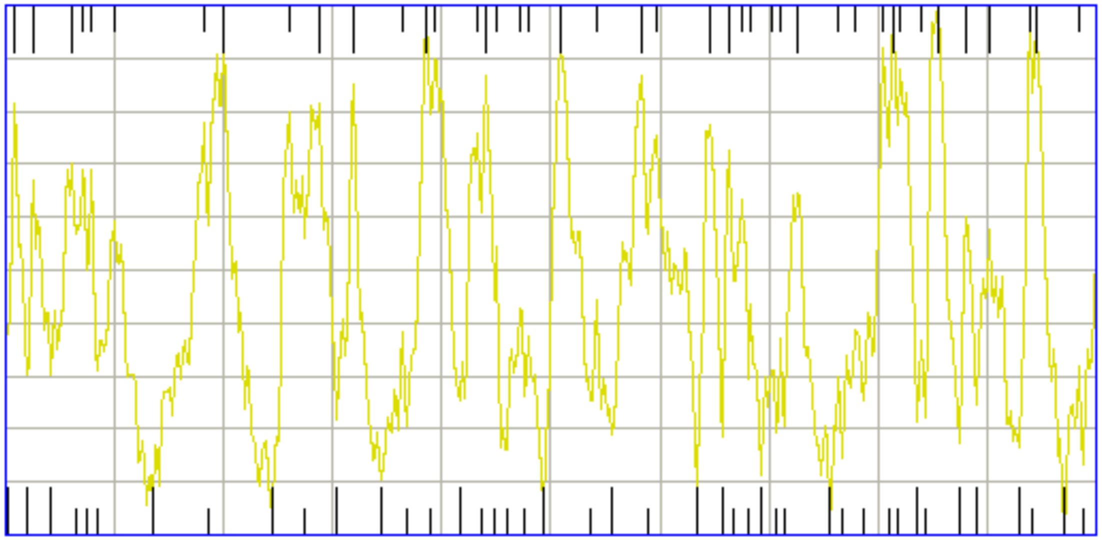


Figure: Overlapping Ictal (top) and Baseline (bottom) Intervals from the Coastline and Intermittency Maps. Black vertical lines mark the locations of peaks and valleys used for the spikiness calculation. Both intervals have high coastline and low intermittency.

<u>More of High Coastline and Low Intermittency</u>

An Ictal Interval with High Coastline and Low Intermittency (Normalized Display).

Note the sharp spikes with rough sides and no obvious period.



We cannot use asymmetry or periodicity to distinguish this interval from baseline.

Coastline vs Spikiness

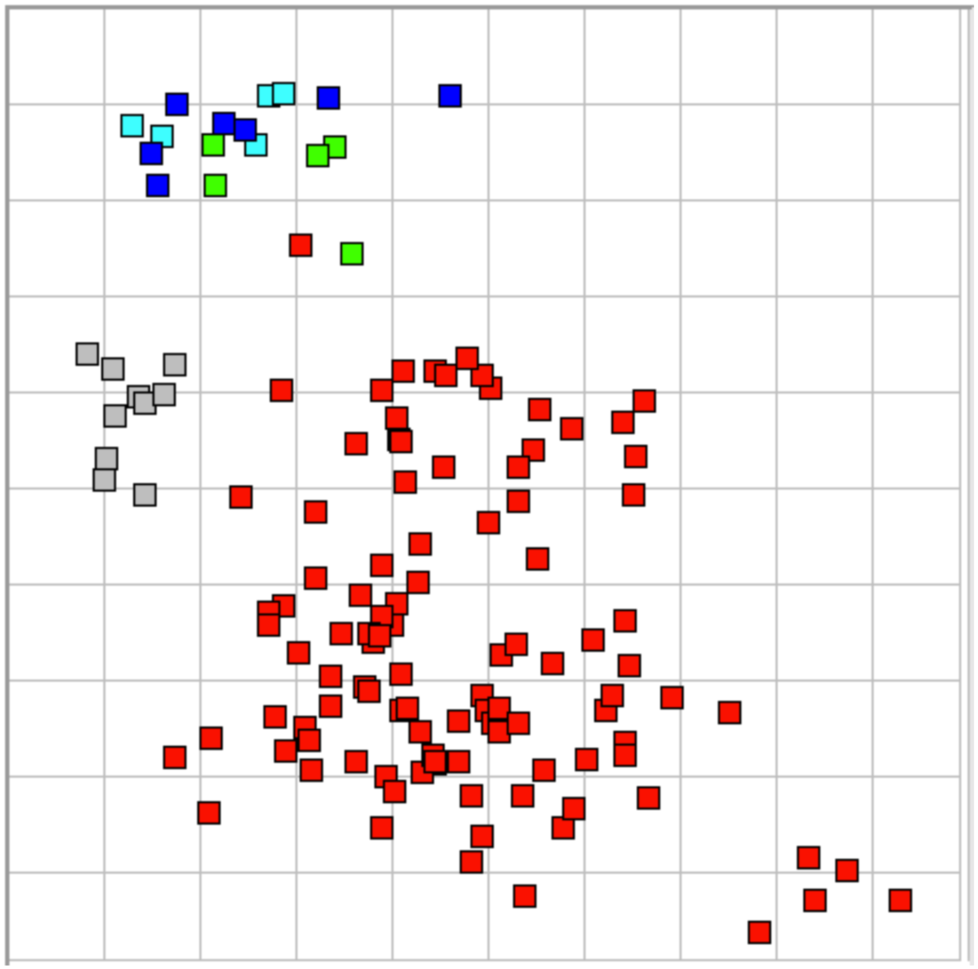


Figure: Spikiness (horizontal) versus Coastline (vertical). Spikiness is the average separation of peaks and valleys that have height 10% or more of the signal range.

Asymmetry

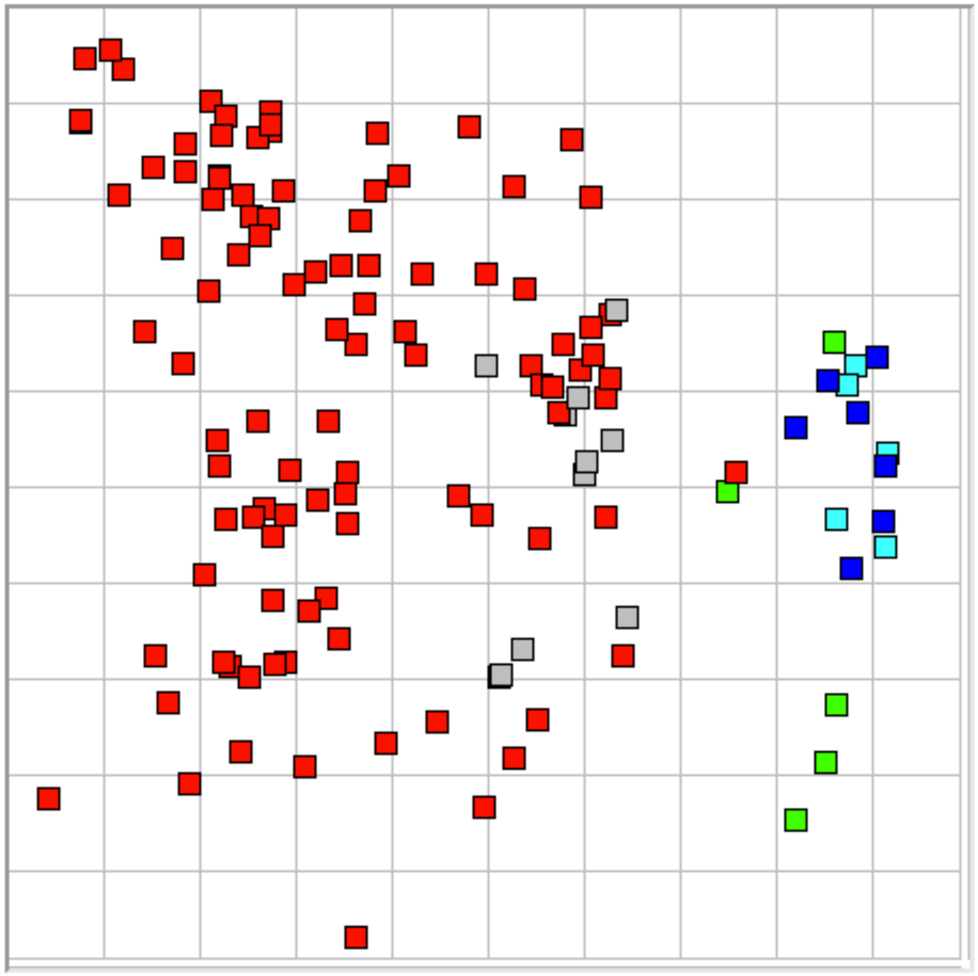
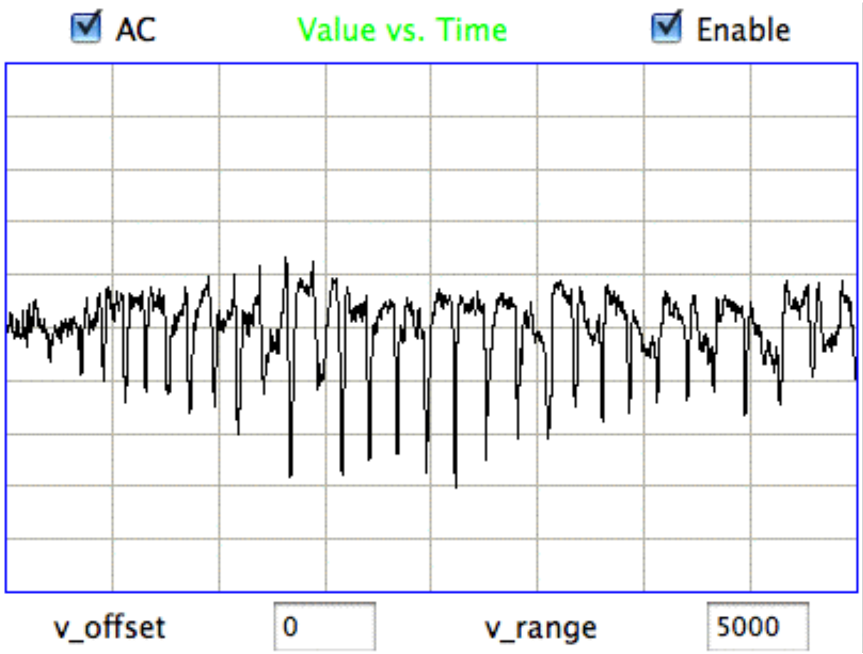
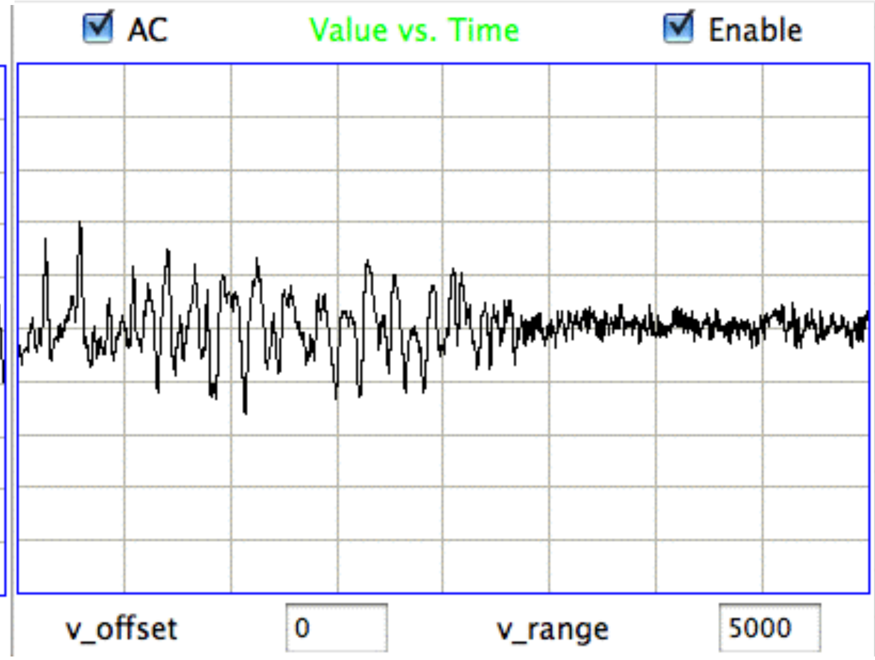


Figure: Coastline (horizontal) versus Asymmetry (vertical) in the Event Map.

Possible Use of Asymmetry

Four-Second Intervals Showing Seizure (left) and Spindle (right).



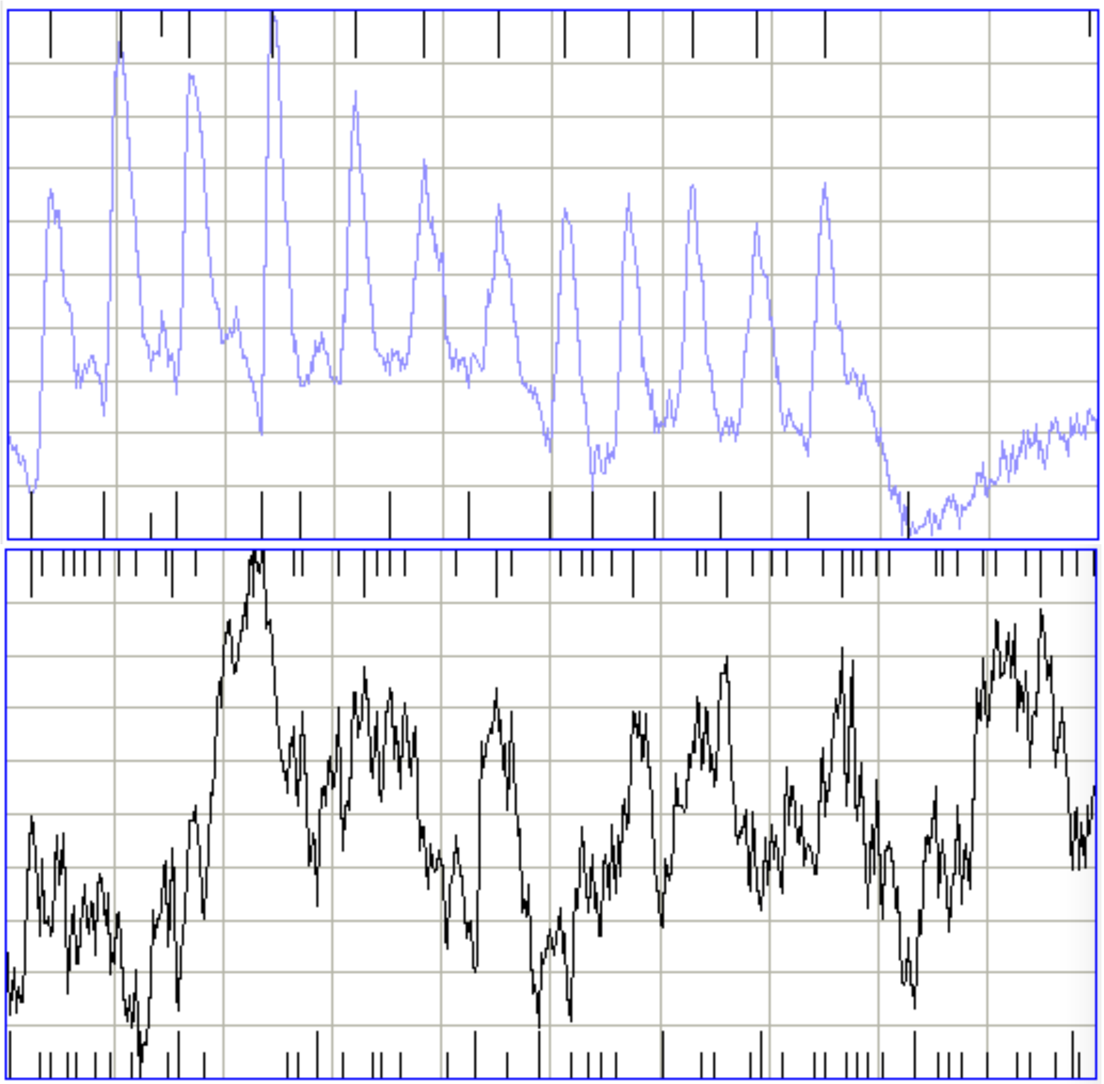


Asymmetry allows us to distinguish between these two.

Might use asymmetry after first classifying as non-baseline.

Periodicity

Two Ictal Intervals, one periodic, one not periodic.



Short black vertical lines are peaks and valleys for spikiness only.

Longer black lines are peaks and valleys used for spikiness and periodicity.

Processing

Ideal arrangement: run processor while recording, and never have to re-run.

In practice, may have to re-process the recording.

Table below gives total time to read, reconstruct, and process one channel-second.

Processing is more efficient for longer playback intervals.

Processing Execution Time ECP15					
MacOS, Dual Core i5 2.4 GHz					
Neuroarchiver 98, LWDAQ_2.8.10					
Interval (s)	VT Plot Enabled	FFT Enabled	Processor	Rate (ch-s/s)	Time (ms/ch-s)
1	No	No	ECP15V3	96.0	10.4
2	No	No	ECP15V3	157.3	6.4
4	No	No	ECP15V3	225.1	4.4
8	No	No	ECP15V3	277.3	3.6
16	No	No	ECP15V3	294.4	3.4
32	No	No	ECP15V3	281.6	3.6

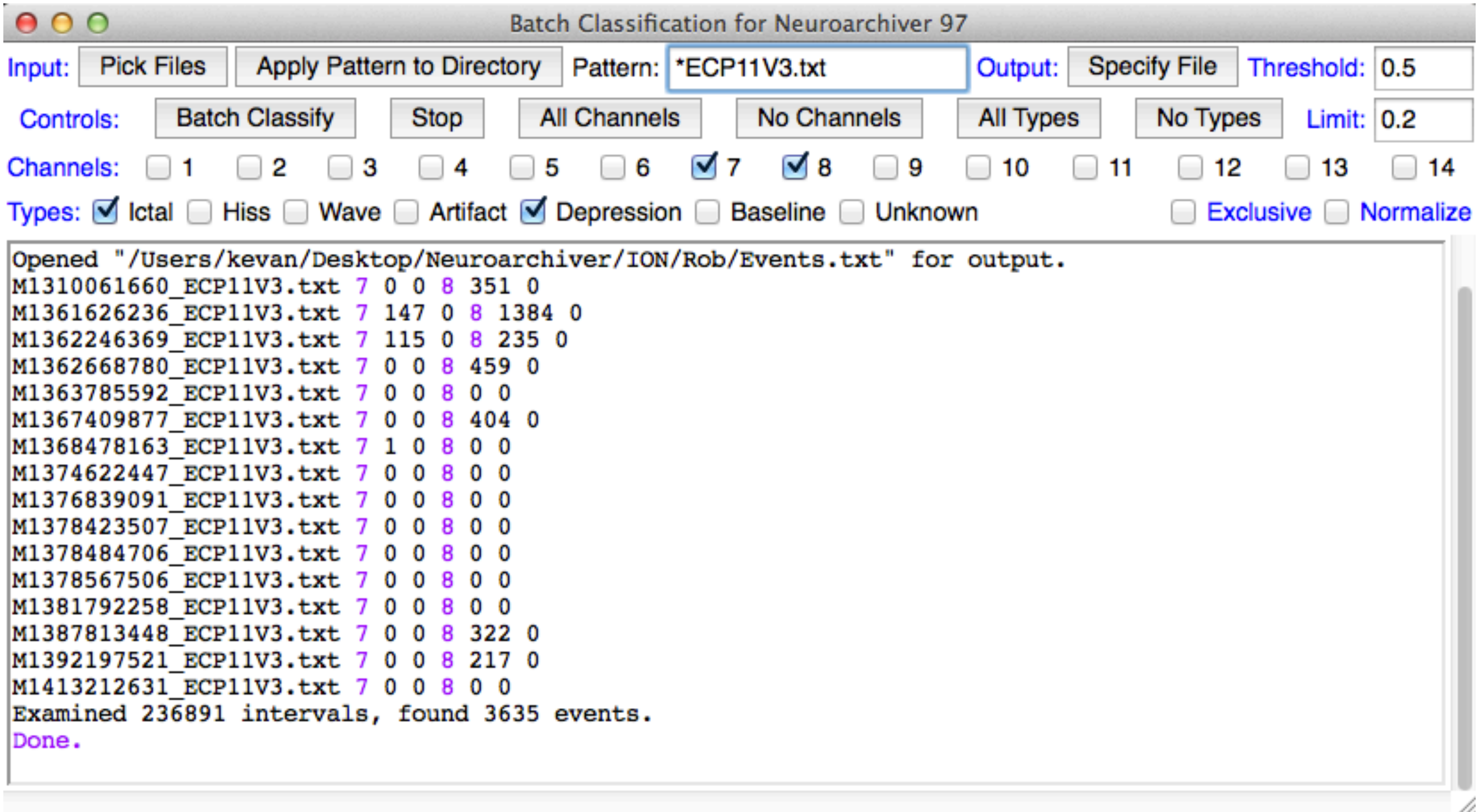
Metric calculation in ECP15 takes 1.8 ms/ch/s for 1-s intervals.

Compare to 4.2 ms/ch/s for ECP11V3 and 31 ms/ch/s for ECP1.

Batch Classifier

Takes characteristics files and event library as input.

Produces lists of events.



Normalized Detection Procedure

1. Set the baseline power so baseline power metric is in the range 0.2-0.5.
2. Use the Neuroarchiver to process the NDF files with ECP15.
3. Configure processor to write power, coastline, intermittency, and spikiness.
4. We now have characteristics files, which allow us to perform classification.
5. Use Event Classifier to prepare an event library.
6. Use Batch Classifier to perform normalized classification.
7. Will ignore intervals below the power threshold (maybe try 0.4).
8. Will ignore power metric during classification (normalize).
9. Writes list of events it finds in the characteristics files.
10. In Neuroarchiver, hop through 100 events in the list to check performance.

Performance

Have 16 hours or recording containing 236887 channel-seconds.

Process with ECP15, use Library_02FEB15.txt containing 137 events.

Here is the fraction of ictal-classified events that we agree are ictal.

We vary the classification configurations.

Event Library	Classification Threshold	Match Limit	Normalize	Exclusive	Event Count	Performance (%)
ECP15_02FEB15	0.4	0.1	Yes	No	34005	97
ECP15_02FEB15	0.4	0.1	No	No	25524	98
ECP15_02FEB15	0.4	0.1	No	Yes	25524	97
ECP15_02FEB15	0.4	0.1	Yes	Yes	34009	98
ECP15_02FEB15	0.4	0.2	Yes	Yes	66827	81
ECP15_02FEB15	0.4	0.2	Yes	No	56969	86
ECP15_02FEB15	0.4	0.2	No	No	54477	89

Normalized classification works as well as if we use the power metric.

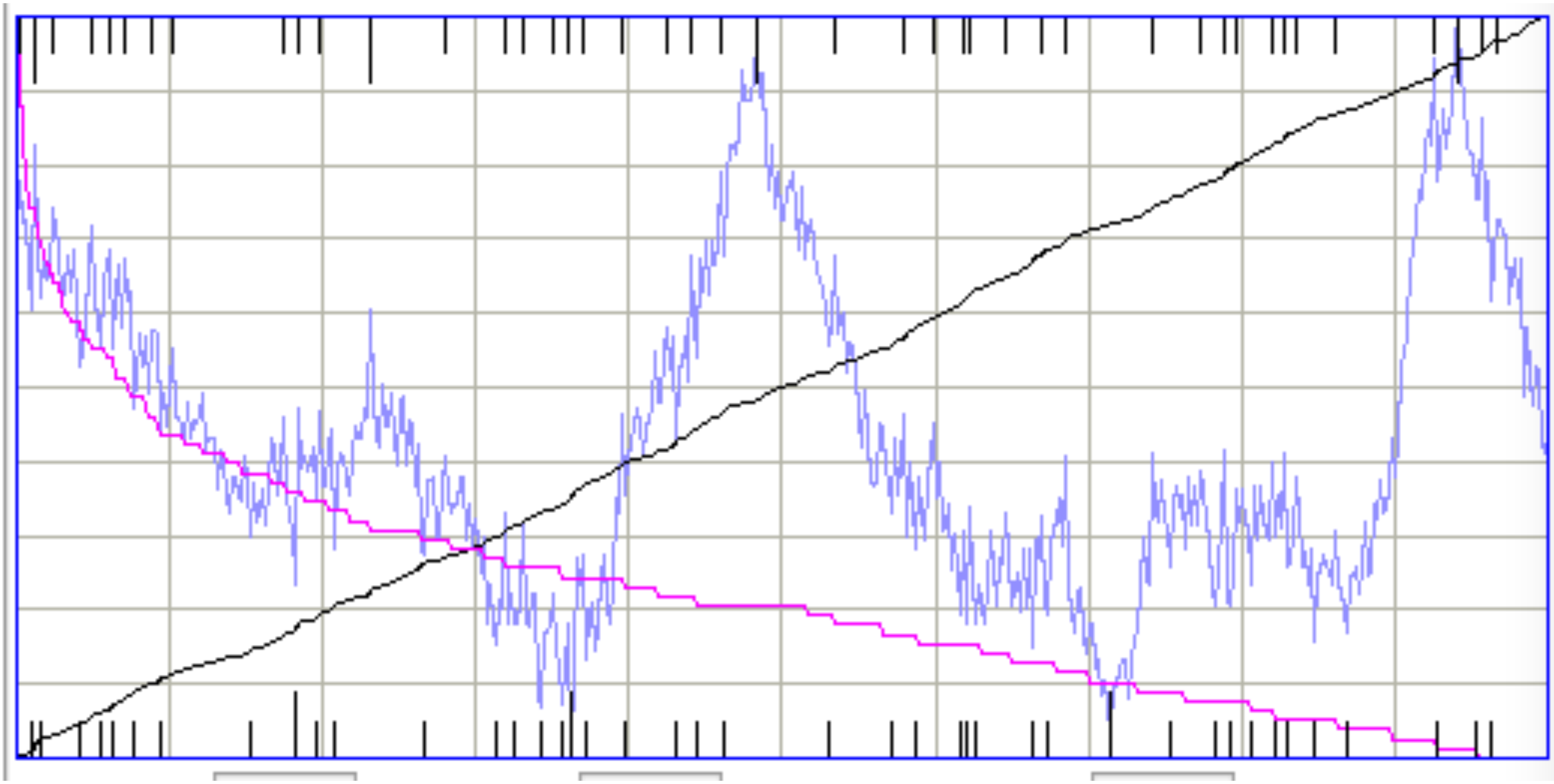
With only three metrics, 137 events are enough.

False positive rate on baseline intervals is around 0.5%.

Conclusion

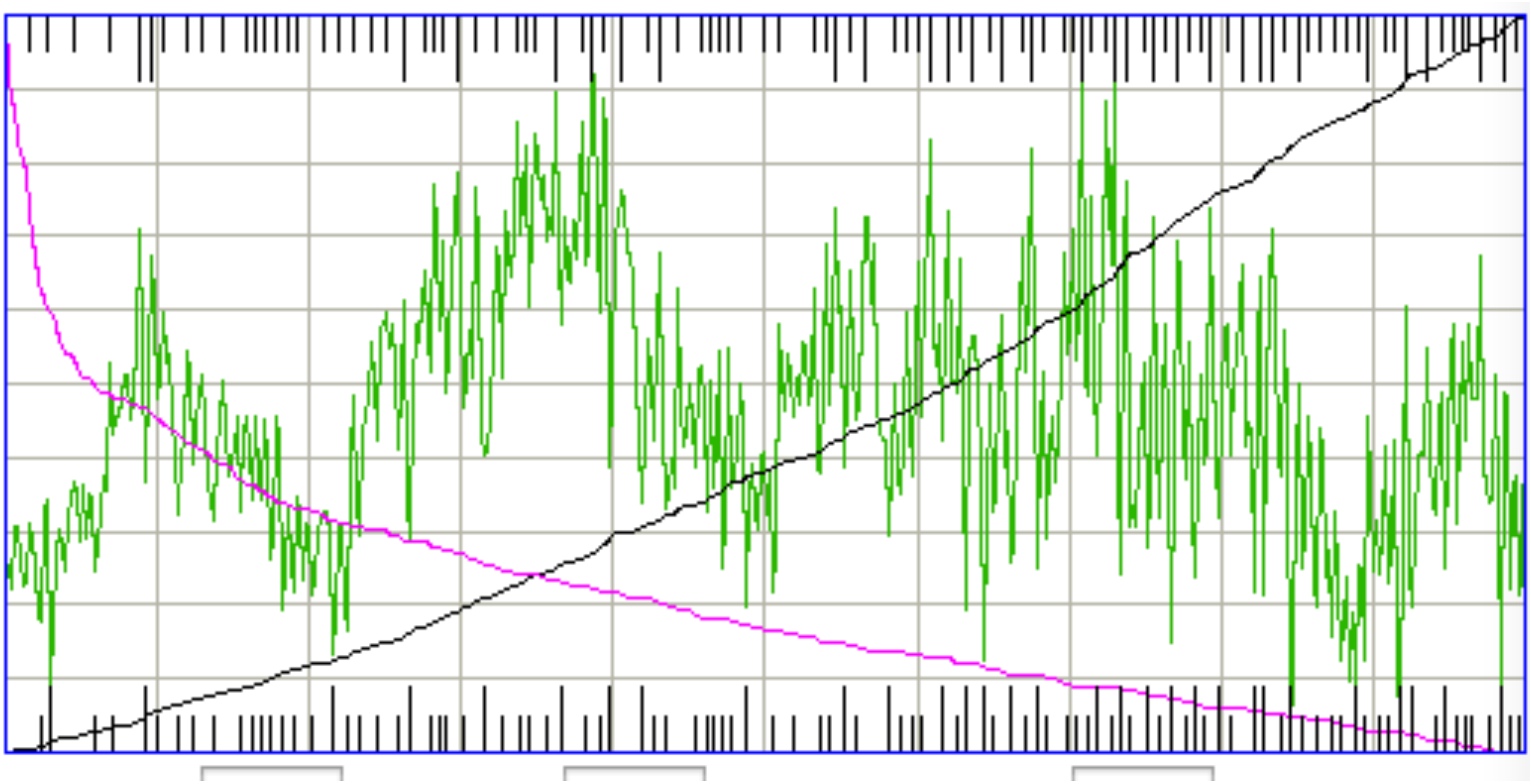
1. Baseline power calibration can be hard-coded for device, animal, and electrodes.
2. No need to calibrate individual imlants, nor run a special calibration procedure.
3. Use baseline power only to select powerful intervals for classification.
4. Normalized classification does not use the power metric.
5. Any example of a pattern, large or small, is just as useful in library.
6. Normalized classification reduces the number of metrics by one.
7. We can classifiy with three metrics: coastline, intermittency, spikiness.
8. We get lists of extraordinary events.
9. The lists give us frequency of occurance with time.
10. The Neuroarchiver lets us jump to events in these lists.
11. Could classify further within these lists using asymmetry or periodicity.
12. Can consolidate events into larger events, such as long seizures.

Supplemental: Baseline



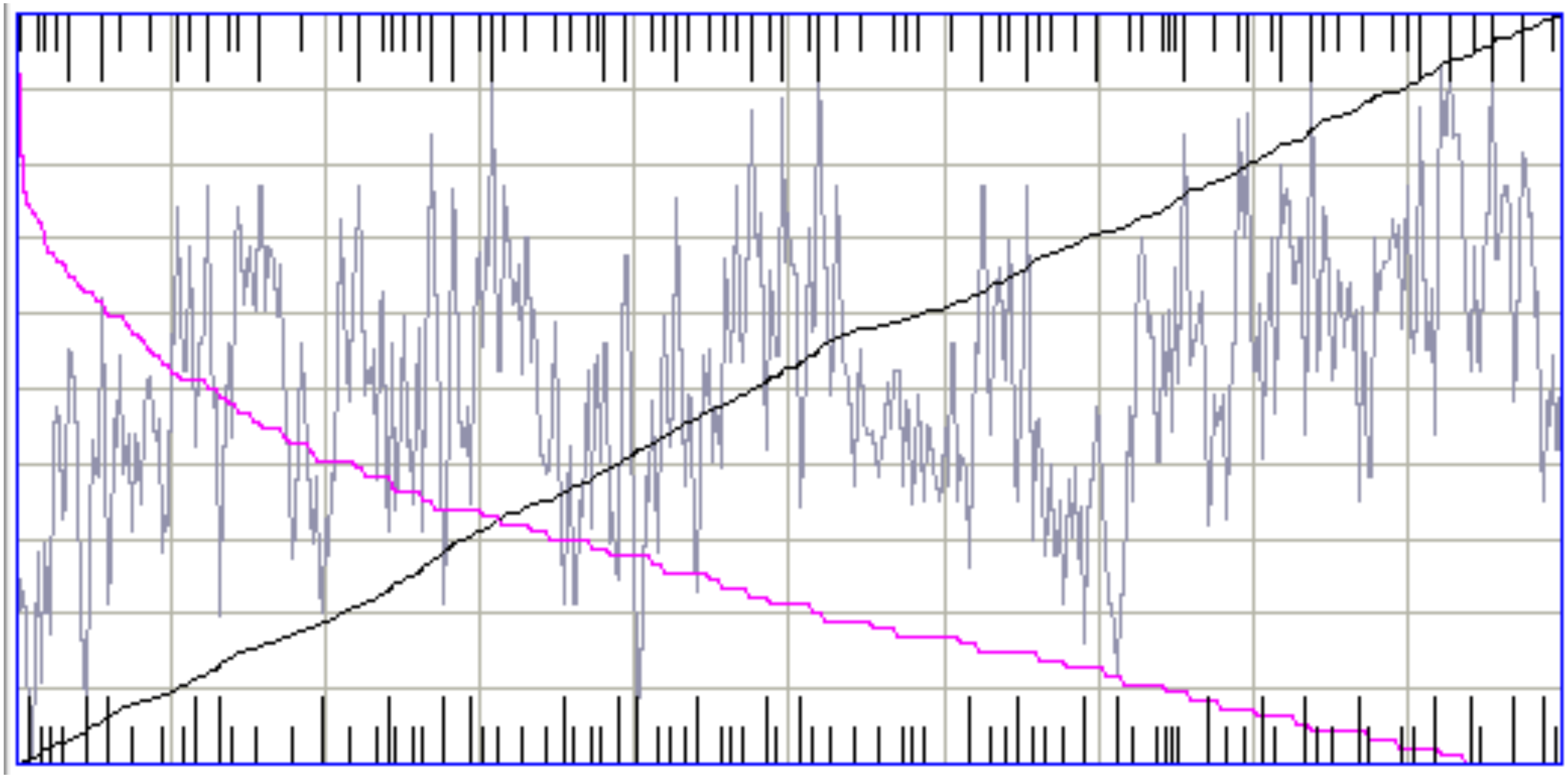
Note:
Purple plot shows sorted coastline step size. Black plot shows progression of coastline. Short marks for peaks and valleys used only by spikiness. Long marks for peaks and valleys used by spikiness and periodicity.

Supplemental: Hiss



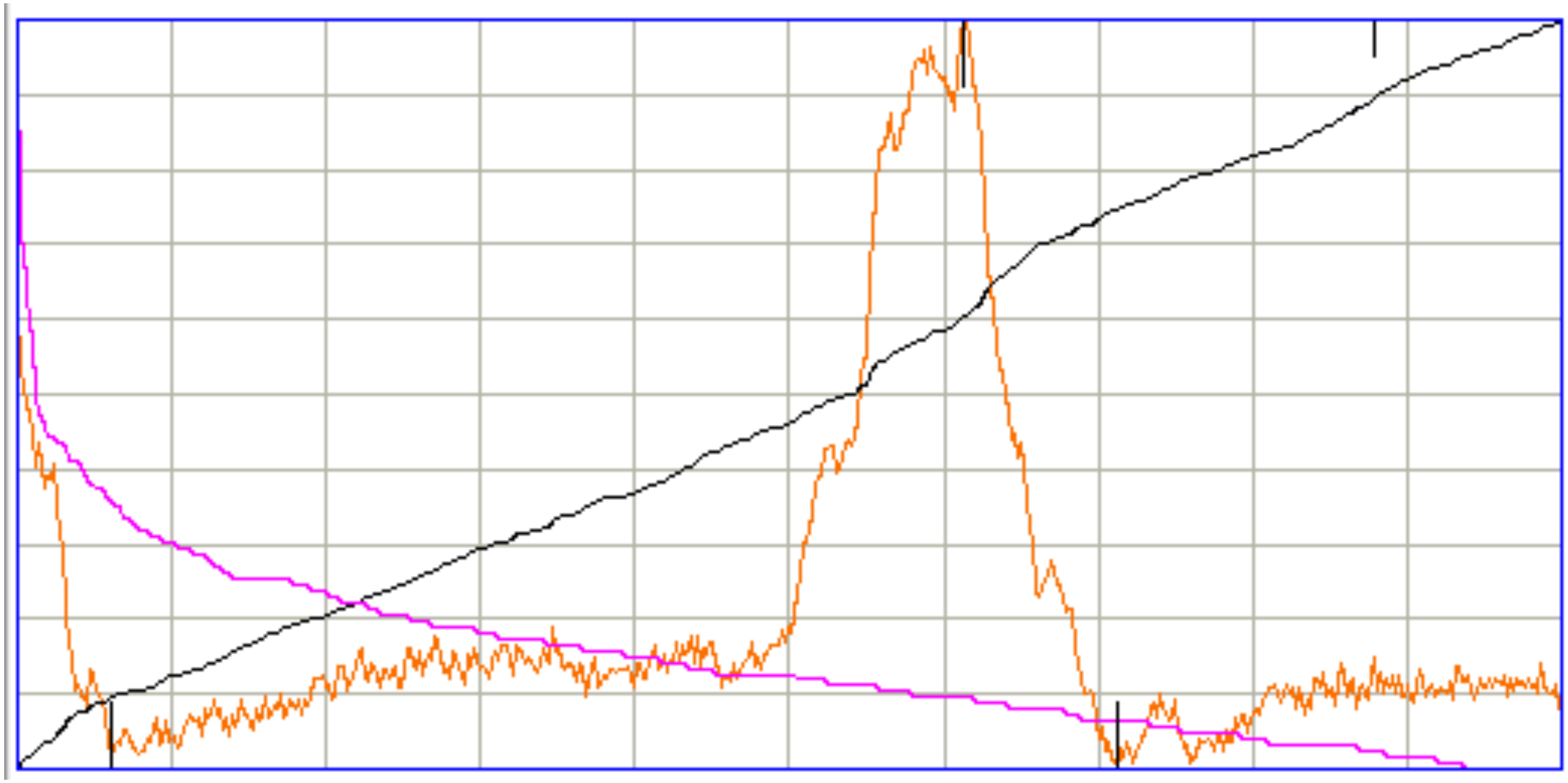
Note: Purple plot shows sorted coastline step size. Black plot shows progression of coastline. Short marks for peaks and valleys used only by spikiness. Long marks for peaks and valleys used by spikiness and periodicity.

Supplemental: Depression



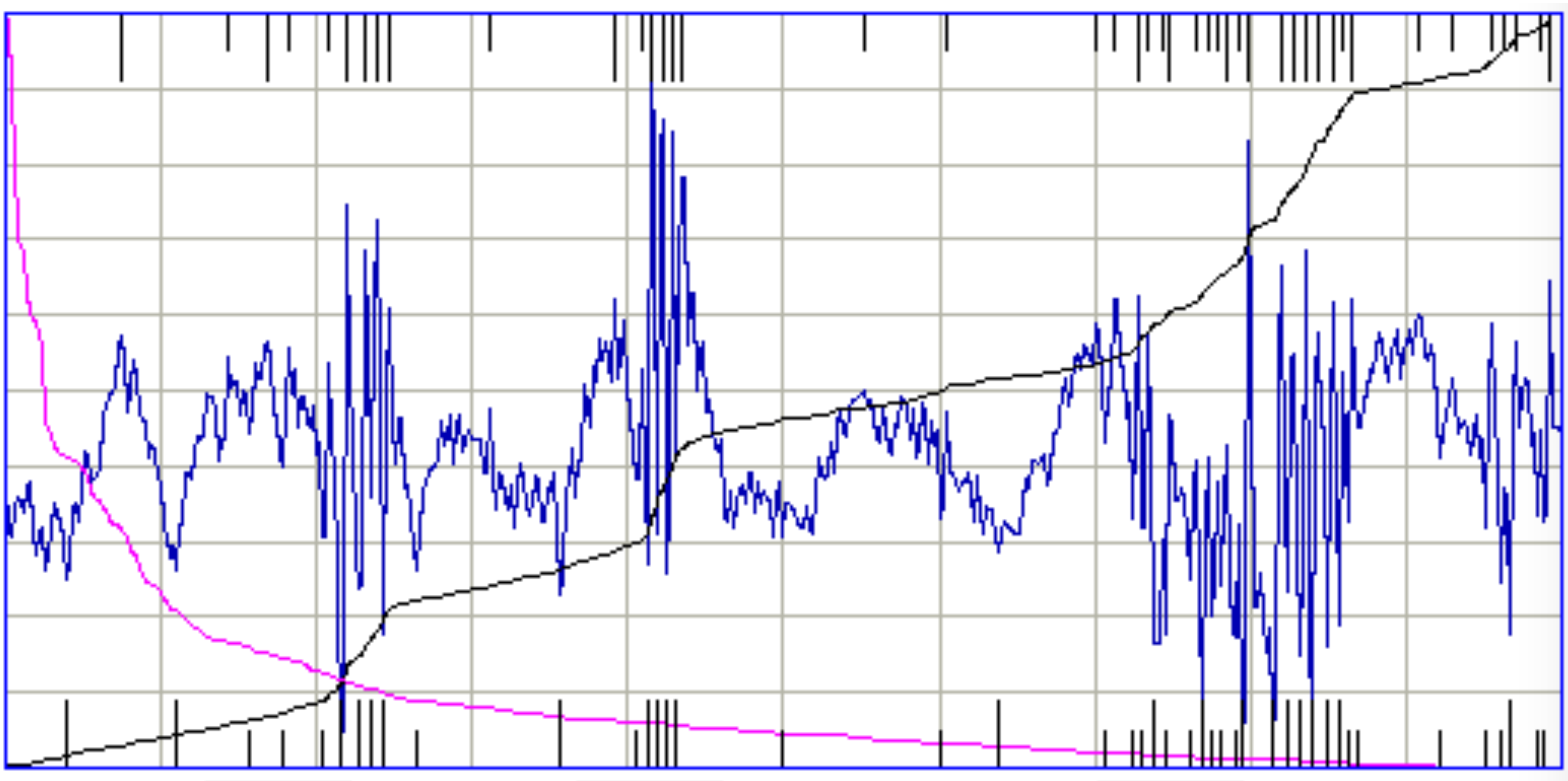
Note: Purple plot shows sorted coastline step size. Black plot shows progression of coastline. Short marks for peaks and valleys used only by spikiness. Long marks for peaks and valleys used by spikiness and periodicity.

Supplemental: Ictal



Note: Purple plot shows sorted coastline step size. Black plot shows progression of coastline. Short marks for peaks and valleys used only by spikiness. Long marks for peaks and valleys used by spikiness and periodicity.

Supplemental: Artifact



Note: Purple plot shows sorted coastline step size. Black plot shows progression of coastline. Short marks for peaks and valleys used only by spikiness. Long marks for peaks and valleys used by spikiness and periodicity.