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Title: Toward Joint Hypothesis-Tests Seismic Event Screening Analysis: Ms mb and Event Depth

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Toward Joint Hypothesis-Tests Seismic Event Screening Analysis: Ms|mb and Event Depth

39th Working Group B

Waveform Expert Group

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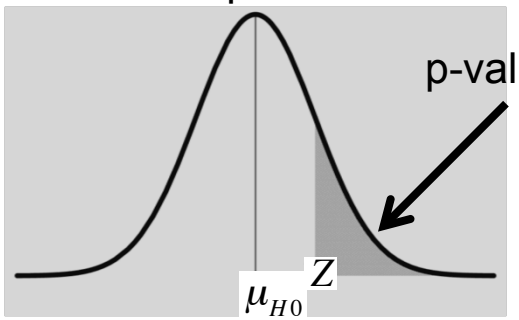
Event Screening Framework for a Single Phenomenology

- **H0: Single-point explosion characteristics**
  - Compute test statistic(s) assuming H0 is true
  - Compute p-value, a measure of evidence against H0
    - p-value near zero rejects H0
    - Otherwise, “fail to reject H0”
- **For Ms:mb event screening**
  - H0: Given mb, event has minimal surface wave energy
- **For depth event screening**
  - H0: Event depth $Z \leq Z_0$

Ms:mb Event Screening

- **H0: Given mb, event has minimal surface wave energy**
  - Single-station (ith station) model to build technical representation of H0
    - $Ms_i - \beta \times mb = \mu_{H0} + Model\ Error + Noise_i$
      - Left side corrects station Ms for event magnitude (Selby et al. prefer $\beta = 1$)
      - Right side is random effects model (Anderson et al. derive test statistic)
      - Model Error is common to all stations observing event (N(0,τ^2))

        (Model Error can include lack of depth correction on left side)
      - Noise is specific to a station (N(0,σ^2))
  - Test statistic
    - Variance components in standard error computed from calibration data



$$Z = \frac{(\overline{Ms} - mb) - \mu_{H0}}{\sqrt{\tau^2 + \sigma^2/n}}$$

Ms:mb Event Screening: Data for Example Analysis

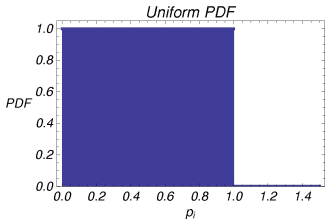
- **International Data Centre Data (Calendar Year 2008)**
  - 12120 events
    - Current IDC screening criteria applied to 1772 events
      - These events removed from data table when formulating Ms|mb hypothesis test
  - Calibrated Ms|mb test statistic applied to 2009 Democratic Peoples Republic of Korea (DPRK) announced nuclear weapon test
  - Under H0: Explosion Characteristics, the calibrated test statistic is

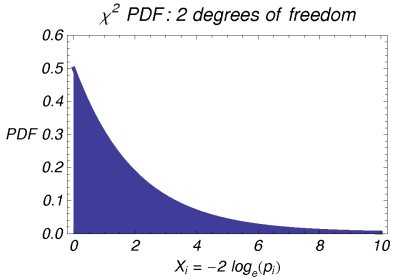
$$Z = \frac{(\bar{M}s - mb) - (-1.4)}{\sqrt{0.15 + 0.1/n}}$$

  - **To illustrate joint hypothesis test, simulated (fabricated) depth hypothesis test was constructed that closely matches IDC depth screening criteria.**

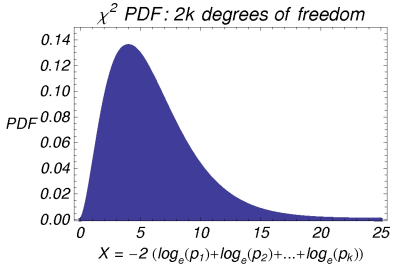
Event Screening Framework with Multiple (orthogonal) Phenomenologies (Fisher)

- **Under H0**
  - Single phenomenology p-values (p_1, p_2, …, p_k) have uniform probability distributions





    - $X_i = -2 \log_e(p_i)$ is distributed χ^2 with 2 degrees of freedom
    - $X = -2 (\log_e(p_1) + \log_e(p_2) + \ldots + \log_e(p_k))$ is distributed χ^2 with 2k degrees of freedom



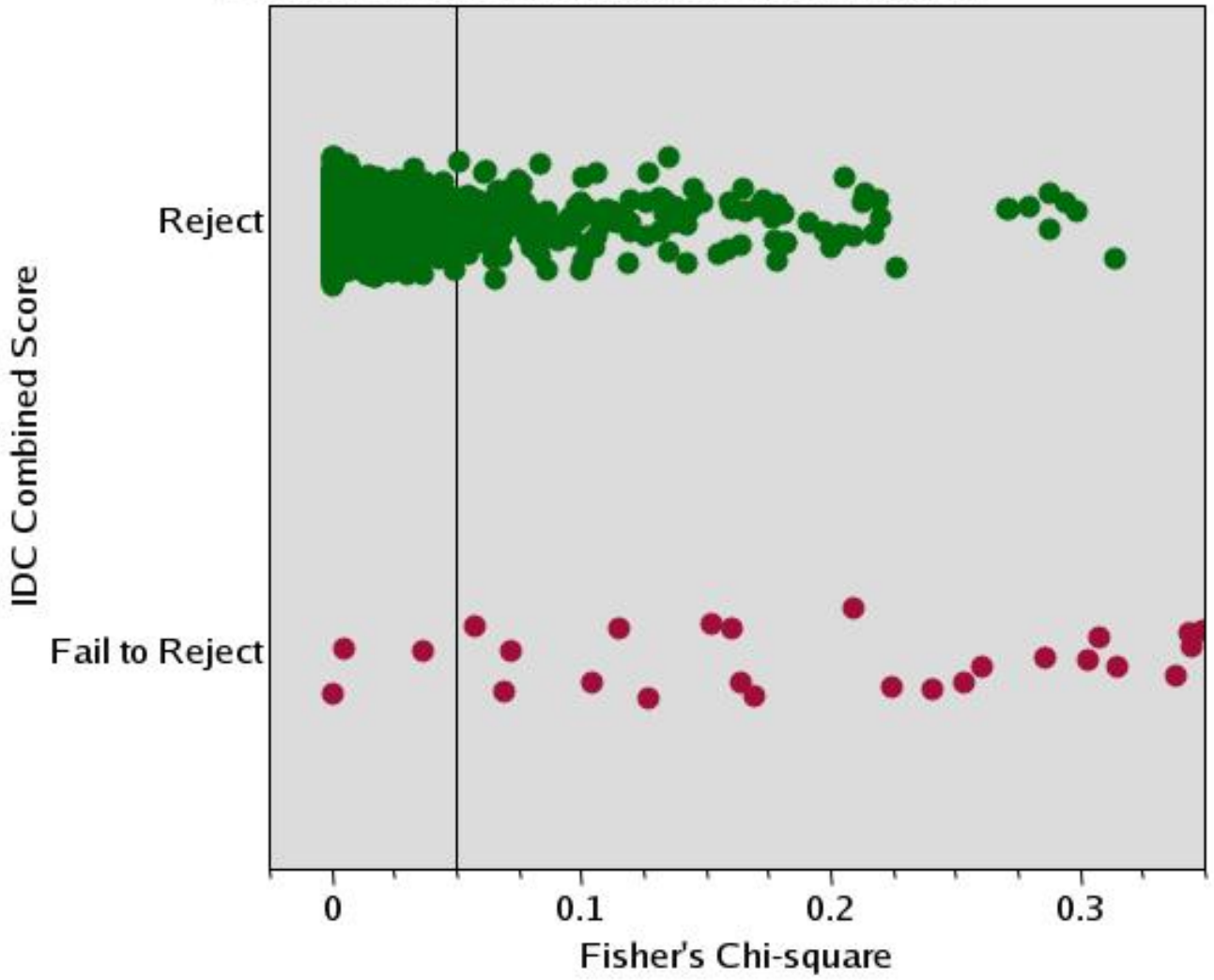
  - Compute p-value with X, a measure of evidence against H0
    - p-value near zero rejects H0
    - Otherwise, “fail to reject H0”

Event Screening Framework with Multiple (orthogonal) Phenomenologies (Tippett)

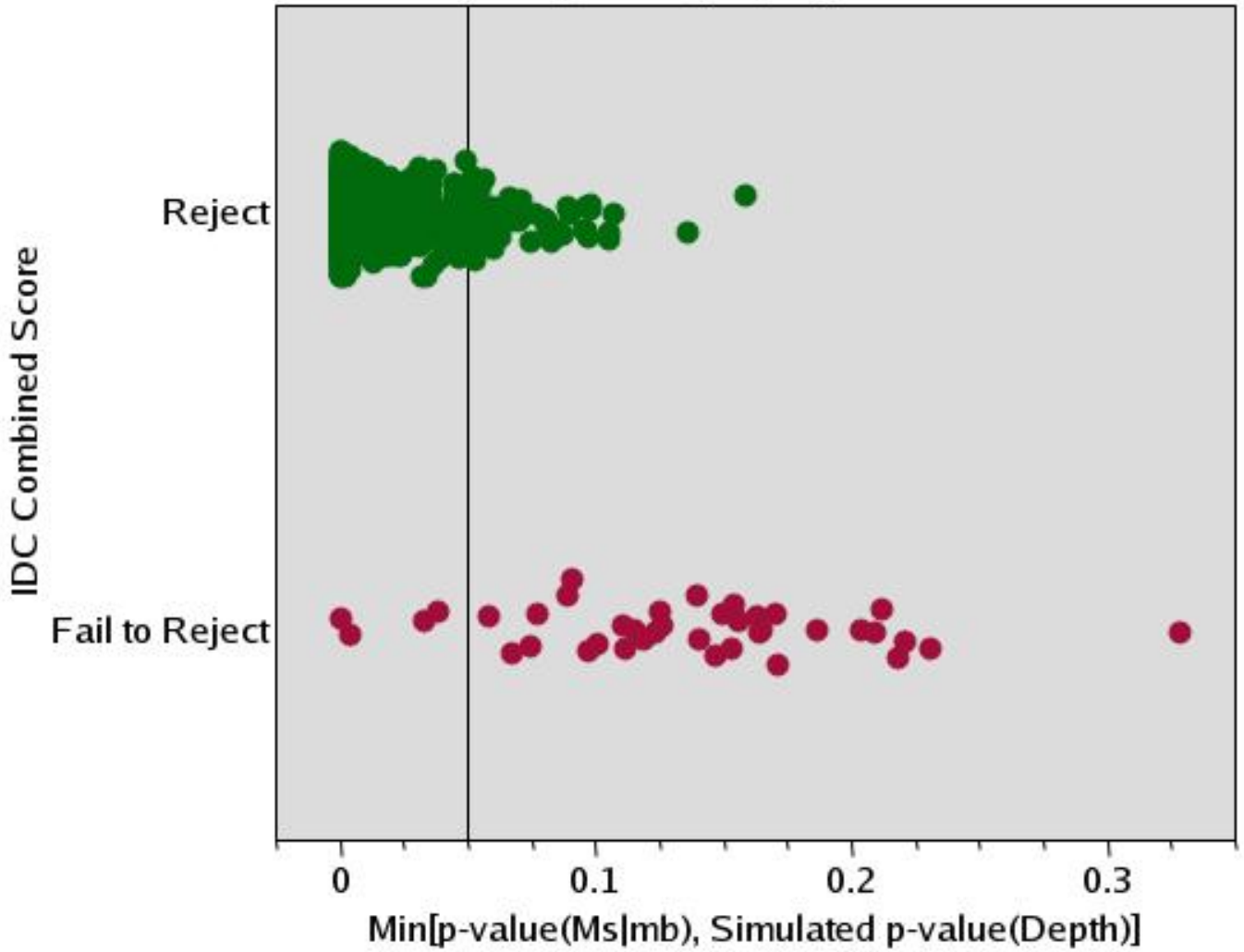
- **Under H0**
  - Single phenomenology p-values measure support for explosion characteristic
  - Screening criteria can be based on Min(p_1, p_2, …, p_k)
  - Requires multiple hypothesis test adjustment to significance level

$$1-(1-\alpha)^{1/k}$$

Fisher's Joint Event Screening: Ms|mb and Simulated Depth Hypothesis Test



Tippett's Joint Event Screening: Ms|mb and Simulated Depth Hypothesis Test



Ms:mb Event Screening for 2009 Announced NWT

- **Contrast**
  - Commonly used standard error
    - p-value = 0
    - reject H0
  - Improved standard error
    - p-value = 0.12
    - fail to reject H0

$$Z = \frac{(\{\bar{M}s = 3.687\} - \{mb = 4.62\}) - (-1.4)}{\sqrt{0.15 + {}^{0.1}\!/_{27}}}$$

Summary

- **Well established theory can be used to combine single-phenomenology hypothesis tests into a multi-phenomenology event screening hypothesis test (Fisher's and Tippett's tests)**
- **Commonly used standard error in Ms:mb event screening hypothesis test is not fully consistent with physical basis**
- **Improved standard error**
  - Better agreement with physical basis
  - Correctly partitions error to include Model Error as a component of variance
    - Correctly reduces station noise variance through network averaging
- **For 2009 DPRK test**
  - Commonly used standard error "rejects" H0 even with better scaling slope (β = 1, Selby et al.)
  - Improved standard error "fails to rejects" H0

Next Steps

- **Formulate Depth Hypothesis test**
- **Demonstrate Joint Ms|mb and Depth Hypothesis Test with IDC Operational Data**
  - Fisher
  - Tippett
- **Evaluate Relevance of Fisher's and Tipett's Methods to IDC Event Screening Charter**
- **Other Phenomenologies**

References

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- Fisher, R.A. (1932) "Statistical Methods for Research Workers.", 4th Edition, Edinburgh: Oliver and Boyd.
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