高知大学
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微小な地殻ひずみ信号検出のための解析技術の確立と超精密観測記録の活用

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極域データサイエンスに関する研究集会
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Background

- **地殻ひずみ観測記録 / 超精密観測記録:**

  high precision (~ 10^{-13} strain), ultra wideband (20 Hz ~ DC)

  - Multi Comp. Borehole $^{>20}$ (Okubo *et al.*, 2004, Itaba *et al.*, 2010),
  - LASER extensometer $^{=1}$ (Araya *et al.*, 2010, 2017)
    - Super Conductivity Gravimeter (ex. Yokoyama *et al.*, 2017)

- **高精度・広帯域ゆえの，地球深部由来信号 & ノイズ**

  - Frequency band/Events time: overlapped
  - Far/Near, various amplitudes: mixed

Disturbed study target

- 地球内部起源の微小変動とノイズ

Aftershocks in Mainshock	$< 10^{-1}$ s
StSSE,VLFE, Earthquake	$> 10^{2}$ s
Inner core motions	$> 10^{4}$ s
LtSSE, After slip	$> 10^{7}$ s
Seasonal change	~ 10^{7} s
(Glacial) Isostatic Adjustment	~ DC

Electrical noise (N)	**$> 10^{-2}$ s**
Other events (N/F)	**$> 10^{-2}$ s**
Precipitation (N)	**$> 10^{2}$ s**
Tidal motion (F)	**$> 10^{4}$ s**
Barometric change (N/F)	**$> 10^{5}$ s**
Aquifers change (N)	**$> 10^{6}$ s**
Deformations (N)	**> 10^{7} s**

加えて，研究対象信号以外も望まざるノイズ！

Aim of Study

- 地球内部起源の微小変動現象の抽出

Aftershocks in Mainshock, StSSE, LtSSE, and Inner core motions

⇦ Multi Comp. Strain Analyses

- (Streaming) Strain Analysis (Okubo 2005)
- Fourier Strain Analysis (Okubo 2007)

⇦ Hilbert-Huang Transform/Empirical Mode Decomposition

- Frequency downshift (Huang *et al.*, 1996)
- Ensemble Empirical Mode Decomposition

(Wu and Huang, 2005)

Empirical Mode Decomposition(EMD)

- 記録から経験的に変動を抽出 (Huang, *et al*.,1996)
  - Frequency downshift (empirical) operation
  - 特徴点抽出 (upper and lower variations)
  - 中点推定 (median point estimation)
  - 固有モード抽出 (intrinsic mode decomposition)

かける
× Hilbert spectral Analysis ⇨ HHT

  - ground motion (Shen *et al*., 2003)
  - nonstationary financial time series (Huang *et al*., 2003)

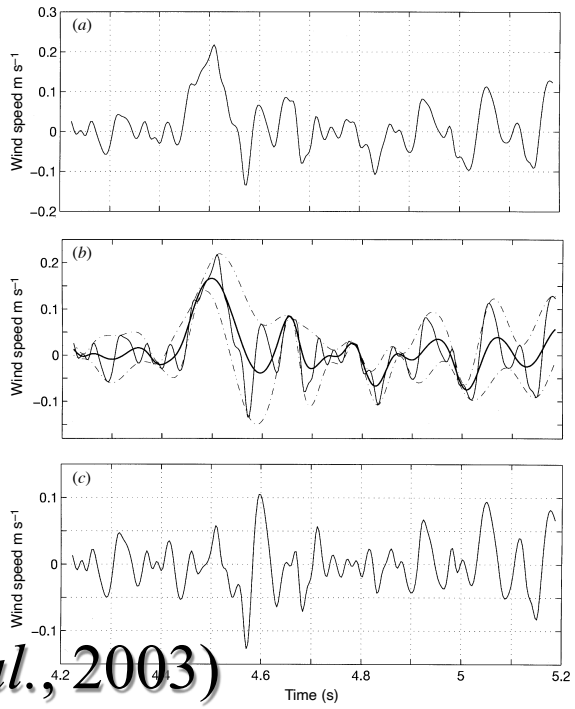


Figure 3. Illustration of the sifting processes: (*a*) the original data; (*b*) the data in thin solid line, with the upper and lower envelopes in dot-dashed lines and the mean in thick solid line; (*c*) the difference between the data and m_1. This is still not an IMF, for there are negative local maxima and positive minima suggesting riding waves.

Hilbert-Huang Transform (HHT)

- Fourier Analysis; linear, stationary
  - Convolution: **global**, *uncertainty*
- Wavelet Analysis; linear, non-stationary
  - Convolution: regional, *uncertainty*
  - *Continuous* Feature extraction
- Hilbert Analysis; non-linear, non-stationary
  - Differentiation: **local**, **certainty**
  - Feature extraction , but difficult *direct extraction* from dynamic strain…

(15RP2021)

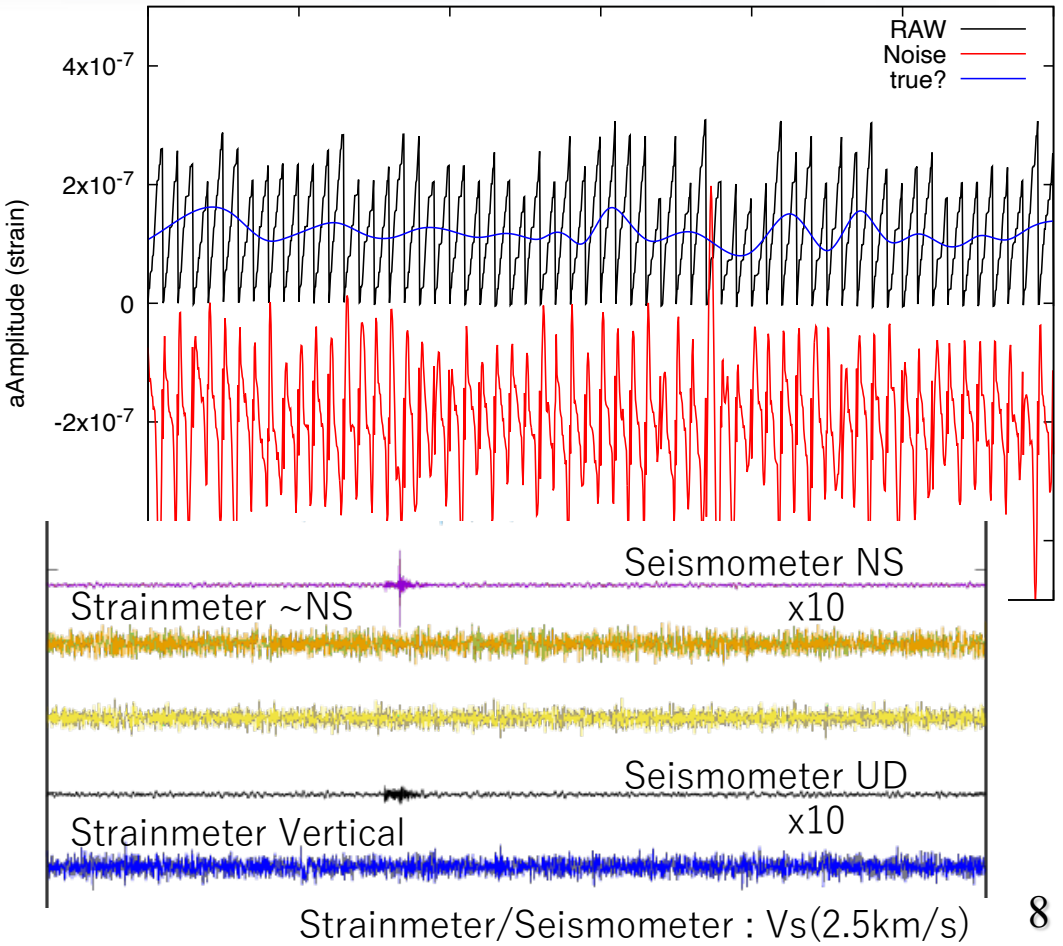
Outputs (015RP2021&018RP2022)

- EEMD with **短周期変動**; extract electrical (saw shape) noise
- EEMD with **長周期変動**; seasonal deformation, tidal motions
- EEMD with Saturated records; tidal motions (not exact!)

- Combine EEMD/HHT and SA to decompose favorite signal
  - Decompose IMFs by EEMD
  - Re-composition coherent signal by SA (*future work*)

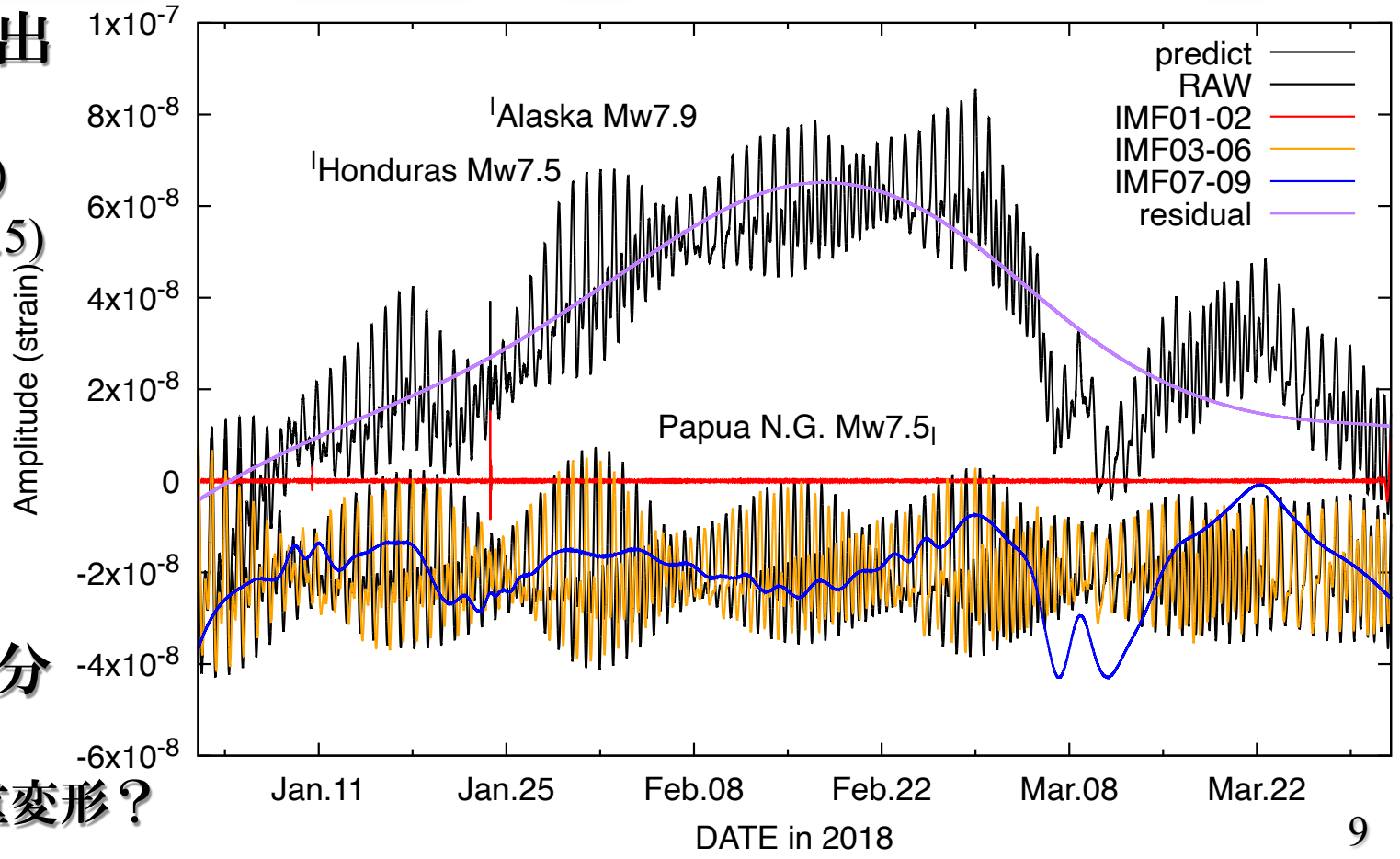
EEMD with short term variations (borehole)

- 短周期ノイズの低減
  - 電源系？処理信号系？
  - S/N　3 倍程度向上
- 微小ひずみ地震動
  - 検出には至らず
    - ⇦ Frequency downshift
      more high sampling data
  - ひずみ地震動∝地動速度動
    比例係数は伝播速度
    ※ V_S = 2.5 km/s
    Okubo *et al.* (2005)



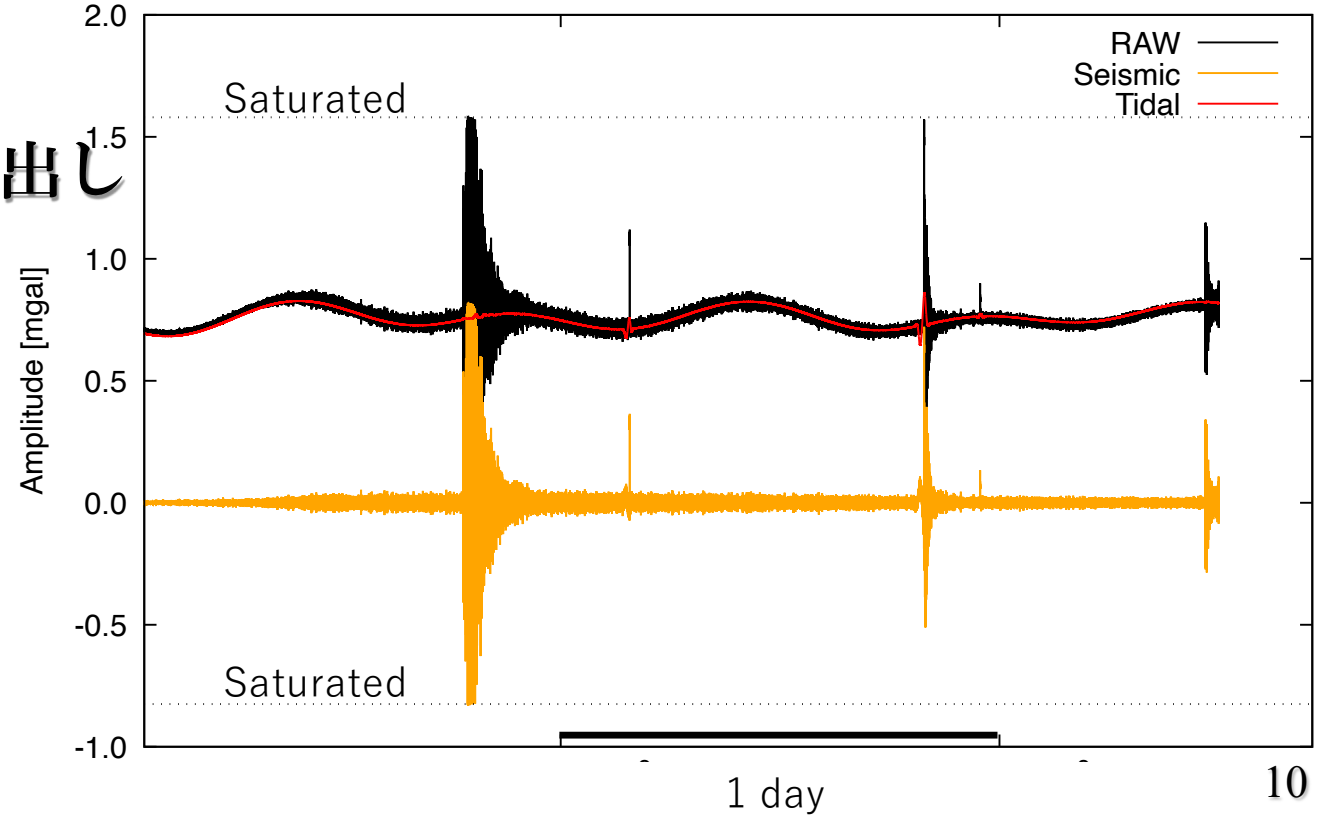
EEMD with long-term variation (Laser extensometer)

- 地震動変動の抽出
  - Alaska (M7.9)
  - Honduras (M7.5)
  - Papua N.G. (M7.5)
- 潮汐成分の抽出
  - 位相ずれ 小
  - 振幅　　同等
- 長期トレンド成分
  - 季節変動？荷重変形？



EEMD with Saturated Gravity variation

- 地殻変動DB(北大運用)より東北大重力計記録@Alaskaを利用
- 地震動抽出 可
  - 地震動の変動
    潮汐変動への染み出し
  - 波形飽和時
  - オフセット変化時
  - 変動中心のずれ



Suitable data for EEMD

- Transitional Change : ○
- 周期変動： ○
- オフセット変化： △

  他帯域IMFへの染み出し，反動

  white noise ensemble により改善可

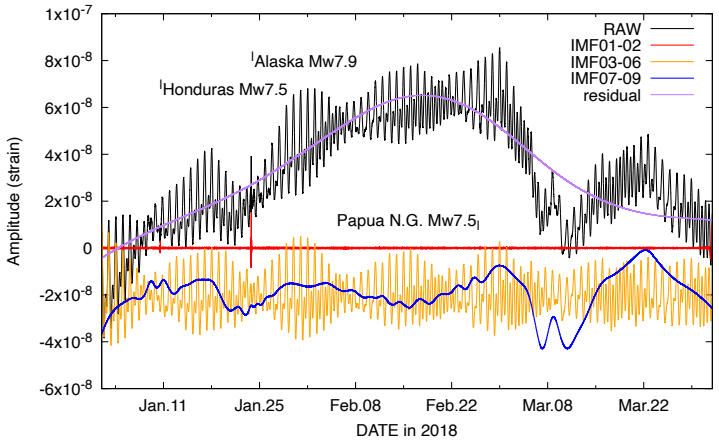
  計算時間とのトレードオフ

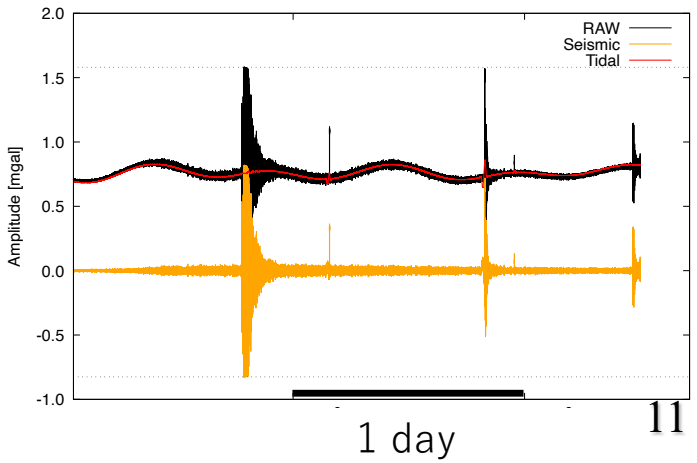
- 振幅飽和： △

  他帯域IMFへの染み出し，反動

  振幅の偏り： ✕

  ⇨ Artificial signal　(18RP2022)





Deformation; Statistical Evaluations

- 変動記録を地球物理学に基づき統計的に評価
  - ひずみ解析による変形推定
    - Streaming Strain Analysis (Time domain)
    - Fourier Strain Analysis (Frequency Domain)
  - 冗長成分・他観測量を利用した統計的な評価
    - Multi-Components Analyses results average and statistical errors

Coherent variation と Incoherent noise との分離

Ideal observation records (dynamic Strain)

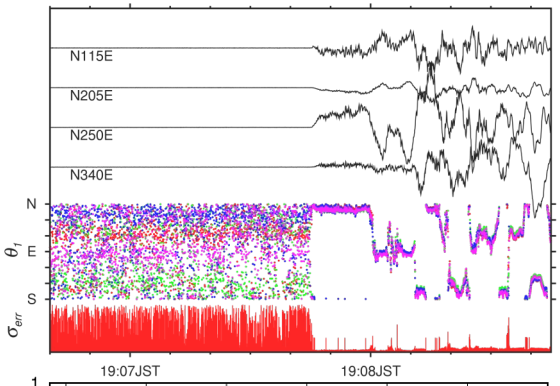
Observation = Long term variation (FSA incoherent, EEMD residual!)

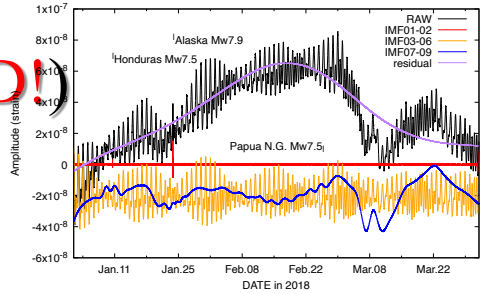
+ SSE (SSA coherent!, EEMD/HHT?)

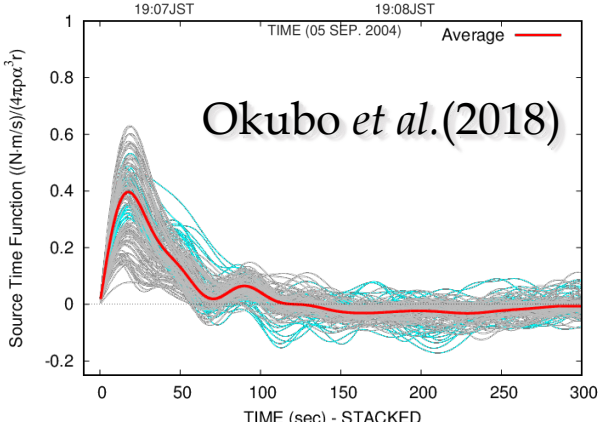
+ tidal variation (FSA coherent?!, EEMD!)

+ Free Oscillation

(FSA coherent!, EEMD/HHT?)





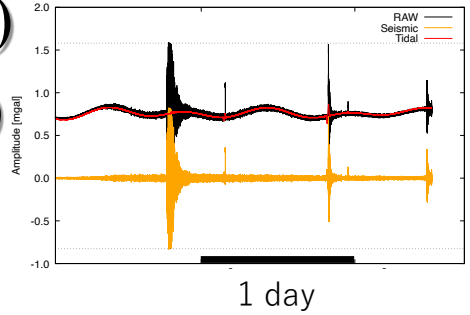


+ Source effects (FSA coherent!, EEMD)

+ Seismic wave (SSA coherent!, EEMD)

non unbalanced amplitude

+ noise (SSA/FSA incoherent, EEMD!)



We will present in detail at

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- Japan Geoscience Union
  - 幕張メッセ，千葉 (2023/05/21~26)
- International Union of Geodesy and Geophysics
  - City Cube Berlin, Germany (2023/07/11-20)

And will propose next ROIS-DS joint collaboration support.