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

2023 ROIS-DS joint workshop (2024/02/26 @ 立川)
018RP2021, 015RP2022, 015RP2023

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Contents overall

- Backgrounds
  - Continuous Crustal Deformation Records
  - Time series data analysis

- FY2023 Works
  - Based on IUGG Presentation:
    - EEMD (Ensemble Empirical Mode Decomposition)
    - HHT (Hilbert Huang Transform)
  - Other Project Collaboration:
    - 2023-B-03 collaborate works ERI, Tokyo Univ.

Why small signal detection requires

- Continuous Crustal Deformation Records
  - Earth: tidal, plate motion, eruption, earthquake




breathing, fidgeting, coughing, hiccupping

* Earth don't care the ants around her feet…
    - Observe sensitive,
- Time series data analysis
  - Ants couldn't not miss the motions of giants….
    - Carefully detect, and *think what to do*.

Contents based on IUGG G06p-021:

An example analysis of high precision Geophysical observations with Hilbert-Huang Transform

- Study backgrounds
  - Geophysical Observation:
- Methods
  - EEMD (Ensemble Empirical Mode Decomposition)
  - HHT (Hilbert Huang Transform)
- Application Examples
  - HHT with 20 Hz borehole strain records (AIST) (2021)
  - HHT with 1min Laser extensometer (ERI) (2021)
  - HHT with Super conductive Gravitimeter (Tohoku Univ.) (2022)

what are suitable data for HHT….

Backgrounds

Geophysical Observation (continuous crustal deformation)

High precision (~ 10^{-13} strain, ~ nano gal)

Ultra wideband (DC ~ 20 Hz)

- Multi Comp. Borehole strainmeter
  (*e.g.* Okubo *et al.*, 2004, Itaba *et al.*, 2018)
- LASER extensometer (<1 Hz)
  (*c.f.* Araya *et al.*, 2010, 2017)
- Super Conductivity Gravimeter (<1 Hz)
  (*c.f.* Yokoyama *et al.*, 2017)

↔ Included/Accompanying problems:

targets'/noises' (Frequency band, amplitude, and Event time) overlapped !

Methods

- HHT (Hilbert - Huang Transformation)

  with nonlinear and non-stationary time series records

  - Gravitational wave detection
  - (Seismic wave / financial chart)

  EMD + Hilbert Transform

- EEMD (Ensemble Empirical Mode Decomposition)

  Code by Prof. H.Takahashi (TCU)

  - with Gravity (ROIS-DS joint 015RP2022)
  - with 長周期変動 (ROIS-DS joint 018RP2021)
  - with 短周期変動 (ROIS-DS joint 018RP2021)

Methods HHT (Huang+, 1998)

- Mode decomposition
  - Decompose IMF from raw data *empirically*

    IMF: Intrinsic Mode Functions

    ⇨ mean less time series

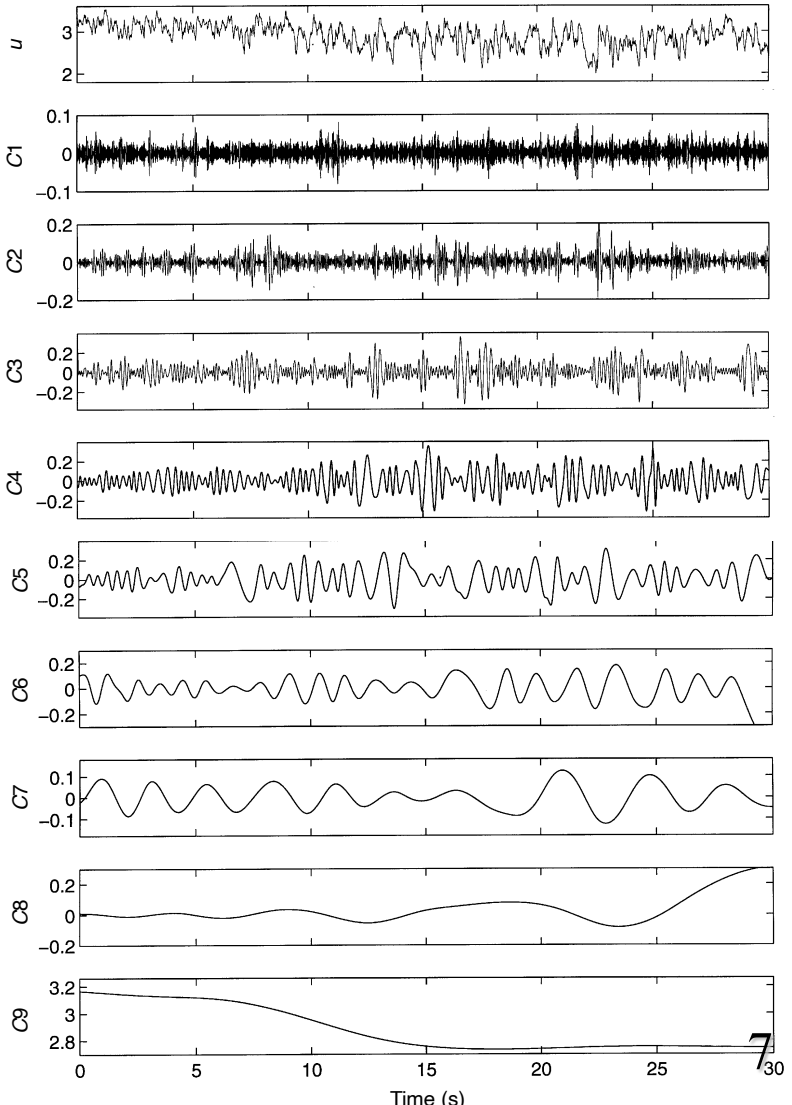
  - Apply Hilbert Transform for IMF

$$H(u) = F_u^{-1}\left(i\,\mathrm{sgn}(\omega)\,F_\omega(u)\right)$$

*Fourier Transform Application

HT: Transitional change detection by

frequency change, amplitude change



Application Examples (*Same Configuration*)

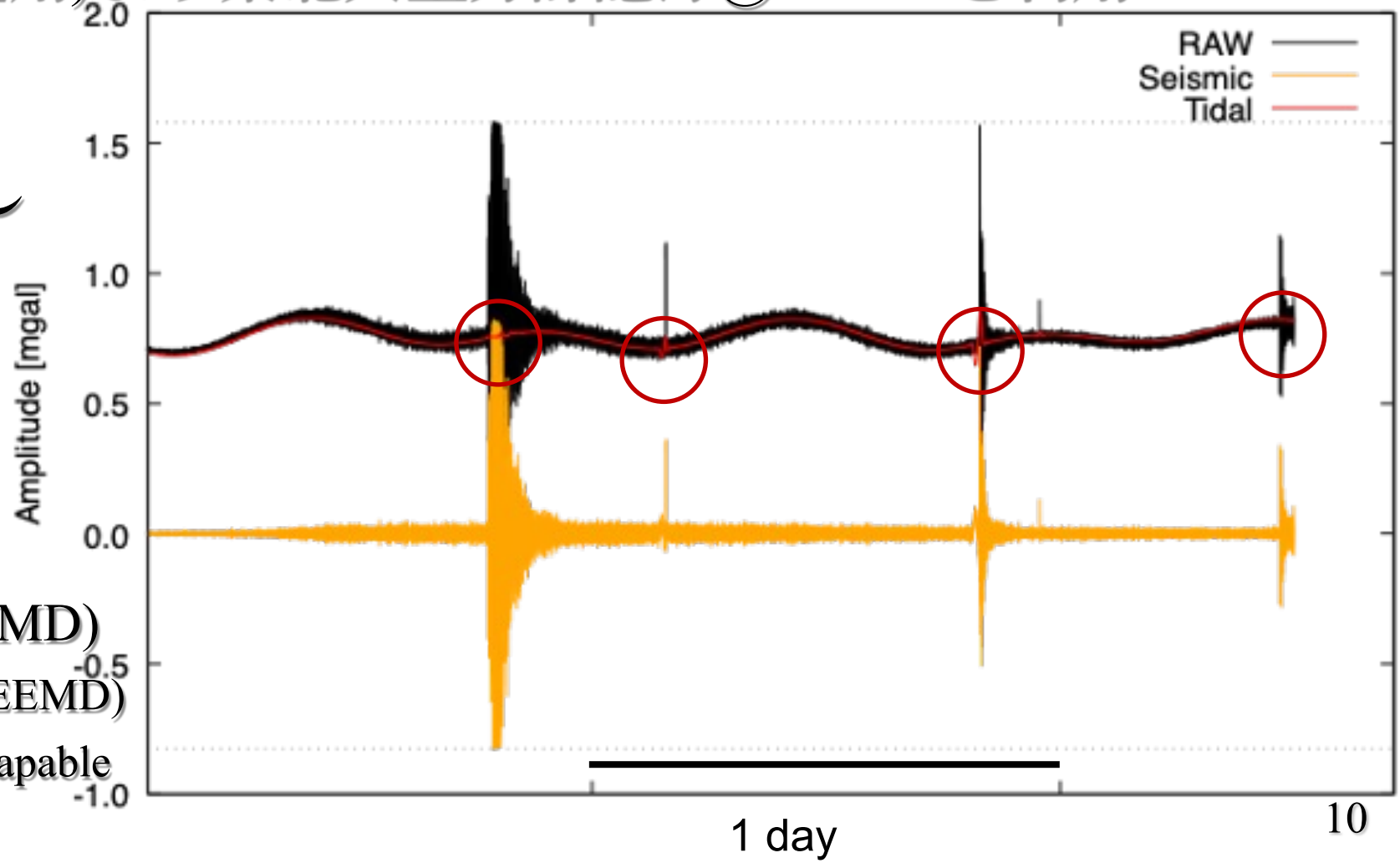
- Super-conductivity Gravitimeter (1 sec, 3 days data):
  - ⇨ Tidal effects
    - ⇨ Earthquakes (HT detectable)
- Laser interferometry extensometer (1 min, 3 months data):
  - ⇨ Annual variations,
  - ⇨ *Tidal effects*,
    - ⇨ Earthquakes (HT detectable)

- Strainmeter/Seismometer (20 Hz strain, 200 Hz ground velocity):
  - ⇨ electrical noise

Super-conductivity Gravitimeter (Miura%Tohoku)

- 地殻変動DB(北大運用)より東北大重力計記録@Alaskaを利用
  - 振幅飽和波形
- 潮汐変動に染み出し
  - 波形飽和時
  - オフセット変化時
  - 変動中心のずれ

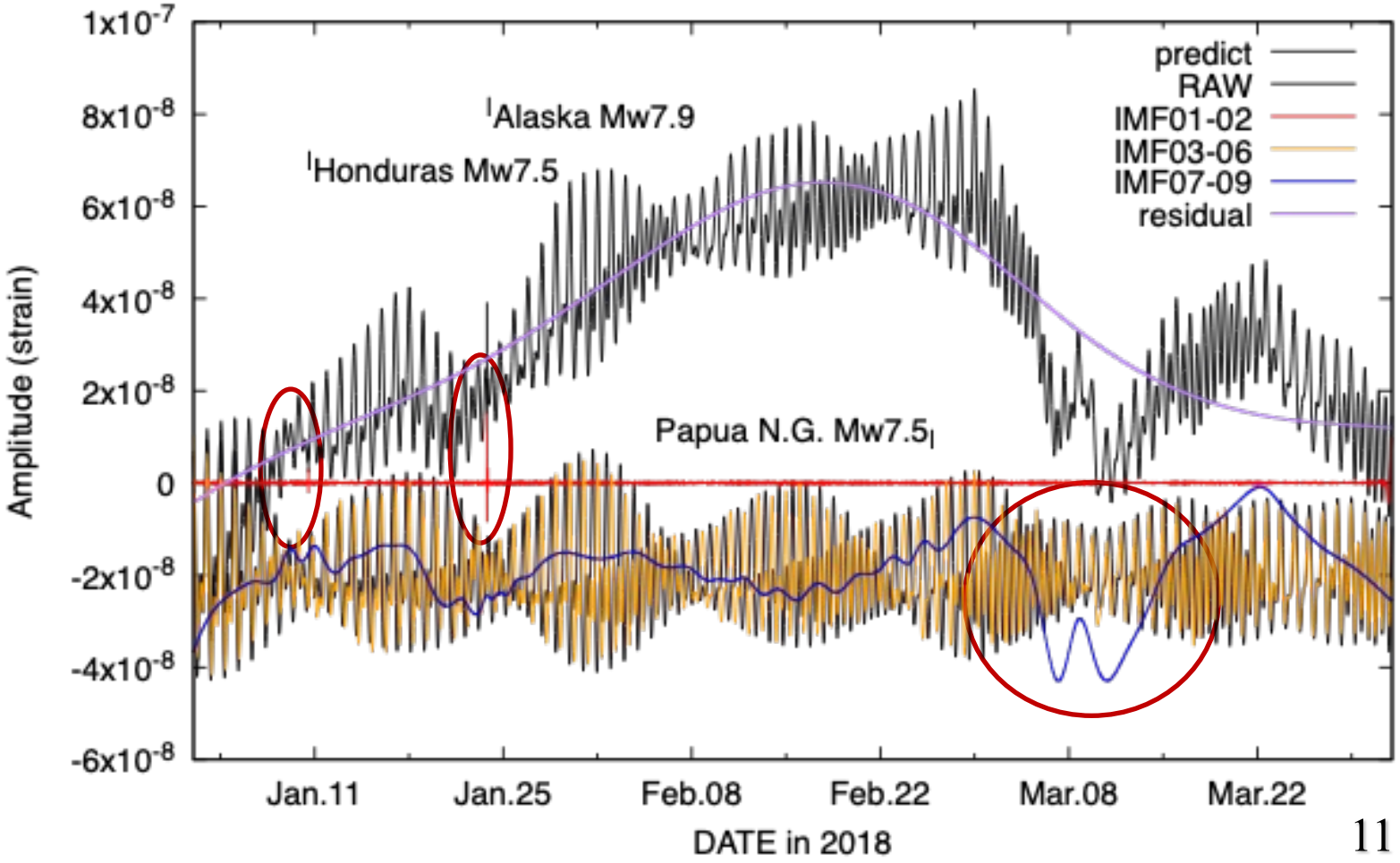
片振幅 → 両振幅 (EMD)
→ Wavelet状 (EEMD)
HT capable



Laser interferometry extensometer (Araya%ERI)

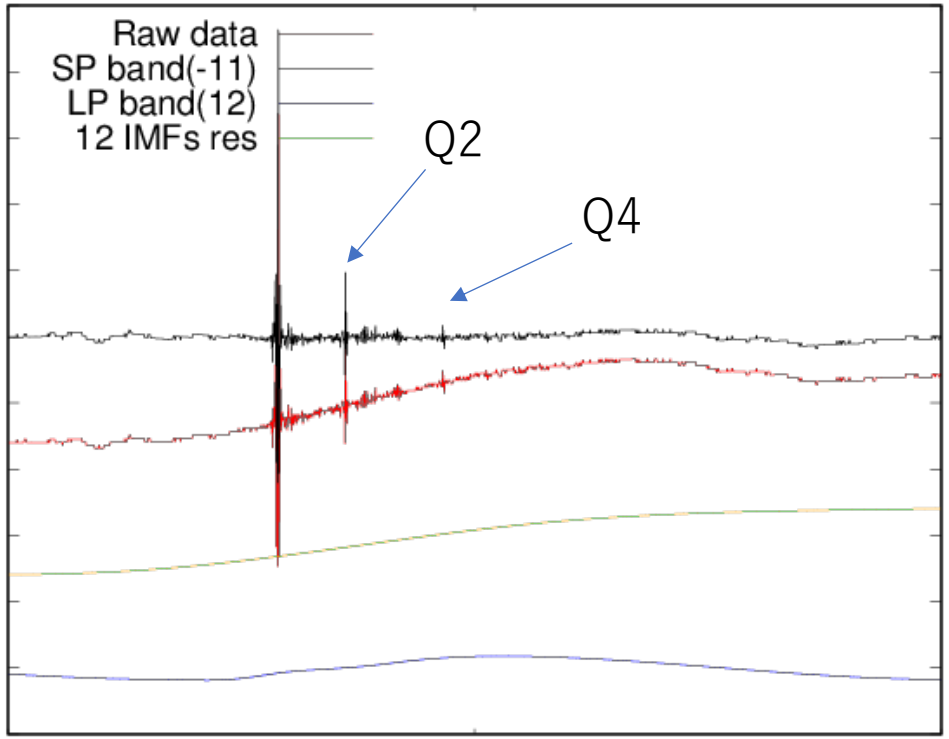
- 長期トレンド成分の抽出
  - 季節変動？
- 地震動変動の除去
  - Honduras (M_W7.5)
  - Alaska (M_W7.9)
- 潮汐成分の抽出
  - 位相ずれごくわずか
  - 振幅ほぼ同様

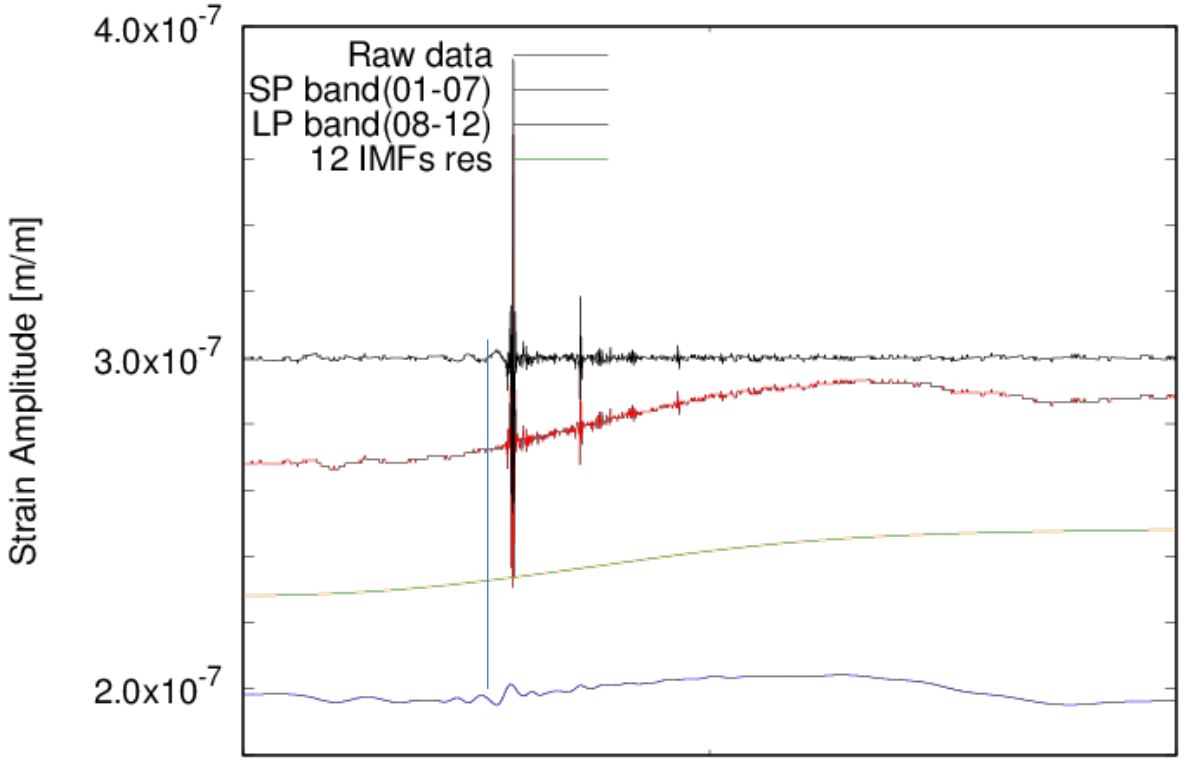
    → non-mean-less?



Amplitude interaction/exchange between IMFs

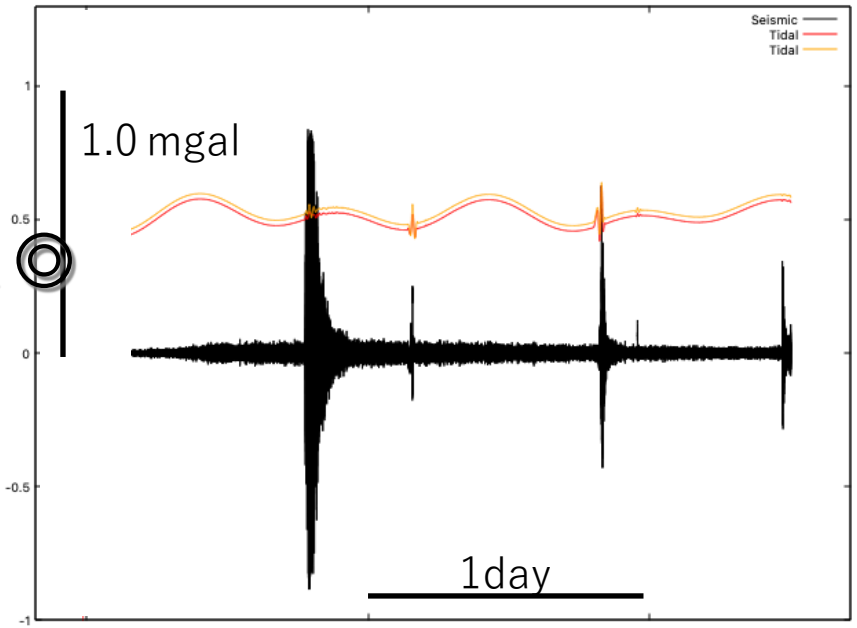
- EEMDによるモード分離は周波数に一対一対応していない
- モード間で信号の染み出しが存在　⇨　不要信号除去後の再合成





What are suitable data for HHT

- オフセット変化：EEMD ✕／△
  - より短周期のIMFへの染み出し
  - 長周期側IMFに反動　⇨ HT event detection ◎
  - オフセット量は保存　⇨ Time reversal estimation ◎
- 周期変動：〇 (モード間振幅比大：◎)
  - 長周期帯での振幅急変部分：〇／△
    - モード間の染み出し ⇨ モード再合成



- 振幅飽和：△(EEMD)
- 振幅の偏り：△ (EEMD)
  - 長周期変動としての fake signals

⇨ HTにより信号検出，モード再合成

Conclusions

Ensemble Empirical Mode Decomposition Application for Geophysics:

Useful to decompose the crustal deformation records.

Single configuration for various targets

e.g. electrical noise, seismic waves, tide, and season/annual variations

*Transitional impulses, saturated amplitude: partially

Future/remained works:

Records re-construction after statistically IMFs evaluation

or Statistically evaluation before EEMD

Possibility for hetero-data joint analysis

e.g. precipitations, barometric pressure, and more

Have a Break !