ANALYZING THE EFFECT OF EARTHQUAKE CORRECTION ON GRACE-DERIVED DROUGHT INDICATORS

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MOTIVATION


Credit: NASA JPL/Caltech

- Satellite missions GRACE (Gravity Recovery and Climate Experiment) and GRACE-FO (GRACE-Follow On)
- GRACE measured mass redistributions of the Earth

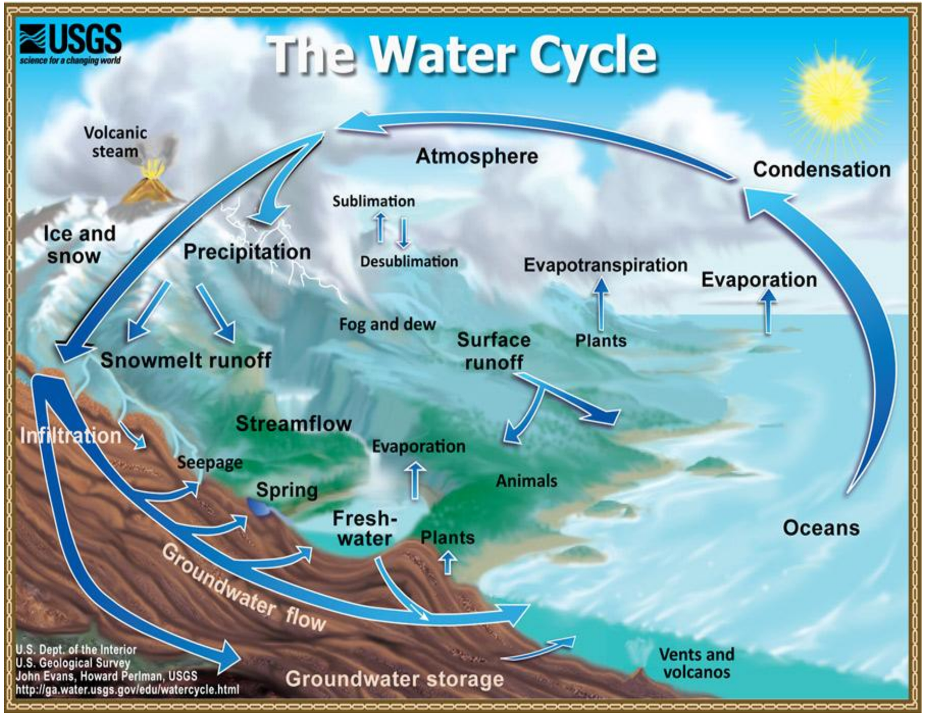
BARRIER

- Not only hydrological signals cause mass redistributions but also, among others, large earthquakes
- Large earthquakes mask the observation of other hydrological processes

GLOBAL WATER CYLCE

- GRACE measurements are transformed to **total water storage anomalies (TWSA)**
- **TWSA** include groundwater, surface water, soil moisture, snow and ice
- In-situ observations of the global water cycle are sparse

  → GRACE offers great possibility to observe changes in all water storages with **global** resolution from space
- Analyzing single storage might be insufficient for processes like drought detection



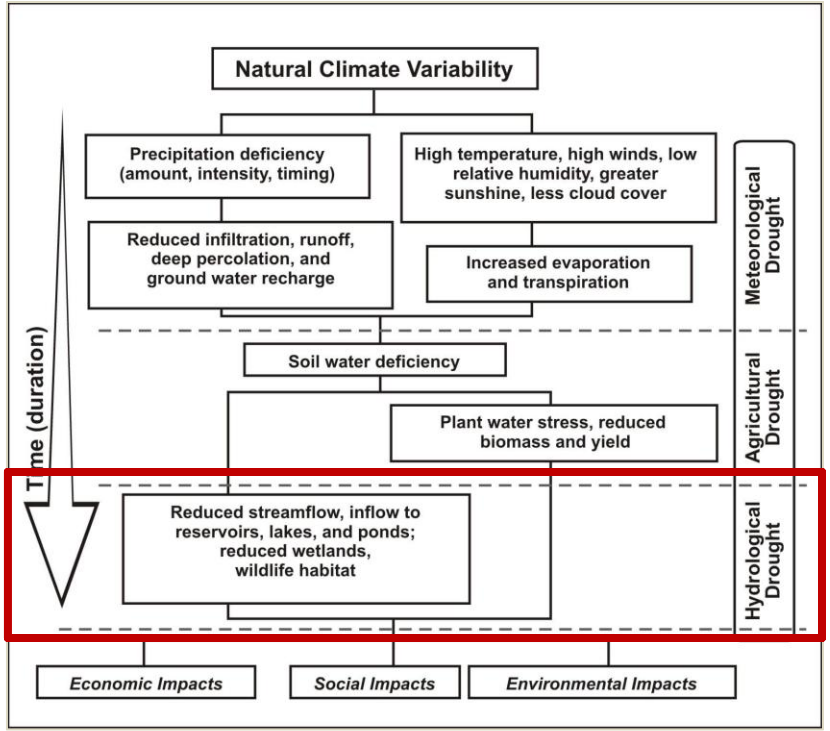
DROUGHT

Hydrological drought

… is one of the processes GRACE can observe

… is the effect of precipitation shortfalls on surface/ subsurface water

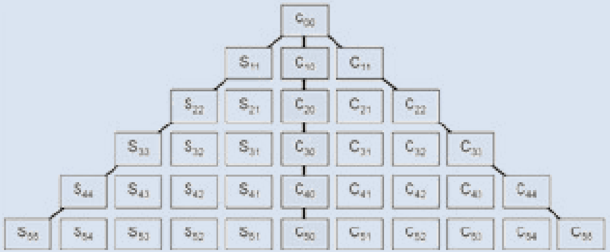
… has a phase shift to meteorological drought



Credit: National Drought Mitigation Center, University of Nebraska-Lincoln, U.S.A

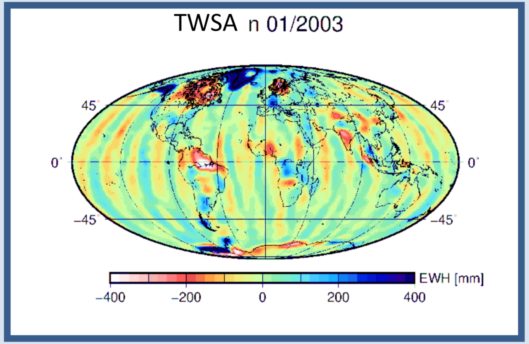
GRACE PROCESSING

GRACE gravity potential coefficients (L2)



Rummel

Total water storage anomalies (TWSA, L3)



Transformation of L2 to final L3 in official processing centers (e.g., CSR, GFZ, JPL)

- Replace degree-1 and c_{20}coefficients
-Spatial filtering
- Removal temporal average
-Spherical harmonic synthesis
- GIA removal

New step included here:

Earthquake correction for large earthquakes (> =M9.0)

EARTHQUAKE CORRECTION

Main processing steps for earthquake correction:

1) Backward modeling of spherical harmonic coefficients (SHC) to geoid changes (L2 to L3) following Wahr et al. (1998)

2) Estimation of earthquake correction based on co- and postseismic signals using a nonlinear Bayes estimator following Einarsson et al. (2010)

$$\Delta GC_{EQ}(\theta_i, \lambda_j, t) = C_{v_{co}} H_{t_v}(t) + C_{v_{post}} H_{t_v}(t) \left(1 - e^{-\frac{t - t_v}{\tau}}\right).$$

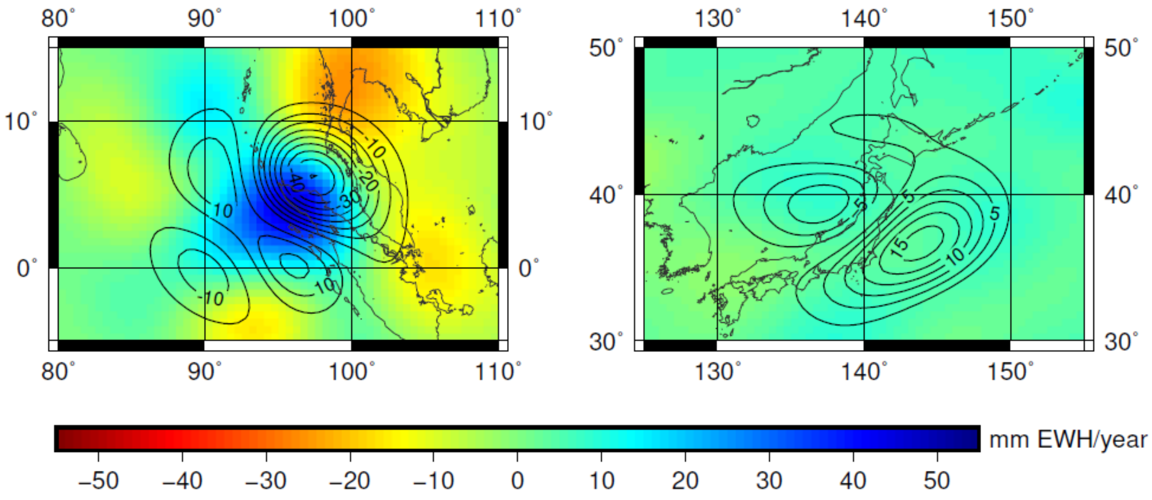
Co- and postseismic model coefficients
Heaviside step function
Delayed onset of postseismic relaxation
Relaxation constant
… of respective earthquake v

3) Forward modeling of geoid changes to spherical harmonic coefficients (L3 to L2)

- Processing of SHC to TWSA (L2 to L3) continued

GRACE LINEAR TRENDS – EARTHQUAKE CORRECTED

Sumatra-Andaman   Tohoku



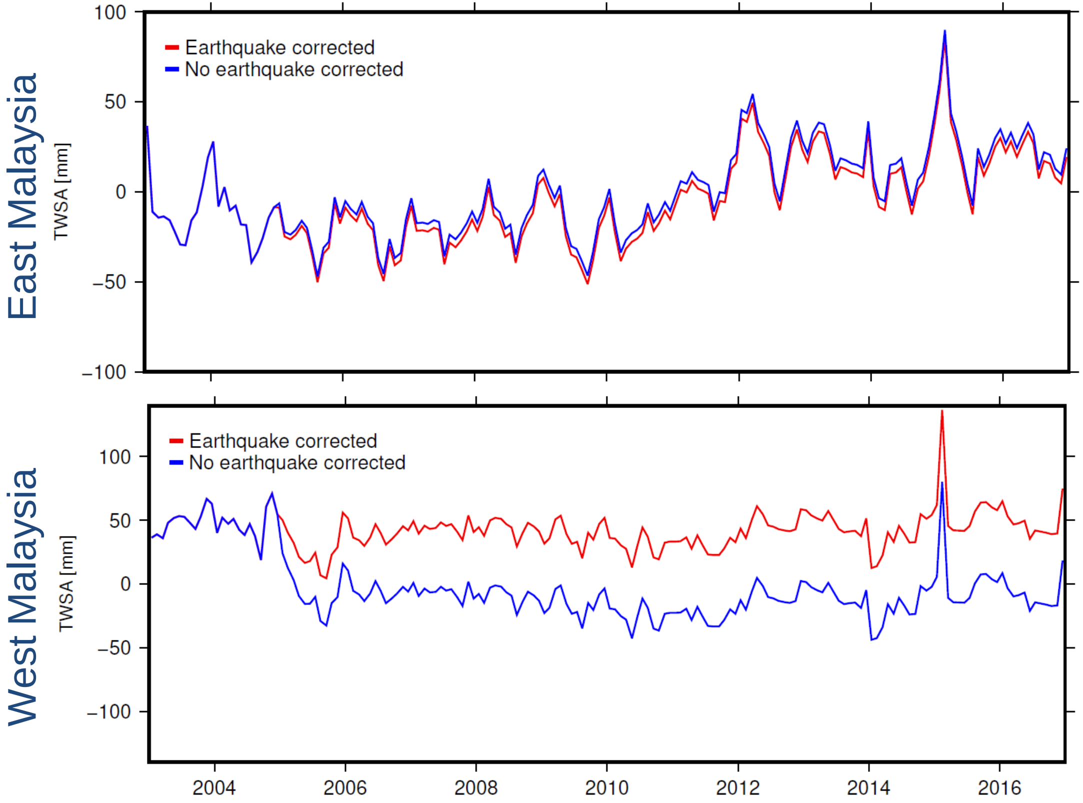
- Earthquake correction applied for Tohoku earthquake in 2011 (M9.1) and Sumatra-Andaman earthquake in 2004 (M9.1)
- Contour lines show difference of uncorrected minus corrected trends
- Larger trend differences over Peninsular Malaysia

→ Earthquakes potentially masks other signals in this region

Download earthquake corrected TWSA:
https://www.apmg.uni-bonn.de/daten-und-modelle/grace-monthly-solutions

Deggim et. al, in preparation

COMPARISON OF CORRECTED AND UNCORRECTED TWSA IN MALAYSIA



- East Malaysia shows minor differences between corrected and uncorrected TWSA
- West Malaysia (or Peninsular Malaysia) shows a strong decrease in uncorrected TWSA end of 2004 resulting from the earthquake
- The corrected TWSA do not contain the strong decrease

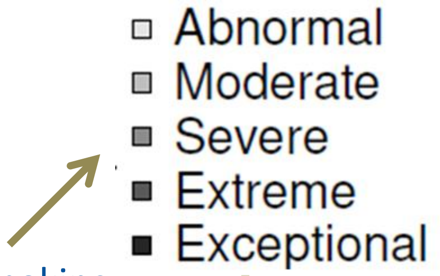
→ Has the correction an effect on drought identification over Peninsular Malaysia?

Deggim et. al, in preparation

DROUGHT INDICATORS

INDICATORS FOR HYDROLOGICAL DROUGHT

- Characterization (retroperspective), monitoring and triggering management plan for drought
- Usually based on single fluxes (e.g. streamflow, reservoir levels)
- Here based on GRACE TWSA
- Describe severity, location, timing and duration of drought
- Indicator values are classified into severity classes to enable e.g. policy making
- Problem: No validation of drought indicators
- Framework that compares GRACE-based drought indicators and analyzes the propagation of drought through these indicators: Gerdener et al. (2020)



GRACE-BASED DROUGHT INDICATORS: ONE EXAMPLE

Basics

GRACE-based Drought Severity Indicator (DSI)

- Used in Zhao et al. (2017)
- Standardization wrt. climatology

Equation

$$DSI_{i,j} = \frac{TWSA_{i,j} - \overline{TWSA_j}}{\sigma_{TWSA_j}}$$

'Climatological' mean of TWSA of month i over all years

'Climatological' standard deviation of TWSA of month j over all years

j … month, i … year

Severity classes

Output of DSI is classified into these five drought severity classes

Drought Severity Level	GRACE-DSI
Abnormal	$-0.8 < Z_{i,j} \leq -0.5$
Moderate	$-1.3 < Z_{i,j} \leq -0.8$
Severe	$-1.6 < Z_{i,j} \leq -1.3$
Extreme	$-2.0 < Z_{i,j} \leq -1.6$
Exceptional	$Z_{i,j} \leq -2.0$

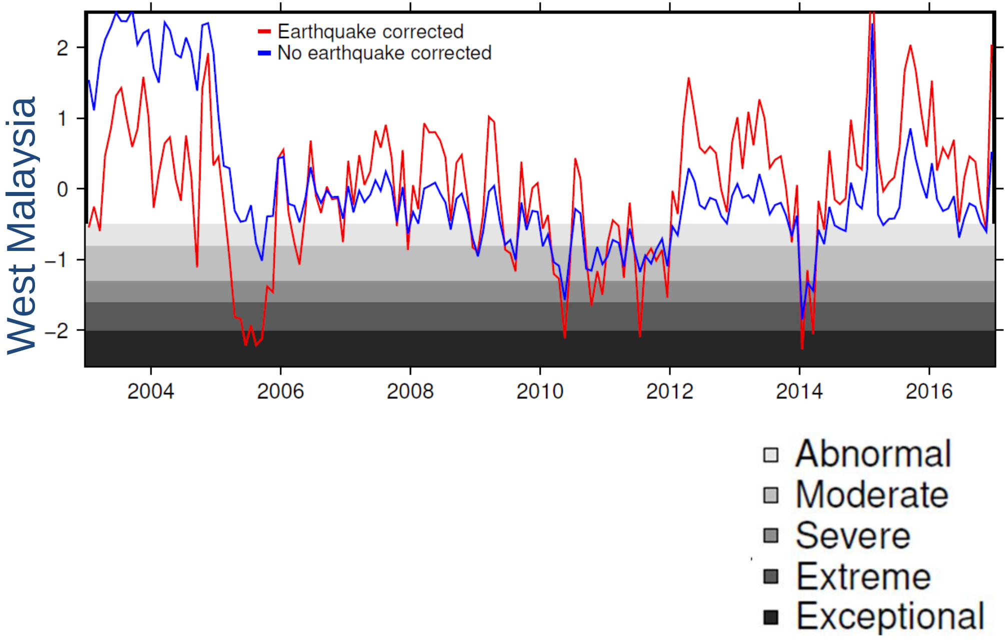
EARTHQUAKE REMOVAL IN WEST MALAYSIA USING DSI

- Uncorrected: 2010/2011 mainly moderate dry, 2014 severe dry
- Corrected: 2010/2011 mainly severe dry, 2005 and 2014 exceptionally dry

  →A third drought identified

  →Droughts more intense

- Findigs are supported by literature (e.g. EM-DAT database, Hashim et al. (2016)
- Strong difference before end 2004, Reason: Indicators are computed w.r.t. climatology



Deggim et. al, in preparation

CONCLUSION & OUTLOOK

Conclusion

1) Drought events are masked by earthquake signals in Peninsular Malaysia, intensity of drought is increased after applying correction

2) Complete period of GRACE indicator time series is affected

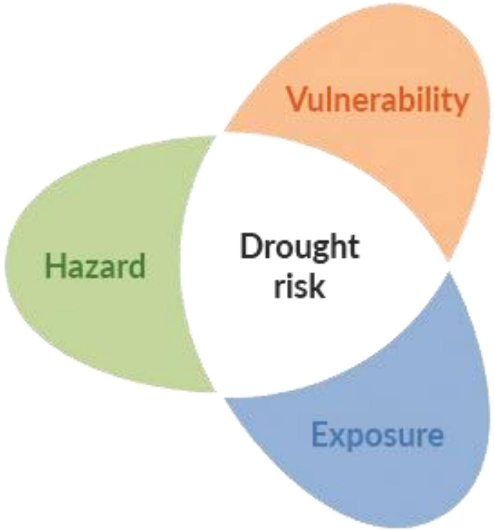
3) Earthquake correction may become a standard tool in GRACE and GRACE-FO time series analysis of level-3 data

Outlook

- Apply methodology to different hydrological processes
- Comparison of findings with model outputs

GLOBE DROUGHT PROJECT

- This work is part of the GlobeDrought project funded by BMBF
- Aim: Developing a web-based drought information system
- Components hazard, vulnerability, and exposure are combined to derive drought risk
- Use GRACE for considering hydrological drought, which is part of drought hazard



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