Introduction

Climate change has a strong impact on hydrologic variables. To investigate the impact of the El Niño phenomenon on terrestrial water storage variation, El Niño / Southern Oscillation (ENSO) index is used to estimate water storage variation through two linear models. The prediction by ENSO is validated against monthly observations from GRACE.

ENSO Index

Figure 1: Regions which ENSO index represents in Pacific Ocean

The ENSO indices show quasi-periodic climate patterns that occurs across the tropical Pacific Ocean.

Methods

Model I

- Considering the different dominant frequency of GRACE and ENSO signals, we build up a linear model which takes the phase delay into account. It describes the relationship between GRACE and ENSO observations at different epochs. In this model, we assume that ENSO signals are always forward to GRACE signals.

\[ \Delta M(t) = \Delta M_0 - \Delta M_1 = \sum_{i=1}^{n} a_i \cdot \Delta S_{e_i} \]

- \( \Delta M_0 \) is monthly water storage anomaly at epoch 0. \( \Delta M_1 \) is the mean for every month. \( \Delta M_0 \) is residual after removing the monthly mean, \( \Delta S_{e_i} \) is monthly sea surface temperature anomaly from ENSO, and \( a_i \) are model parameters for different epochs with prediction step \( p \).

\[ \Delta M_{0,1} = \Delta M_0 - \Delta M_1 = \sum_{i=1}^{n} a_i \cdot \Delta S_{e_i} \]

Model II

- The target of building this auto-regressive model is to combine 4 ENSO indices together, so as to see how they influence the water storage variation.

\[ \Delta M(t) = \Delta M_0 - \Delta M_1 - \Delta M_2 - \Delta M_3 = \sum_{i=1}^{n} a_i \cdot \Delta S_{e_i} + b_i \cdot \Delta S_{e_i+1} + \ldots + h_i \cdot \Delta S_{e_i+p} \]

- \( \Delta M_0 \), \( \Delta M_1 \), \( \Delta M_2 \), \( \Delta M_3 \) represent respectively monthly water storage anomaly, monthly mean and monthly residual at time \( t \). \( \Delta S_{e_i} \) are observations from \( m \) different ENSO indices, and \( a_i \) and \( b_i \) are model parameters with various lead time \( p \) in months.

\[ \Delta M_{0,1,2,3} = \sum_{i=1}^{n} a_i \cdot \Delta S_{e_i} + b_i \cdot \Delta S_{e_i+1} + \ldots + h_i \cdot \Delta S_{e_i+p} \]

- Different from Model I, this model contains more information in spatial domain and less information in time domain.

Metrics for performance analysis

- Nash-Sutcliffe Efficiency (NSE)

\[ NSE = 1 - \frac{\sum_{i=1}^{N} (Y_i - \bar{Y})^2}{\sum_{i=1}^{N} (Y_i - \bar{Y})^2} \]

- \( Y_i \) is the modeled data, \( \bar{Y}_i \) is the observed data, and \( \bar{Y} \) is the mean of observations.

- NSE with respect to monthly mean (NSE)

\[ NSE = 1 - \frac{\sum_{i=1}^{N} (Y_i - \bar{Y})^2}{\sum_{i=1}^{N} (Y_i - \bar{Y})^2} \]

- \( Y_i \) is the modeled data, \( \bar{Y}_i \) is the observed data, and \( \bar{Y} \) is the monthly mean of observations.

Results: Model I

Model parameters are solved by using a least-squares regression with data in training period, and Nino 3.4 was used here to predict water storage variation.

ENSO Index

Figure 2: 4 ENSO indices

Figure 3: Power spectrum of 4 ENSO indices time series. All of them show strong frequency at or close to 0.34 and 0.65, which presents 3-year and 1.5-year cycle.

Results: Model II

Four ENSO indices are used here to estimated water storage variation through model. Because of the time lag between GRACE and ENSO after El Niño happened, we test the sensitivity of prediction to different lead time \( \tau \).

Here is an example of Amazon basin in South America to show the performance of the model.

ENSO Index

Figure 4: NSE for each grid cell between observations from GRACE and estimation by ENSO with different lead time.

To see how the ENSO influence the catchments on the globe, we do prediction at catchment scale and evaluate the prediction by NSE.

ENSO Index

Figure 5: NSE for 28 catchments in different continents with different lead time. The catchments with NSE above 0.5 are influenced greatly by ENSO.

Here are prediction time series shown as examples from four catchments (Niger in Africa, Yangtze in Asia, Danube in Europe, and Amazon in South America), which are influenced by ENSO.

Conclusion

- Model I has better performance than Model II on predicting water storage at catchment scale.
- Model I can be applied to predict the water storage variation in catchments, and for different catchments, we need to choose an optimal lead time.
- Model II has potential to combine more different climate indices together to predict water storage variation.
- ENSO index has influence on water storage variation in catchments, which might help to analyze the hydrological cycle, and also to fill the potential GRACE gaps in the future.

References


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