Response to the referee comment for article hess-2016-313

Note: The text in black is the original comments from the referee, and the text in blue, headed with "Reply", is the response from the authors.

This manuscript aims to identifying the water deficit under an extreme drought in North China by using the GRACE data, and comparing with the response of vegetation, towards the implications for the well-known South-to-North Water Diversion (SNWD) project. It is not new to investigating the GRACE-derived water storage changes under droughts. As the author mentioned that several previous studies have done this with varying focuses, but it remains very interesting in the North China, where the water shortage is aimed to be mitigated by the SNWD. Besides, due to the differences on the drought characteristics such as duration and severity, the detection and variation of GRACE-derived water storage changes may vary from place to place. Thus, this manuscript addressed a good scientific question and may attract interests from the community of hydrology, geodesy, and even the public people. To achieve above purposes, the study derived the total water storage anomalies (TWSA) and groundwater storage anomalies (GWSA) from GRACE time-variable gravity data, and compared it with model simulations and LAI. The method used in this study is generally appropriate and the result is reliable. However, some efforts may still be needed to improve the quality of this manuscript and make it easier to be understood.

Reply: We greatly thank the reviewer for the constructive comments. According to the comments and suggestions, we provide more information here and we will improve our manuscript. The detailed point-by-point responses are listed below.

Major Comments

Comment 1

Section 2.3.2, Evaluation of GRACE TWSC: This manuscript compares the so called net recharge (this name is confusing, actually it is commonly written as dS/dt or TWSC in many papers) derived from GRACE and land surface models. It should be noticed that in Equation (2), the runoff should be the net runoff (i.e. outflow minus inflow). Since the North China is a self-defined region with a shape of rectangle, it is definitely not a closed basin. How is the net runoff calculated? Please give more explanations. Instead of the net recharge, there is another way for evaluation, i.e. using the observations of groundwater storage (GWSA) and surface water storage (SWSA), and model simulations of the soil moisture storage (SMSA), with the equation: TWSA = GWSA + SWSA + SMSA.

Reply: The net recharge (i.e., the total water storage change, dS/dt) can be calculated with two approaches. One is the water storage-based approach as mentioned above by the reviewer. This approach depends on multi-source data, including GRACE (for TWSA), groundwater storage measurement (for GWSA), surface water storage measurement (for SMSA) and soil moisture simulation/measurement (for SMSA). So this approach may induce substantial known/unknown uncertainties in the evaluation of GRACE. The other one is the flux-based approach used in this study (i.e, $\Delta S_i =$

$P_i - E_i - R_i$). It requires data only from GRACE and land surface modeling. Moreover, the precipitation (P), evapotranspiration (E) and runoff (R) are consistent because they are from the same land surface model (VIC or NOAH). Therefore, we employed the flux-based approach.

The runoff (including surface runoff and subsurface runoff) simulated by the land surface models (VIC and NOAH) is for each grid cell at 0.25-degree resolution, and it generally flows through the study area in a period less than one month. The 0.25-degree simulation data were aggregated to the entire area of North China and then used in Equation (2). So it does not matter whether the area is a close basin or not.

Comment 2

Section 4.2, Vegetation response: More deep analysis is needed to figure out the vegetation response under the drought. For example, can the monthly LAI help to interpret the response while compared with the monthly TWSA?

Reply: This is a useful suggestion. The TWSA represents the changes including surface water storage, soil moisture and groundwater storage. Soil moisture generally has larger impact on the LAI change than the TWSA does. So we analyzed the correlation between LAI and soil moisture. The result is shown below (Figure 1). The variations of LAI and soil moisture have similar patterns. Both reach the low points in 2009 and their Pearson correlation coefficient is up to 0.74. Please note the state of LAI is impacted not only by soil moisture and but also by human activities (e.g., crop

planting). Moreover, the spatial distribution of the LAI reduction in 2009 is consistent with the soil moisture deficit to some degree (Please see Figures 1 and 2 and related discussions in the response to Referee 2). Therefore, the vegetation growth has been substantially restricted during the 2009/10 drought event.

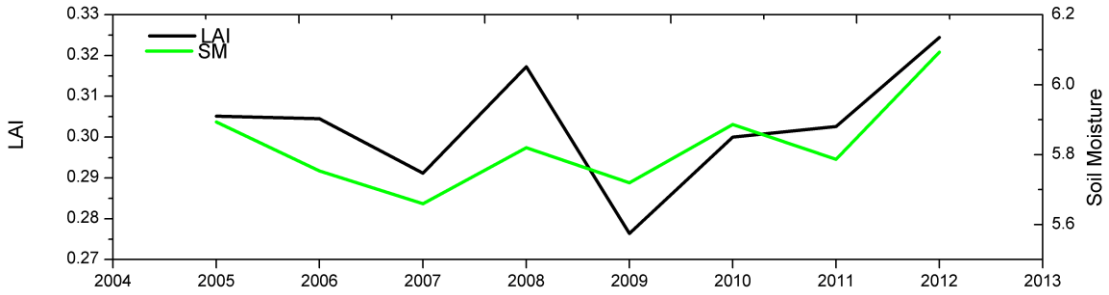

Figure1. Soil moisture and LAI variations during the growth season (May-October) in North China

Minor Comments

Comment 1

Line 22: should be: is one of the most damaging. . .

Reply: We will revise it in the manuscript.

Comment 2

Line 27: 'quality data sets' is confusing.

Reply: 'quality data sets' used here means the GRACE data are acceptable for the total water storage detection. We will reword the sentence in the manuscript.

Comment 3

Line 111: please point out the GRACE data used is Level-2 or Level-3.

Reply: The GRACE data used is Level-2.

Comment 4

Line 120: ‘total water’ should be ‘total water storage’

Comment 5

Line 121: ‘groundwater water change’ should be ‘groundwater storage change’

Comment 6

Line 159: ‘groundwater table’ is better to be replace with ‘groundwater level’

Comment 7

Line 199: ‘to detect groundwater’ should be ‘to detect groundwater storage’

Comment 8

Line 204: ‘groundwater level measured in situ’ should be ‘in situ measured groundwater level’

Reply 3-8: Thanks for these useful suggestions. The manuscript will be improved as suggested.

Comment 9

Line 209: the symbol of G S M C W is not typically used in the GRACE hydrology community, I suggest to using GWSA = TWSA – SMSA – SWSA – CWSA.

Reply:

This expression is acceptable in the GRACE community, but some readers may confuse the multiletter variables. For example, GWSA may be misunderstood as G × W × S × A. So we kept the simple symbols of G S M C W. The other referee (i.e., the editor) suggested such simple symbols.

Comment 10

Line 222: what is precipitation deficit? I can not understand how is the 14 mm and 47

mm derived.

Reply: Precipitation deficit is the difference between the precipitation of a period and the long-term mean. So the precipitation deficit of 14 mm is the total precipitation during 2009/10 minus a long-term (1960-2012) average precipitation in North China.

Comment 11

Line 253: 'fluctuations' better to be replaced with 'amplitude'.

Comment 12

Line 261: 'departure' is not easy to understand, usually we use 'anomaly' or 'difference'.

Reply 11-12: Thanks. The manuscript will be revised as suggested.

Comment 13

Line 262: it is hard to say the drought events mainly occur in the south of North China, as the groundwater exploitation is complicated in space.

Reply: We agree that the groundwater exploitation is complicated in space. Please note drought occurrence generally means more groundwater exploitation.

The total water storage is especially low in the south of North China during 2009/10, comparing to other areas where anomalies above zero. After the drought event, the total water storage recovers to some degree. So the drought impact is severer in the south of North China.

Comment 14

Line 264: 'normal' or 'average'?

Reply: Both words are right here, while I think the 'normal' to modify a condition or

state is better.

Comment 15

Line 275: ‘public supply’ should be ‘domestic use’

Comment 16

Line 283: ‘downward’ should be ‘decreasing’

Comment 17

Line 287: delete ‘approximately’, same in many other places throughout the manuscript

Comment 18

Line 311: ‘groundwater decline’ should be ‘groundwater level decline’

Comment 19

Line 352-354: references are not commonly found in the conclusion section

Reply 15-20: Thanks for the valuable suggestions.

Comment 20

Figure 1: the year for annual precipitation, long-term mean or some specific year?

Reply: It is the long-term mean annual precipitation.

Comment 21

Figure 1: ‘Groundwater Gauge Stations’ should be ‘Groundwater Level Monitoring Wells’

Reply 21: Will be revised as suggested. Thanks.

Comment 22

Figure 2(b): do not use abbreviation for the name of y-axis

Reply: We will replace it as difference.

Comment 23

Figure 2(a): what is the time for annual average, 53-year mean?

Reply: Yes, the annual average is the mean from 1960 to 2012.

Comment 24

Figure 3(b): No name for the x-axis in the small figure inside. The green histogram and red dots seems represent the same thing. If not, please give more explanation.

Reply: The histogram shows each year's precipitation ordered from high to low, while red dots represent each year's probability using Weibull equation (Helsel D, 2002).

Comment 25

Figure 5: What is the meaning of '/' in 'May/Jun 2009' and the others? Is it the average TWSA of May and June 2009? Please make it clearer.

Reply: Yes, 'May/Jun 2009' is the average total water storage anomaly of May and June 2009.

Comment 26

Figure 7: The name of the right y-axis should be 'Equivalent Water Height (mm)'

Reply 26: Thanks for your valuable suggestions.

Reference:

Helsel D, H. R.: Statistical Methods in Water Resources Techniques of Water Resources Investigations, U.S. Geological Survey, chapter A3 of Book 4, 2002.