**Journal:** Biogeosciences

**Special Issue:** Ecosystem processes and functioning across current and future dryness gradients in arid and semi-arid lands

**Manuscript Title:** Relating historical vegetation cover to aridity index patterns in the greater desert region of northern China: Implications to planned and existing restoration projects

**MS No.:** bg-2016-376

**Dear Editor,**

Thank you very much for your effort. We have revised the manuscript according to the comments of the reviewers and responded point-by-point to their comments, as listed below. I would like to re-submit the revised manuscript and hope you find it acceptable for publication in Biogeosciences. Looking forward to hearing from you.

With kindest regards.

Yours Sincerely

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Response to Reviewer 1

**General comments:**

*The paper addressed relevant scientific questions within the scope of BG. Based on long-term meteorological records, this research work analyzed the impact of climate change on the trends in aridity (aridity index), and vegetation cover (satellite-based NDVI) in the greater desert belt of N China. Trend analysis indicated that the overall environmental conditions were improved in the western desert and declined in the eastern China. The cause-and-effect relationship analysis indicated that aridity controls the majority of change in vegetation cover at the 8-km spatial resolution of this study. This information is useful for re-vegetation projects in this area. This finding is novel.*

**Response:** Thank you for your positive and constructive feedback.

**Specific comment:**  
*Suggestion from the aridity index trend (Fig. 5), the west was getting wetter and the east was getting drier. From NDVI trend (Fig 7), the vegetation had the improving trend in the west, but there are some scattered red regions, which denote the vegetation was declined in these places. The discrepancy between climate becoming wetter and vegetation decline in these local areas could be caused by revegetation programs, which over exploited ground water and cause natural vegetation nearby declined. If this is true, it will support the recommendation of the paper that more information, such as tolerance of vegetation cover in an environment of increasing demand for water by residential, agricultural, and industrial sectors, be obtained to ensure socio-economic and ecological sustainability of dryland systems. I would suggest the authors discuss it in the manuscript.*

**Response:** As per the reviewer’s suggestion, we address the discrepancy in lines 25-30 of page 9 as follows:

However, vegetation in some scattered areas in the western desert region (denoted by the small red areas in Fig.7) have shown to have undergone some level of decline, notwithstanding improvements in precipitation overall. Discrepancy with regional wetting and vegetation decline is most likely relate to the presence of small-scale re-vegetation projects or prevalence of land use practices associated with resource over-exploitation and over-grazing. Many re-vegetation projects rely on the exploitation of groundwater, which may cause natural vegetation nearby to decline because of insufficient water (Cao, 2008; Cao et al., 2010).

Response to Reviewer 2

**General comments:**

*The desert ecosystems are vulnerable to climate change, particularly its effect on vegetation development. Previous study on climate change in desert regions of north China was mostly focused on large-scale modelling of arid climate features. This manuscript provides a local to regional-scale analysis of climate changes in the greater desert belt of north China, based on long-term meteorological records, aridity index (AI) and satellite-based NDVI calculation. The obtained results are quite interesting, particularly the change in precipitation which shows“dry areas becoming wetter and wet areas becoming drier”in the north China deserts, an opposite trend compared to global observations. The research plan in this manuscript is sound and overall presentation is well structured. However, some weaknesses may need to be clarified/ improved.*

**Response:** We appreciate reviewer #2’s positive and constructive feedback.

**Specific comment 1:**

*In general, the writing quality in the sections of “Introduction” and “Results” is obviously low, compared with Abstract and Discussion. It would be worth improving the writings accordingly. My specific suggestions are to:*

1. *Re-write the paragraph at Page 2 Line 13-20. Maybe start with a key sentence stating general research findings and pay an attention on linkage of context.*

**Response:** According to the comments, we have revised the “Introduction” and “Results” sections of the manuscript. For logical flow, we have re-written the paragraph on page 2, line 9-28 (lines 13-20, in the original manuscript) as follows:

Extended periods of dryness can alter local-to-regional biogeochemical cycles and key ecosystem functions and services and, in the process, enhance regional desertification ([Delgado-Baquerizo](http://www.nature.com/nature/journal/v502/n7473/abs/nature12670.html#auth-1) et al., 2013). Knowledge regarding drying and wetting trends regionally is critical for proper planning and management of land and state resources, including their allocation and deployment, to ensure the sustainable development of vulnerable desert environments.

Previous studies have indicated that increasing precipitation and subsequent wetting in northwest (NW) China during the past 50 years represents a major climate signal anticipated to persists for some time into the future (Wang et al., 2007; Xu et al., 2010; Huo et al., 2013; Li et al., 2013 and 2016). Some drylands in northern (N) China have been reported to have undergone some expansion in the last 50 years with their boundaries extending eastward to NE China by about 2° of longitude and southward to the middle-to-lower reaches of the Yellow River by about 1° of latitude (Li et al., 2015). This expansion has led to water scarcity and land degradation in many parts of the region. Differences in wetting and drying patterns across China are clearly not uniform, potentially condemning many existing and planned re-vegetation projects in N China to failure.

Earlier studies addressing the variation and long-term patterns of aridity in N China are generally unsuitable for ecological-restoration-project planning because of their coarse spatiotemporal resolutions. Precipitation, air temperature, and aridity patterns over large areas vary in both space and time as a result of differences in climatic regimes induced by differences in geographic placement, synoptic-scale weather patterns, topography, prevailing wind directions, proximity to sources of moisture, and other controlling configurations. Spatial variation in related eco-hydrometeorological variables in N China have yet to be investigated at spatial resolutions appropriate for ecological-restoration planning. Under the background of climate change, it is largely undetermined if aridity patterns in N China, particularly at sub-regional scale resolutions (e.g., < 10-km resolution), have changed appreciably over the past 50 years.

**Specific comment 2:**

*Revise the sentence at Page 6 Line 19-21, such as: “The increasing trend is statistically significant and strongest in the northern-half of the western desert region (p < 0.05). Comparably, a decreasing trend, though not statistically significant (p > 0.05), was observed in the eastern part of the study area, affecting about 30% of the greater desert region.”*

**Response:** We revised the sentence on page 6, line 23-27 as follows:

The results show that during the observation period (1961-2013), an increasing trend in precipitation occurred within about 70% of N China, mainly in the western half of the greater desert region, with a particularly strong, statistically significant trend in the northern-half of that region (*p* < 0.05; Fig. 1). Whereas, a decreasing trend, though not statistically significant (i.e., *p* > 0.05), was observed to have occurred in the eastern part of the study area, affecting about 30% of the greater desert region.

Response to Reviewer 3

**General comment 1:**

*What are the merits of the research? Is the merging of AI calculations with space-borne evidence of vegetation change novel here? What about the usage of convergent cross mapping? Are the results of the analysis supported by prior studies of this kind? The authors should highlight them in the discussion.*

**Response:** We merged AI calculations with space-borne evidence of vegetation change and use convergent cross mapping to investigate their cause-and-effect relationship. We highlighted the merits in the “Concluding Remarks” section (see page 10, lines 12-16 in the re-submitted manuscript). The results of the analysis are supported by prior analysis with and without convergent cross mapping (see page 9, lines 32-33).

Page 10, lines 12-16: We present a new framework in the analysis of climate change and associated trends in aridity and vegetation cover in the greater desert belt of N China. We use convergent cross mapping to investigate the cause-and-effect relationship between aridity and NDVI, as well as other variables. The framework, combined with convergent cross mapping, provides a means to assess historical climate change impacts on vegetation dynamics and ecosystem function and services, important for decision-making.

Page 9, lines 32-33: Many of the conclusions drawn from this analysis are consistent with those reported in Brookshire and Weaver (2015).

**General comment 2:**

*In terms of convergent cross mapping and the lack of feedback between AI and NDVI, does this support the current state of knowledge about the relationship between these two variables? The authors should try to expand/elaborate on the extent that this may or may not be true. The proposed reason of spatial resolution coarseness may be right, but is this understanding supported by the scientific literature? Corroborative evidence in the existing literature would help firm this explanation as a possibility; so, more insight on this issue is needed in the discussion part.*

**Response:** Yes, in terms of convergent cross mapping and feedback between AI and NDVI, this is supported by the current state of knowledge about the relationship between these two variables. The statement is highlighted on page 10, lines 14-16 in the re-submitted manuscript. The reason associated with spatial resolution coarseness provided, is supported by the scientific literature. New references have been added in the reference list; please refer to page 9, lines 14-18 of the main text.

Page 10, lines 14-16: The framework, combined with convergent cross mapping, provides a means to assess historical climate change impacts on vegetation dynamics and ecosystem function and services, important for decision-making.

Page 9, lines 14-18: Clearly, the integrity of the vegetation cover assessed at moderate resolutions (i.e., 8-km resolution) is more greatly influenced by changes in mesoscale-to-synoptic scale circulation patterns (Ye et al., 2013) and the delivery of glacial meltwater to the oases in the west (Bourque and Matin, 2012; Matin and Bourque, 2015). Prominence of small-scale land use practices on aridity (e.g., von Hardenberg et al., 2001) and AI, especially those related to over-exploitation and over-grazing (if present), can remain undetected at the current spatial resolution.

**Added citations:**

Ye, J. S., Li, W. H., Li, L. F., and Zhang, F.: “North drying and south wetting” summer precipitation trend over China and its potential linkage with aerosol loading, Atmos. Res., [125-126](http://www.sciencedirect.com/science/journal/01698095/125/supp/C), 12-19, 2013.

Bourque, C.P.-A., and Matin, M.A.: Seasonal snow cover in the Qilian Mountains of Northwest China: Its dependence on oasis seasonal evolution and lowland production of water vapour. Journal of Hydrology, 454-455, 141-151, 2012.

Matin, M.A., and Bourque, C.P.-A.: Relating seasonal dynamics of enhanced vegetation index to the recycling of water in two endorheic river basins in northwest China. Hydrology and Earth System Science, 19, 3387-3403, 2015.

von Hardenberg, J., Meron, E., Shachak, M., and Zarmi, Y.: Diversity of vegetation patterns and desertification, Physical Review Letters, 87(19), 198101-1-4, 2001.

**General comment 3:**

*The statements regarding existing and planned re-vegetation projects. Is there any evidence within the desert belt at the field level that supports some of the conclusions reached in the manuscript, i.e., wetting and vegetation improvement in the west and drying and vegetation decline in the east. Field-based evidence showing some of these trends would help solidify the paper.*

**Response:** Yes, there is some evidence regarding wetting and vegetation improvement in the western part of N China, including Zhao et al. (2011) and Jiapaer et al. (2015); for full citation, see below. Support for this conclusion appears on page 9, lines 21-23, and added citations in the Reference list.

Recent studies have shown that the change from hot-dry to hot-wet conditions have led to an increase in vegetation cover in Xinjiang Province (western part) of NW China (Zhao et al., 2011; Jiapaer et al., 2015).

**Added citations**

Zhao, X., Tan, K., Zhao, S., and Fang, J.: Changing climate affects vegetation growth in the arid region of the northwestern China, Journal of Arid Environments, 75, 946-952, 2011.

Jiapaer, G., Liang, S. L., Yi, Q. X., and Liu, J. P.: Vegetation dynamics and responses to recent climate change in Xinjiang using leaf area index as an indicator, Ecol. Indic., 58, 64-76, 2015.

**General comment 4:**

*According to Regional Climate Model or Global Climate Model projections for N China, are the expectations for western (wetting) and eastern (drying) N China borne out in their future climate projections for the region. The reason why I ask is because the study as you know is based on historical trends; is there any expectation that these trends will continue into the future? An evaluation of modelled trends for the area would help firm up the importance of past trends in describing the potential risk of future climate change to the persistence of existing and planned re-vegetation projects. If there are no expectations that these trends will continue, what is the value of the current research regarding existing and future projects. In the manuscript, the authors state that the trends will continue. Is this supported in the scientific literature and/or climate change projections for the region?*

**Response:** Yes, these trends are supported in the scientific literature; we add a new reference pointing this out (see below). For detailed statements, please refer to page 9, lines 23-25 and lines 30-32 of the new submission.

Lines 23-25: Continued wetting of the western desert region with climate change (Yin et al., 2015) could potentially improve ecological conditions, promote desertification reversal, and reduce reliance on groundwater for crop irrigation.

Lines 30-32: Continued drying in the eastern semi-arid region would likely encumber agricultural operations, vegetation re-growth, and ecological restoration in the Hulun Buir, Horqin, Otindag, Hobq, Mu Us, and Tengger Deserts (Fig. 7) for some time into the future (Yin et al., 2015).

**Added citation**

Yin, Y., Ma, D., Wu, S., and Pan, T.: Projections of aridity and its regional variability over China in the mid-21st century, International Journal of Climatology, 35, 4387-4398, 2015.

**Specific question 1:**

*Page 5, line 10. How are the numbers of “m” and “” calculated? The authors should give more explanation.*

**Response:** We explained “*m*” and “” on page 5, lines 12-13 as follows:

“m” is the number of sets having the same value in a time series, and denotes the number of duplicate data in dataset k.

**Specific question 2:**

*Page 5, line 19. The method of convergent cross mapping is well addressed, but the application of the method in this study is not explained clearly. For example, how the samples were collected?*

**Response:** The application of the method and the sample collection is now addressed on page 6, lines 6-10 in our new submission.

Convergent cross mapping in this study is based on analyzing random paired, co-located time series of NDVI and AI with the *multispatialCCM* R-library developed by Clark et al.’s (2015) in prior work. System embedded dimensions and time delay required as input to *multispatialCCM* were generated with the *pdc* library, also coded in R. Secondary analyses were carried out to explore relationships between different variables (e.g., within-oasis production of precipitation vs. NDVI) in the greater desert region.

**Specific question 3:**

*Page 20, Fig. 7. Based on Figs. 6 and 7, the temporal change of NDVI mainly appears in the climate transition from desert to steppe. The authors should address this in greater detail.*

**Response:** Added statements on page 7, lines 28-30 in the re-submission.

Greatest changes in spatial patterns in NDVI occurred mainly along the transitional zone between the grassland and desert biomes along the vast east-to-west transect (Fig. 7). Temporal changes in NDVI across the desert belt paralleled changes in local-to-regional climate patterns.