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Short Communication

Comments on 'Influences of the Bermuda High and atmospheric moistening on changes in summer rainfall in the Atlanta, Georgia region, USA'

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ABSTRACT: In a recent article, Diem (2012) examined the impact of the North Atlantic Subtropical High (NASH) and atmospheric moistening on summer rainfall variability in the Atlanta, Georgia region. In his paper, he indicated that the results concerning the variability of the NASH western ridge discussed in Li *et al.* (2011) are incorrect. We present new evidence here to show that the comments by Diem (2012) are unjustified; the main conclusions in Li *et al.* (2011) were drawn according to the data over a 60-year (1948–2007) and 45-year (1958–2002) periods of NCEP/NCAR and ERA-40 reanalysis, whereas conclusions of Diem (2012) were based upon the trend analysis of a similar but different index of the NASH using sub-periods of 1948–2009 (since late 1970s). The comment emphases the importance of climate dynamics to study precipitation variability over the Southeastern US and further strengthens the conclusions originally put forth in Li *et al.* (2011): over the last 60 years (1948–2007), the NASH has shown a significant trend of westward movement, and the meridional movement of the NASH western-ridge (i.e. its latitudinal change) has enhanced in the recent three decades.

KEY WORDS Bermuda high; summer precipitation; trends; western ridge

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1. Introduction

In a recent article, Diem (2012) examined the impact of the North Atlantic Subtropical High (NASH) (or Bermuda High) and atmospheric moistening on summer rainfall variability in the Atlanta, Georgia region. In his paper, he asserted that 'the explanation put forth by Li *et al.* (2011) for the increased variability is incorrect. The western ridge of the Bermuda High has not moved westward over the past three decades, in fact, it has moved significantly eastward. In addition, there was no significant change in the latitudinal movement of the western ridge over time.' In this note, we show that the above described differences between Diem (2012) and Li *et al.* (2011) are due to Diem's misinterpretation of the finding of Li *et al.* (2011) and different analysis periods using different, although seemingly similar, western ridge indexes in the two studies. The NASH has shown a significant trend of westward movement during the last 60-year (1948–2007), and the number of summers characterized by large anomalies in the ridge-latitude has nearly doubled in the second 30-year period (1978–2007) relative to the first 30-year period (1948–1977). The recent summer rainfall variabilities are mainly caused by the variability of moisture transport, which is closely tied to the dynamics of the NASH (Li *et al.*, 2013a).

2. Results

2.1. Trend of the westward movement of the NASH western ridge

The results of Li *et al.* (2011) considered the 60-year (1948–2007) of the NCEP/NCAR reanalysis and 45-year (1958–2002) of the ERA-40 reanalysis data set. Figure 3 in Li *et al.* (2011) showed the normalized longitude change of the summer western ridge for the 60-year (NCEP/NCAR reanalysis) and 45-year (ERA-40) period, respectively. The secular trend is significant, as suggested by both data sets. Specifically, the 60-year trend of -1.12° per decade is significant at the

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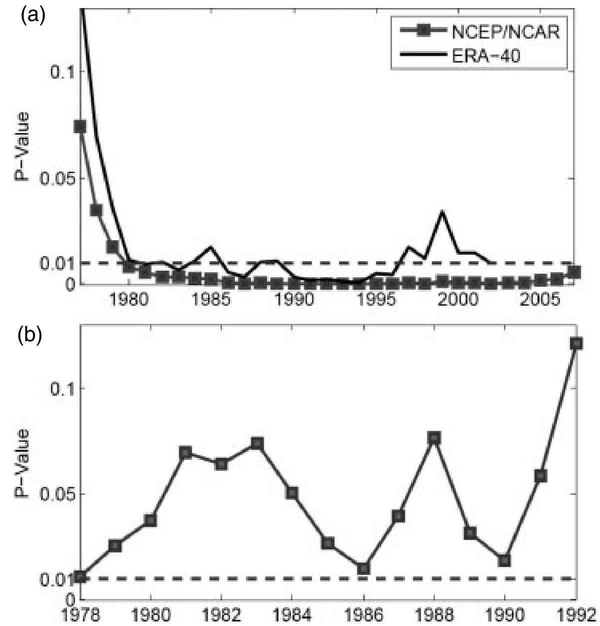

Figure 1. The significance level of the trend in the western ridge longitude with different temporal windows using the Mann–Kendall test: (a) the trend of time series beginning with 1948 (1958) for the NCEP/NCAR (ERA-40) reanalysis and ending at the year in the x-axis; (b) the trend of time series ending at the year 2007 and beginning with the year in the x-axis. The dashed lines in (a) and (b) refer to the 99% significance level. The curves below the dash lines pass the 99% significance test.

99% significance level (Mann–Kendall test) using the NCEP/NCAR reanalysis; and the 46-year trend is -1.17° per decade at the 99% significance level for the ERA-40. The Mann–Kendall tests suggest that westward extension of the NASH western ridge becomes increasingly significant when more years are added in the second period (Figure 1). Thus, Li *et al.* (2011) concluded that the western ridge moved westward relative to its climatological mean position during this period. We further examined the trend of the NASH western ridge for the period 1948–2009, the same period in the studies of Diem (2012). The result confirmed that the westward movement trend of the NASH western-ridge is still significant over this 62-year period albeit at a slight lower level (95%).

Using a different index of the NASH western ridge, Diem (2012) found the 'eastward movement' in the late 1970s when the NASH western-ridge moved to the west (Figure 2). Figure 2 indicates that the mean position of the NASH moved significantly westward (at a level of 99.99%) during the second 30-year period (1978–2007) relative to its position during the first 30-year period (1948–1977). The eastward movement stated in Diem (2012) is likely to be a decadal/multi-decadal signal rather than a long-term secular trend (Li *et al.*, 2011). Since Diem (2012) and Li *et al.* (2011) are essentially discussing secular trends for different periods using different indexes, it is not a surprise to see different conclusions being reached (Figure 2).

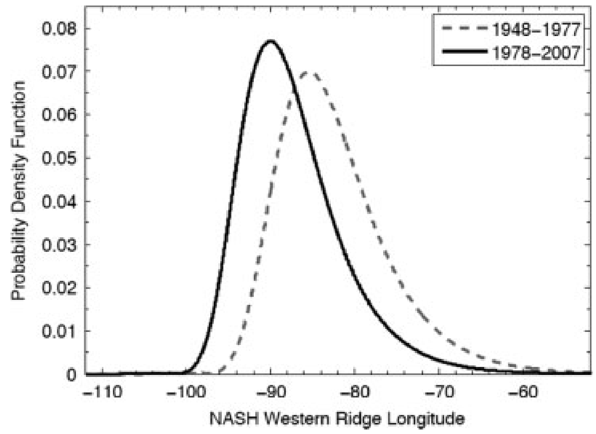

Figure 2. Probability density functions of longitude of the NASH western-ridge fitted for the 1948–1977 (gray) and 1978–2007 (black) based on the 850hPa geopotential height field of NCEP/NCAR reanalysis.

2.2. Enhanced meridional movement of the NASH western-ridge

Diem (2012) found that there was no significant change in the latitudinal movement of the NASH western ridge over time. However, the number of summers with large anomalies in the ridge-latitude, defined as summers with anomalies greater than one standard deviation in the latitude of the NASH western-ridge, has nearly doubled in the second 30-year period (significant at a level of 95% by the chi-square test). The increase in latitudinal movement is also discussed in more details in Li *et al.* (2013b), where the standard deviation of the NASH ridge-latitude increases from 1.03° to 1.60° excluding the outlier 1953, and latitudinal distribution of the NASH western-ridge is visibly wider in the second 30-year period (1978–2007) compared to the first 30-year period (1948–1977). Therefore, Li *et al.* (2011) suggested that the inter-annual variation in the latitude of the western-ridge has increased. The same results can be obtained from the ERA-40, that is, the standard deviation of the latitude of the western-ridge increased from 1.56° during 1958–1976 to 1.93° during 1977–2002.

3. Discussion and conclusions

In this note, we have clarified and strengthened the conclusions originally put forth in Li *et al.* (2011). Over the long-term, 60-year period (1948–2007), the NASH has shown a significant trend of westward movement associated with its centre's intensification (Li *et al.*, 2012b) and the meridional movement of the NASH western-ridge has enhanced in recent three decades.

The 'eastward movement' of the NASH western-ridge in Diem (2012) was based on the trend analysis of a different index of the NASH in recent three decades using NCEP/NCAR reanalysis, whereas the main conclusions in Li *et al.* (2011) were drawn according to 60-year (1948–2007) NCEP/NCAR reanalysis and 45-year (1958–2002) ERA-40 reanalysis data, respectively.

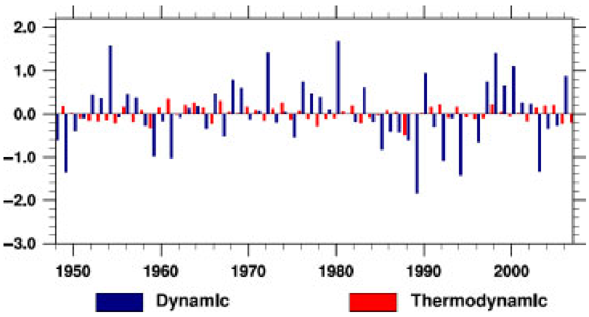

Figure 3. The anomalies of moisture transport over the SE US cause by thermodynamic (due to humidity change, red bars) and dynamic (due to wind change, blue bars) components during 1948–2007 (unit: mm d^{-1}).

Since Diem (2012) and Li *et al.* (2011) are essentially discussing secular trends for different periods, it is not a surprise to see different conclusions being reached (Li *et al.*, 2013b).

Trend analysis in climate field is sensitive to the chosen periods (e.g. Chapman and Walsh, 2007; Stevenson *et al.*, 2012). Diem (2012) also found the westward movement of the NASH western ridge in a longer period of 1948-2009 (Figure 3 also see Li *et al.,* 2013a), same as ours. This points out the need of applying climate dynamics to study precipitation variability over the Southeastern (SE) US besides using trend analysis.

Enhancement of SE US summer rainfall variability in recent decades has been linked to changes of the NASH intensity and its western ridge (Li *et al.*, 2011, 2012a). Over the last 60 years (1948–2007), the NASH has shown a significant trend of westward movement, and its impact on SE US summer rainfall has increased. When the NASH western ridge is located southwest (SW) of its climatological mean position, above normal summer precipitation over the SE US is observed due to enhanced moisture transport driven by the lower tropospheric wind anomalies accompanying the location anomaly of the NASH. In contrast, when the western ridge is located in the northwest (NW), a precipitation deficit prevails as subsidence dominates the region (Li *et al.*, 2012a). In recent decades, both the SW and NW ridge positions have been observed to increase in frequency, leading to enhanced summer rainfall variability in the SE US (Li *et al.*, 2012a). Analysis of the atmospheric moisture budget over the SE US indicates that the increased precipitation variability is mainly caused by the variability of moisture transport which is dominated by dynamical processes (i.e. atmospheric circulation) rather than thermodynamic processes (specific humidity) in recent decades (Figure 3 also see Li *et al.*, 2013a). Such conclusions based on climate dynamic processes of rainfall variability in SE US agree with the results of the trend analysis in Li *et al.* (2011).

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