# *Interactive* comment on "On the Relationship between Teleconnections and Taiwan's Streamflow: Evidence of Climate Regime Shift and Implications for Seasonal Forecasting" *by* Chia-Jeng Chen and Tsung-Yu Lee

**Anonymous Referee #2**

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## General comments

The authors found significant correlation between Taiwan summer (July-September) catchment streamflow and the WP (West-Pacific) and PJ (Pacific-Japan) teleconnection indices, and demonstrated that the correlation relationship is not stable over a period of 50 years by calculating the correlation in a 20-year running window. Significantly high correlation appears only during the years from 1979–1999. The authors further used Rodionov's method to identify the correlation change points and found two significant points at 1988 and 2000. These findings prompted the authors to discuss potential problems of using teleconnection indices as predictors for forecasting seasonal catchment streamflow. Although the subject is of great importance, the authors did not present sufficient scientific evidence to support the argument. I suggest the authors to continue the research and taking the following comments into account. The writing need to be more exact and concise.

We are grateful for the reviewer's insightful comments (special thanks to the notice of the importance of the subject), which we address in detail below. We will incorporate our responses to your comments into our revision, and look forward to the re-evaluation of the article for publication.

## Specific comments

1) P2L19-P2L26: I don't understand the point of this paragraph. "East Asia" is rather big compared with "Taiwan." Why is that "seeking the relationship between Taiwan's climate and large-scale circulations can provide some clue to dissect the mechanisms of East Asian climate?" What are the mechanisms of East Asian climate?

In that paragraph, we merely wanted to use the analogy between the weather systems found in Taiwan and those in East Asia to indicate our findings could be applicable to other East Asian regions. Climate similarity among these areas (e.g., Taiwan and south-to-southeast China) can be identified by employing EOF analysis (e.g., Wu et al., 2009). Nevertheless, we acknowledge that this paragraph might not be precise enough to clearly depict our motivation, and the scale difference between Taiwan and East Asia could be somewhat confusing. As noted by the reviewer too (e.g., next comment), the scope of this study is certainly *not* to scrutinize the mechanisms of East Asian climate. In accordance with your fourth comment below, in the revised article, we will rearrange the two paragraphs in Sections 1 and 2 to compose a new paragraph to emphasize more Taiwan's climates and our motivation. The new paragraph will be as follows:

> *"Several studies (e.g., Wang et al., 2000; Yang et al., 2002; Wang and Fan, 2005; Choi et al., 2012) have witnessed the various effects of teleconnection patterns on East Asian regions, in which an island country Taiwan is situated (Figure 1). Taiwan has an area about 36,000 km$^2$ and features most weather systems found in East Asia, including spring rains, Mei-Yu, and East Asian monsoon from spring to summer, typhoons from summer to autumn, and the Mongolian high pressure system and associated northeast monsoon in winter. Because of the Central Mountain Range (topographic variations) and gradually varied climate zones (latitudinal differences), the influence of those weather systems on precipitation in particular can show great east-west and north-south contrasts. As a result, while the wet season generally spans from summer to autumn based on the long-term average, Taiwan's precipitation and streamflow in the wet season exhibits great spatial distributions of prominent intra-seasonal and inter-annual variations. Thus, seeking the relationship between Taiwan's climate in the wet season and large-scale circulations can guide the development of a hydro-climatic forecasting framework potentially of benefit to water resources management in this area."*

2) P3L14-P3L17: It seems to me that the authors wanted to use Taiwan as an example for "diagnosing underlying mechanisms of predictability and pointing caveats on intrinsic covariability between regional streamflow and large-scale circulation." However, the "predictability" and "caveats" depend strongly on the prediction model under discussion. Therefore, the "backbone" (P3L17) of the research should be a prediction model with acceptable prediction skill at least for a substantial period. In this regard, the following missing material is required to support the argument the authors trying to make.

2-1) The authors need to present a prediction model that uses large-scale circulation to predict Taiwan streamflow with proved skill.

2-2) The authors need to provide scientific evidence to explain the underlying mechanisms of the predictability of the prediction model.

2-3) The authors need to show how variations of the intrinsic covariability influences the performance of the prediction model.

2-4) With the evidence listed above, the authors can discuss the observed facts of climate regime shift and point out the caveats on using large-scale circulation indices to predict regional streamflow.

We totally agree that the inclusion of a prediction model with acceptable skill in our study can facilitate the discussion about how regional streamflow prediction can be affected by potential climate regime shifts (CRS). In fact, it is our intention to develop a new hydro-climatic forecasting method that takes the effect of CRS into account. The new forecasting method is going to be a renovation of the “dipole forecasting model,” previously developed by the coauthor and his colleague (Chen and Georgakakos, 2014) and designed to excel at auto-identifying dipole-like predictor patterns from various oceanic and atmospheric fields (e.g., SST, SLP, geopotential height, and wind). However, we are still in the process of brainstorming the most adequate plug-in module of the CRS detection for the dipole forecasting model. Even though this work is still ongoing, we try to incorporate the reviewer’s suggestion into our article by performing multiple linear regression as a surrogate for our new forecasting method (yet to come) to illustrate the effect of CRS on streamflow prediction in this study.

Linear regression is widely used in climate forecasting studies (e.g., Hastenrath 1995, 2004; Chen and Georgakakos, 2015) to generate forecasts based on a calibrated, linear equation that depicts how a hydro-climatic predictand (**Y**, streamflow in our case) responds to selected predictors (**X**, climate indices in our case):

$$\mathbf{Y} = \mathbf{X}\beta, \qquad \text{(R1)}$$

where $\beta$ are coefficients estimated by ordinary least squares. In each catchment, we will develop a linear regression equation as the prediction model. In terms of predictors (i.e., independent variables), we adopt 13 climate indices described in the paper (with AAO excluded as relatively short in record) and perform stepwise model selection based AIC (Akaike Information Criteria). Model selection can be performed in forward or backward direction, and we use both directions to ensure a thorough search in the variable space. Afterwards, to avoid possible multicollinearity issues resulting from some highly correlated climate indices, the variance inflation factor (VIF) is assessed:

$$VIF_j = \frac{1}{1-R_j^2}, \qquad \text{(R2)}$$

where $R_j^2$ is the coefficient of determination from a regression of the $j^{th}$ predictor on any other predictors. According to the literature (Chen and Georgakakos, 2014; Hidalgo-Muñoz et al., 2015), the VIF tolerance threshold is set to be 4 for small samples (say ~50 points). The final model is thus determined and used for generating hindcasts (i.e., retrospective forecasts) for that catchment. The generation of hindcasts is subject to the leave-one-out cross-validation (LOOCV) procedure to circumvent artificial skill. Eventually, the LOOCV correlation and Gerrity Skill Score (GSS, Gerrity, 1992) are calculated to assess the prediction skill in that catchment. The above framework will be repeated for all 41 catchments.

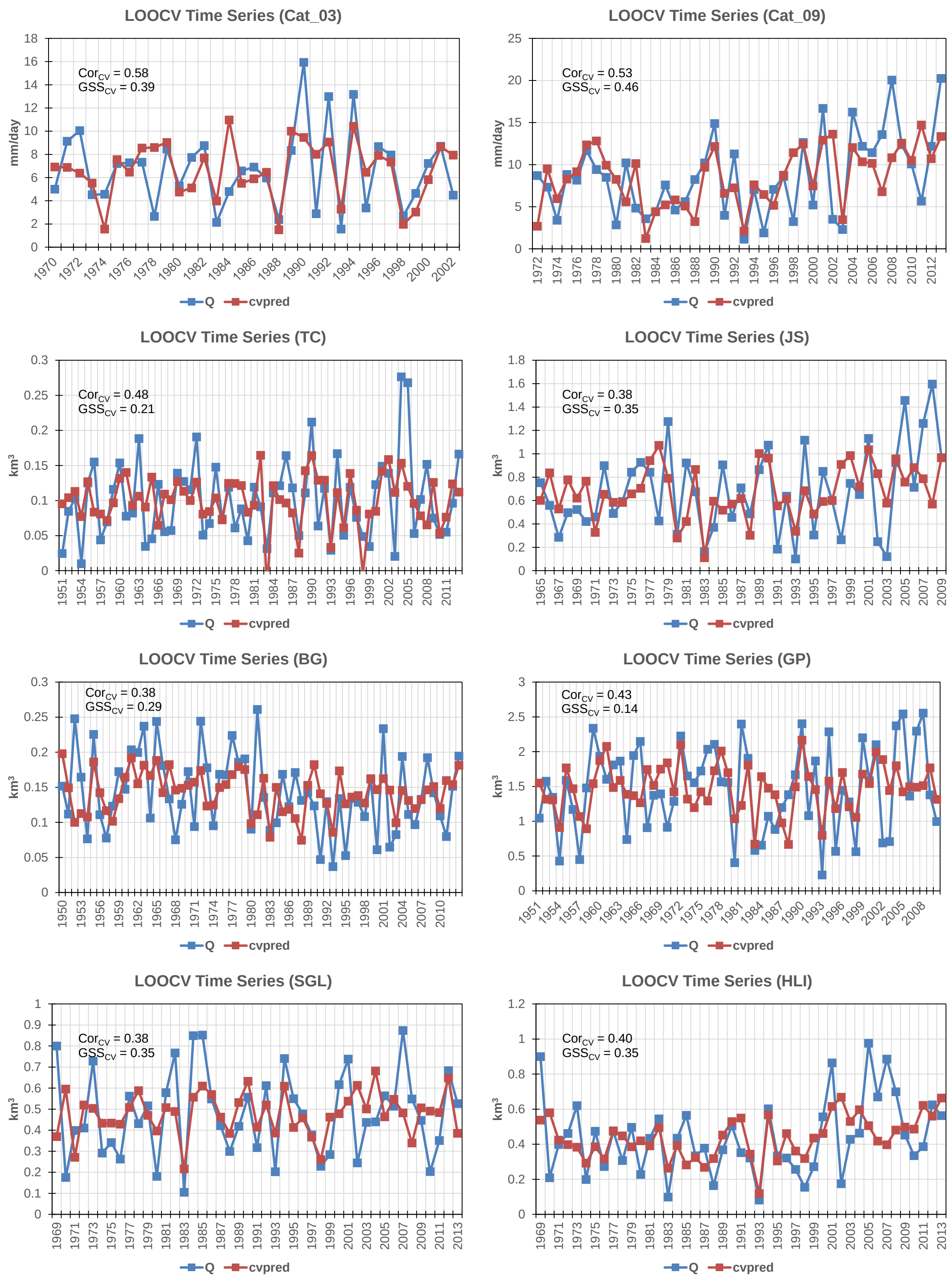
Figure R1 below shows some hindcasting results for selected upstream and downstream catchments. LOOCV correlations vary from one catchment to another, and can be as high as *~0.6*. As a more stringent metric, cross-validated GSS values are generally lower, but most of time pass the significant threshold (e.g., *~0.25* for data size 30, determined by the bootstrap-based hypothesis testing, Chen and Georgakakos, 2014). Overall, using large-scale circulation indices can produce fair to good prediction skills in summer streamflow prediction in Taiwan. Among those many climate indices, the PDO and PJ indices are selected most frequently as the predictors for the catchments [while the former is selected seven times (except for SGL), the latter is selected five times (except for Catchments 3 and 9 and BG) for the results shown in Figure R1]. This result is to a certain extent consistent with our general correlation assessments (e.g., Table 2 in our original manuscript) and indicates the general dominance of summer climate in Taiwan. Regarding the origin of the predictability, Chen and Chen (2011) indicated that the PDO coincides with the specific meridional SST contrast (i.e., warming in the tropical central and eastern Pacific and cooling in the extratropical North Pacific), which plays a dominant role in modulating summer rainfall in Taiwan. Choi et al. (2010), Kosaka et al. (2013), and Kubota et al. (2016) all provided sufficient evidence of the significant impact of the PJ on tropical cyclone activity and rainfall over the western North Pacific during summer. Based on our findings, the predictability for summer rainfall can be extended to streamflow in Taiwan.

From Figure R1, we can note that the relatively better performance of each LOOCV time series occurs during the period from the late 1970s to the late 1990s, which coincides with the CRS epoch discussed in the manuscript. Hindcasts during the pre-regime shift epoch seem to be still able to capture the general variability of observed runoff (with relatively poorer performance), whereas hindcasts during the post-regime shift epoch appear to present more opposite signals and apparent departures from observed runoff. It is worth noting that some of the departures occur in years when JAS typhoon activity is abnormally high. For example, in 2007, typhoons Pabuk, Sepat, and Wipha together generated the highest amount of cumulative rainfall for some watersheds over the past decade, and in 2008, typhoons Kalmaegi, Fung-Wong, Sinlaku, Hagupit, and Jangmi made a record of continuous invasions of intense typhoons (all Category 2 and above) in JAS. To further illustrate the effect of CRS on streamflow prediction, we fit a new regression model using the data from 1979 to 1998, and then evaluate how the fitted model performs in the remaining years. Using the SGL watershed as an example, Figure R2 shows the new hindcasting result. In comparison with the bottom-left plot in Figure R1, the new fitted model exhibits some definite improvement during the period from 1979 to 1998, showing the outstanding CV correlation and GSS values as *0.84* and *0.56*, respectively. However, the fitted model can generate nothing but extremely poor hindcasts for the remainders.  In fact, both skill metrics show a reverse sign, clearly illustrating distinct climate regimes over the temporal horizon.  In contrast to the above experiment, if we fit another regression model using the data outside the time frame of 1979–98, the stepwise model selection scheme discloses *no* climate indices qualified for being a predictor.  To sum up, the linear regression experiment points out that the assumption of a stable predictor-predictand relationship could be quite problematic for hydro-climatic forecasting due to the observation of CRS.

In addition to the above response to your specific comment, we would like to forward the following message (response to the other reviewer) to you since we wonder if the inclusion of our article in the special issue has caused any misconceptions about evaluating our work:

> *"We wish to restate the original scope of this work, which was set to focus more on the discussion about the general relationships between teleconnections and Taiwan's streamflow, rather than the development of a prediction model for the pursuit of forecasting utility.  This article is currently included in the special issue of 'sub-seasonal to seasonal hydrological forecasting' (as per the editor's suggestion), but we do not want to mislead the reviewer about our original intent.  Since we have agreed with the transfer decision of our manuscript, we certainly realize it should be our responsibility to include more forecasting elements in the study."*

In essence, as indicated above, we have developed a prediction model using linear regression to support our argument.  This part of analysis and associated results will be included in the revised article (likely as new Section 3.3) to make our work fit better within the scope of the special issue.


LOOCV Time Series (Cat_03)

LOOCV Time Series (Cat_09)

LOOCV Time Series (TC)

LOOCV Time Series (JS)

LOOCV Time Series (BG)

LOOCV Time Series (GP)

LOOCV Time Series (SGL)

LOOCV Time Series (HLI)

**Figure R1.** Selected hindcasting results for upstream and downstream catchments in Taiwan using linear regression. Time series in red are model estimates based on the leave-one-out cross-validation (LOOCV) procedure. Cross-validated (CV) correlation and GSS values are also denoted in each plot.

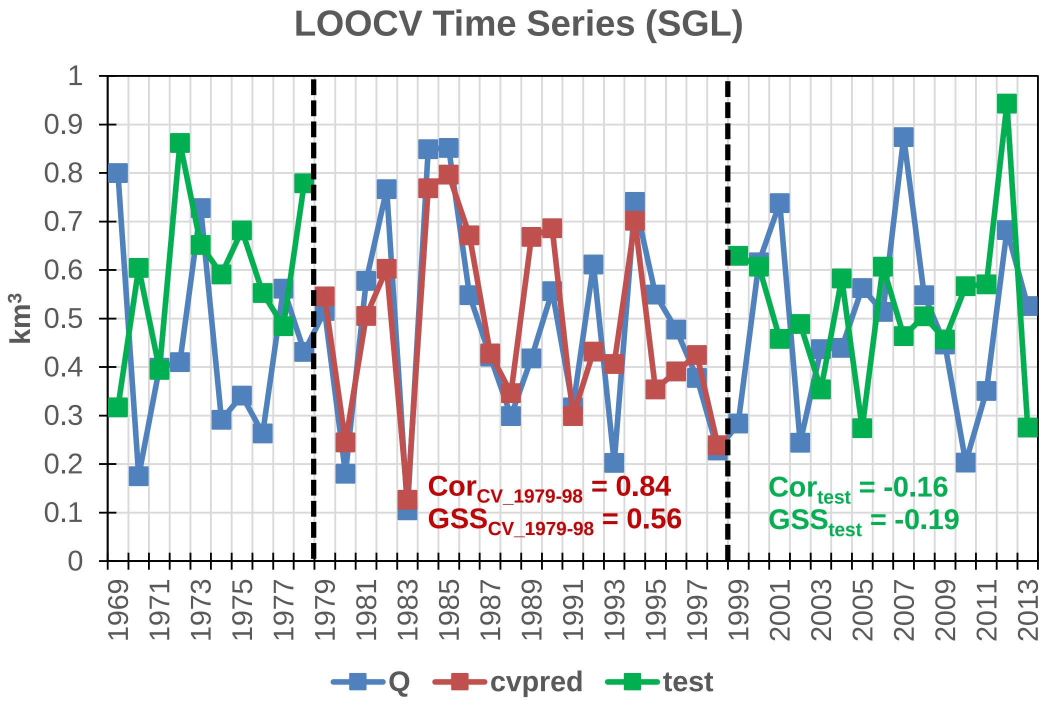


**Figure R2.** Similar to the bottom-left plot in Figure R1, but the linear regression model is trained/fitted with the data from 1979 to 1998, and then the fitted model is tested with the rest of data points (i.e., 1969–78 and 1999–2013).

3) P3L28-P3L31: The two objectives listed here cannot be "objectives" because the scientific questions/purposes are not clear.

We wish our responses to the above comments (as well as other comments below) have made the scientific questions/purpose clear. Moreover, another specific purpose as already stated in the paragraph above (original manuscript P3L3–17) is that a similar analysis has not conducted before in this area to the best of our knowledge.

We will revise the second objective as:

> *“To verify the existence of any CRS signals in the correlation and to discuss associated changes in large-scale circulation patterns.”*

We will also add a third objective:

> *“To illustrate the overall prediction skill and the effect of CRS on streamflow prediction in Taiwan using a linear regression approach.”*

4) P4-P6: The “Data and Analysis Procedures” section should focus on discussing the “Data” and “Procedure”, such as the data length (e.g. beginning and end years), quality check (e.g. missing data issue and solution), and methodology (e.g. decision principles of the teleconnection/large-scale indices). Other discussion such as the season (JAS) of study and references of teleconnection indices should be presented in the Introduction section.

As pointed out by the first reviewer as well, the information about data length and quality check will be amply supplemented in the revised article. We also list the periods of record and missing data percentage for all 41 catchments in the table below. Note that the periods of record are not entirely the same, and we decided to use all available data for the calculation of correlation values. 30 out of 41 gauges present missing data less than 3% (e.g., 1 out of 40 years is missing), indicating the quality of JAS flow data is quite reasonable. For those missing-data years, we do not perform any data filling because we do not want to create any artificial, subjective flow quantities that may skew correlation values; that is, we simply skip the pair of data (flow and climate index) in those missing-data years for the calculation of correlation values.

**Table R1.** Period of data record and missing data percentage for all 41 catchments used for our analysis. Note that we use only JAS data in each year, and the missing data percentage is referred to as the percentage of years in which no JAS data is available.

| **Catchment (downstream)** | **Period of Record** | **Missing Data %** | **Catchment (upstream)** | **Period of Record** | **Missing Data %** | **Catchment (upstream)** | **Period of Record** | **Missing Data %** |
|---|---|---|---|---|---|---|---|---|
| TC | 1951–2013 | 0% | Cat_01 | 1970–2013 | 2.3% | Cat_15 | 1970–2013 | 2.3% |
| HLO | 1981–2013 | 0% | Cat_02 | 1970–2006 | 0% | Cat_16 | 1971–2013 | 0% |
| WU | 1966–2013 | 2.1% | Cat_03 | 1970–2002 | 0% | Cat_17 | 1970–2013 | 11.4% |
| JS | 1965–2009 | 0% | Cat_04 | 1970–2002 | 0% | Cat_18 | 1971–2013 | 2.3% |
| BG | 1949–2013 | 0% | Cat_05 | 1971–2007 | 0% | Cat_19 | 1970–2013 | 11.4% |
| ZW | 1960–2013 | 0% | Cat_06 | 1972–2013 | 2.4% | Cat_20 | 1970–2013 | 11.4% |
| ER | 1971–2013 | 0% | Cat_07 | 1970–2008 | 0% | Cat_21 | 1970–2013 | 11.4% |
| GP | 1951–2010 | 0% | Cat_08 | 1976–2013 | 5.3% | Cat_22 | 1970–2001 | 0% |
| BN | 1948–2013 | 4.5% | Cat_09 | 1972–2013 | 0% | Cat_23 | 1974–2013 | 5% |
| SGL | 1969–2013 | 0% | Cat_10 | 1970–2013 | 0% | Cat_24 | 1977–2011 | 5.7% |
| HLI | 1969–2013 | 0% | Cat_11 | 1970–2013 | 2.3% | Cat_25 | 1977–2011 | 2.9% |
| HP | 1975–2013 | 5.1% | Cat_12 | 1970–2008 | 0% | Cat_26 | 1970–2012 | 2.3% |
| LY | 1949–2009 | 0% | Cat_13 | 1970–2013 | 9.1% | Cat_27 | 1970–2013 | 0% |
|  |  |  | Cat_14 | 1970–2013 | 4.5% | Cat_28 | 1970–2013 | 2.3% |

As aforementioned, we will move some of the general description of Taiwan, its climates (P4L3–8), and the target high-flow season (P4L22–25) to the introduction section and merge them with the revised third paragraph in response to your first comment.

Regarding the references of teleconnection indices, most of them have already been presented in the first two paragraphs of the original manuscript. The paragraph in Section 2.1 mainly focuses on explaining the decision principles of the teleconnection indices, as pointed out by the reviewer. In accordance with the comment below, we will add some short descriptions of the physical meaning of the teleconnection indices in that paragraph.

5) P5L1-P5L14: The physical meaning of the teleconnection indices listed here is barely mentioned. It is not possible to diagnose “underlying mechanisms of predictability” without presenting the physical insight of the relationship between Taiwan climate and the large-scale circulation indices. Are all of the indices relevant to Taiwan climate variability?

Many of the teleconnection indices (e.g., ENSO, NAO, and PDO) are well known and their physical meaning have been substantially elaborated in dedicated articles (e.g., Trenberth, 1997; Trenberth and Stepaniak, 2001; Hurrell, 1995; Mantua et al., 1997). However, we support the reviewer’s assertion that we should at least summarize the physical definition of each teleconnection index in that paragraph.

For instance, the ENSO is characterized as an air-sea coupled phenomenon: a zonal Sea Level Pressure (SLP) anomaly in the tropical Pacific (i.e., the Southern Oscillation) and a quasi-periodic Sea Surface Temperature (SST) warming/cooling in the tropical eastern Pacific (i.e., El Niño/La Niña). The NAO is referred to as the meridional seesaw of the SLP field with the north and south centers near Iceland and the Azores, respectively. The PDO is characterized by a long-lived ENSO-like pattern that shifts phases with a period of at least 15 to 25 years.

The complete summary of the physical definition of all the 14 indices used in the study will be added to the revised article.

All of the indices have been proven to show certain signs of connections to East Asian climate variability in general (e.g., precipitation, monsoon and cyclone activity across seasons; see original manuscript P5L1–14), which is the main decision principle of the indices. Very likely only a few indices are relevant to Taiwan’s hydro-climate variability (summertime streamflow in particular), and one way to figure out the significant indices is through our correlation analysis.

6) The authors clearly showed that Taiwan JAS catchment streamflow is significantly correlated with the WP and PJ teleconnection indices and the correlation relationship changes with time. The large-scale climate also shows decadal-scale variations. However, time coincidence cannot be used for arguing physical relationship. For example, the argument of “The CRS firstly emanates from the change in the basin-scale climatology over the Pacific (e.g., shift in the PDO), and then the reorganized large-scale patterns can reset the relationship between the island-scale streamflow with established regional circulations (e.g., the PJ pattern)” on P9L12-14 is a hand-waving argument. Nothing is explained about how the decadal-scale changes of sea surfaces temperature (PDO) influences the regional circulation pattern (PJ) in the atmosphere and then the rainfall pattern and subsequently the streamflow pattern in Taiwan. There are many more hand-waving type of argument in the paper. There is no point to list out all of them here if the above points are not addressed.

Whilst time coincidence cannot explain any physical relationship, it certainly motivates us to look into whether the physical relationship does exist. We wish to state that it is not our pure speculation by providing more explanation *and* evidence (references) below.

Since the PDO is strongly tied to ENSO, the shift in the PDO can induce changes in the ENSO-related SST anomalies as well as ENSO-related teleconnections (Duan et al., 2013). Such SST anomalies have been found robust in the western North Pacific during summer (Alexander et al., 2002), and numerical model experiments have verified the ENSO-forced PJ pattern (Kosaka et al., 2013). Kubota et al. (2016) further pointed out the ENSO-PJ relationship strengthened after 1980, and then weakened after 2000, likely due to the phase shift in the PDO. When the ENSO-PJ relationship is more pronounced, the systematic impacts of the PJ pattern on TC activity, rainfall, and subsequently streamflow in Taiwan are clear. By contrast, if the PJ pattern is less forced by ENSO, the associated impacts can be ambiguous. Consequently, Taiwan’s streamflow become less predictable after the post-regime shift epoch.

We will supplement the above information to the revised article to make our argument sounder.

## References

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