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On the unstable ENSO-Western North Pacific Monsoon relation during the 20th Century

Inmaculada Vega Martín, David Gallego Puyol, Pedro Ribera Rodriguez, Francisco de Paula Gómez Delgado, and Cristina Peña-Ortiz
Universidad Pablo de Olavide, Seville, Spain

The concept of the Western North Pacific Summer Monsoon (WNPSM) appeared for the first time in 1987. Unlike the Indian Summer Monsoon and the East Asian summer monsoon, the WNPSM is an oceanic monsoon driven essentially by the meridional gradient of sea surface temperature. Its circulation is characterized by a northwest-southeast oriented monsoon trough with intense precipitation and low-level southwesterlies and upper-tropospheric easterlies in the region [100º-130º E, 5º-15ºN]. Although this monsoon is mainly oceanic, it modulates the precipitation of densely populated areas such as the Philippines.

To date, the WNPSM has been quantified by the so-called Western North Pacific Monsoon Index (WNPMI), an index based on wind anomalies over large domains of the Western Pacific. The requirement of continuous observed wind over remote oceanic areas to compute the WNPMI has limited its availability to the 1949-2014 period. In this work we have extended the index by almost 100 years by using historical observations of wind direction taken aboard ships. Our Western North Pacific Directional Index (WNPDI), is defined as the sum of the persistence of the low-level westerly winds in [5º–15ºN, 100º–130ºE] and easterly winds in [20º–30ºN, 110º–140ºE]. The new WNPDI index is highly correlated to the existent WNPMI for the concurrent period (1948-2014). ($r=+0.88$, $p<0.01$), indicating that the new approach based in the use of wind direction alone (a variable that can be considered instrumental even before the 20th Century), captures most of the monsoonal signal.

Previous studies found that, during the second part of the 20th Century the WNPSM exhibited two basic characteristics: first a large interannual variability and second, a significant relation between the WNPSM and the El Niño/Southern Oscillation (ENSO) in a way in which a strong (weak) WNPSM tends to occur during the El Niño (La Niña) developing year or/and La Niña (El Niño) decaying year. The analysis of our extended series suggests a more complex scheme. We have found evidences of a persistently strong WNPSM during 1918-1948, a period in which the WNPSM was considerably less variable than today and a change in the ENSO-WNPSM relation during the first half of the 20th Century, with a reversal in the sign of the WNPSM-ENSO correlation for ENSO decaying years. These changes seem related to an alteration in the timing of the ENSO events between the first and the second parts of the 20th century.

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Inmaculada Vega[1*], F. de Paula Gómez-Delgado[1], David Gallego[1], Pedro Ribera[1], Cristina Peña-Ortiz[1] and Ricardo García-Herrera[2]

[1]Universidad Pablo de Olavide. Sevilla (SPAIN), [2] Universidad Complutense-IGEO/CSIC, Madrid (SPAIN)
*Author to whom correspondence should be addressed, email: ivegmar@upo.es

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The Western North Pacific Summer Monsoon (WNPSM)

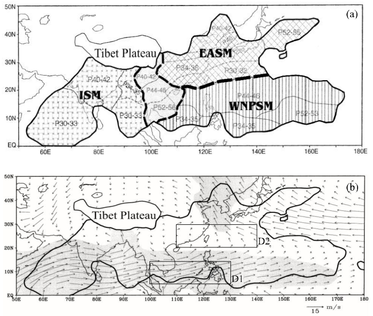

FIG 1: (a) Asian–Pacific monsoon division. (b) Summer (JJA) minus winter (DJF) 850-hPa winds (vector). The arrow shown in the lower-right corner gives wind scale. The shading indicates regions where the differential wind speed exceeds 4.5 m s^{-1}. Adapted from [1].

The Asian Monsoon region could be divided into three subregions: the Indian, the East Asian and the Western North Pacific. Both the Indian Summer Monsoon (ISM) and the East Asian Summer Monsoon (EASM) are continental while **the Western North Pacific Summer Monsoon** (WNPSM) is oceanic. Despite its pronounced year-to-year variability and impacts on global climate, the WNPSM has not been as studied as the ISM, probably, because meteorological variables to quantify its strength are required in open ocean.

The **Western North Pacific Monsoon Index** (WNPMI), the main index that has been used to characterize the WNPSM back to 1948, was defined as the difference of 850-hPa westerlies between two regions (D1 and D2 in Fig 1b) by Wang et al. (2001). Our goal has been **to extend** this index **as back in time as possible** by using **instrumental meteorological data** such as wind direction. Thus, it allows to study the **multidecadal variability** of the WNPSM.

The Western North Pacific Directional Index (WNPDI)

The International Comprehensive Ocean-Atmosphere Data Set (ICOADS) provides meteorological information from logbooks of thousand of ships which have circumnavigated the globe since at least the 17th century. In particular, wind measurements were the most important from the point of view of navigation and therefore they were so routinely taken offering the best potential to develop long-term climate indices. As the descriptors used to indicate wind speed have changed in a non-trivial way along time, a bias difficult to assess can be introduced in climatic indices based on wind force [2]. Nevertheless, wind direction was measured using a compass essentially in the same way than it is done nowadays.

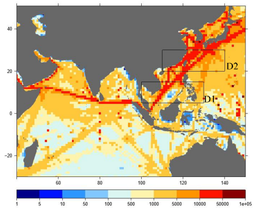

FIG 2: Gridded observations in ICOADS for summer (JJA) throughout the 1750-2014 period.

Recently, it has been demonstrated the feasibility of computing indices based only on the wind direction to quantify monsoonal circulations such as the African [3] and the Indian [4]. Fortunately, both domains, D1 and D2, lie over some of the main historical ship routes sailing nearby Asia (Fig 2).

We define the **Western North Pacific Directional Index** (WNPDI) using **solely wind direction** data as the sum of persistence of the low-level westerly winds in D1 and easterly winds in D2. The WNPDI shows a high correlation with the previous WNPMI ($r = +0.88$, $p < 0.01$) in summer for the concurrent period (1948-2014).

$$WNPDI\,(monthly) = \left[\frac{number\ of\ westerly\ days\ (D1)}{days\ with\ observations} + \frac{number\ of\ easterly\ days\ (D2)}{days\ with\ observations}\right] \cdot 100$$

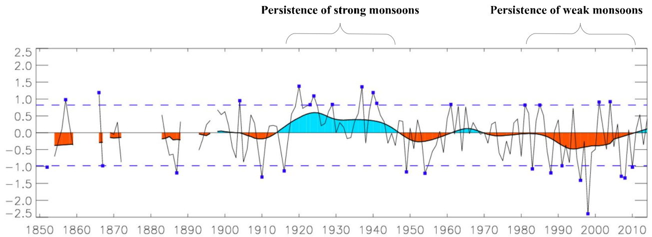

FIG 3: Evolution of the standarized JJA WNPDI (thin black line), robust locally weighted regression with a 21-year window (shaded curve) and extreme monsoons (blue squares) based on the 10th and 90th percentiles (dashed blue lines) of the WNPDI for the 1949-2014 period.

Precipitaton associated with the WNPSM

- Extreme monsoons

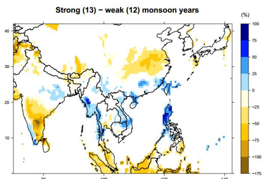

FIG 4: Summer composite difference of precipitation (in % related to the JJA average local precipitation) between extreme monsoon years throughout the 1901-2013 period. Shading denotes what is significant at the 95% confidence level.

- Regimes of the WNPSM

Persistent strong monsoons (accumultaion of 47% extremely strong monsoons)

Persistent weak monsoons (accumulation of 53% extremely weak monsoons)

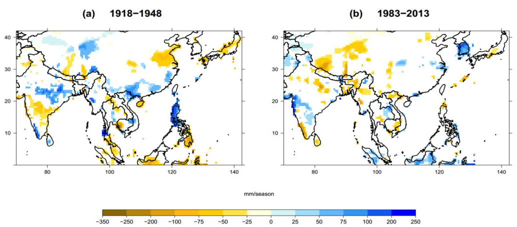

FIG 5: Summer precipitation anomaly for the period 1918-1948 (a) and 1983-2013 (b) regarding the 1901-2013 period. Shading denotes what is significant at the 95% confidence level.

The WNPSM-ENSO relationship throughout the 20th century

Currently it is believed that the ENSO/WNPSM relationship implies that a strong monsoon is often preceded/followed by colder/warmer than average SSTs over the EN3.4 area [5]. Nevertheless, our results evidences that this is only the case since the 1960s.

EN3 and EN3.4 indices are usually considered to represent ENSO. However, ENSO indices based on SST might have a bias before the 1950s. As a consequence, we also include the SOI in our analysis.

A lag sliding correlation analysis was performed for the three seasonal ENSO indices with respect to the JJA-WNPDI (Fig 6a). In all cases, the correlation swaps before the 1960s for negative lags (i.e. before JJA-Monsoon), meaning that a strong (weak) WNPSM* tends to be preceded by La Niña (El Niño) conditions from the 1960s whereas the opposite occurred before.

As ENSO conditions do not imply ENSO events, monsoon years has been divided into: ENSO developing years, ENSO decaying years and non-ENSO years, similarly to [5].

- ENSO developing years
  A strong (weak) WNPSM tends to occur when El Niño (La Niña) is developing and to be preceded by La Niña (El Niño) conditions. This behaviour is stable during the 20th century.
- ENSO decaying years
  A strong (weak) WNPSM tends to occur after La Niña (El Niño) event from the 1960s whereas the opposite occurred before. This change is more remarkable for EN3.
- Non-ENSO years
  Significant relation has not been found between the WNPDI and ENSO indices within non-ENSO years.

*Strong WNPSM when WNPDI>0 and viceversa

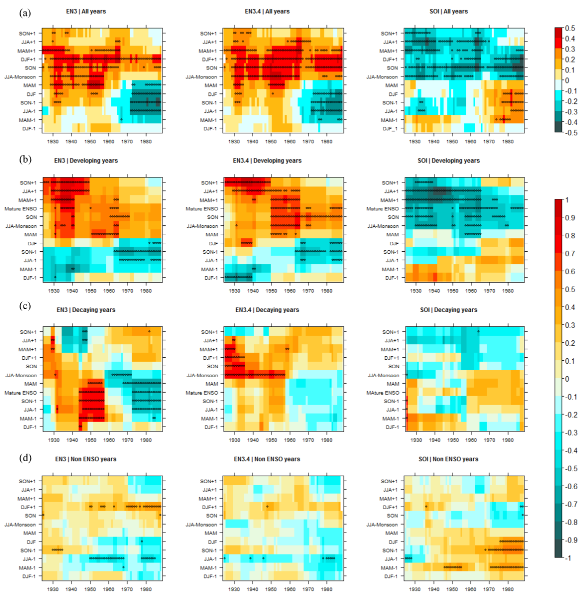

FIG 6: Lag sliding correlation (51-year window) of seasonal ENSO indices (EN3 -left-, EN3.4 -centre- and SOI -right-) in relation to the JJA-WNPDI throughout the 1900-2013 period for: (a) all years (b) the ENSO developing years, (c) the ENSO decaying years and (d) the non-ENSO years. Summer monsoon is indicated as "JJA-Monsoon" whereas the peak of ENSO events is marked as "Mature ENSO". Years correspond to the central year of the sliding 51-year window. Black points indicate significant correlations at 90% significance level.

The take-home message

- It is possible to compute a quantitative index of the WNPSM strength without the use of the wind speed, a value usually rather uncertain for historical wind measurements.
- The WNPDI goes back to the middle of the 19th century and is 100 years longer than any previous index characterizing the WNPSM (possible extension further back in time as soon as more observations in logbooks, preserved in historical archives, are digitized).
- The WNPDI has a strong impact on the precipitation in densely populated areas in South-East Asia, such as the Philippines or the west coast of Myanmar where the changes in precipitation between well developed and weak monsoons can exceed 75% or -100% (related to the summer mean precipitation) in southeast India.
- Two regimes of the WNPSM have been identified in the 20th century: persistence of strong monsoons between 1918 and 1948 and the accumulation of weak monsoons during the 1983-2013 period. Both regimes had a strong impact on precipitation.
- The relationship between ENSO and the WNPSM during the ENSO decaying years changed in the 20th century, being more remarkable when considering EN3 index. Thus, a strong (weak) WNPSM tended to occur after La Niña (El Niño) ever since the late-1950s, whereas the opposite occurred before.

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