

## Changing Characteristics of Extreme Temperature Events in the Yangtze River Delta and Their Relationship with ENSO (Postprint)

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### Abstract

Based on daily maximum, minimum, and mean temperature data from 65 meteorological stations during 1960-2014, this study analyzes the variation patterns of extreme temperature events in the Yangtze River Delta region and the influence of ENSO event intensity on the changing trends of extreme temperature indices. The results show that over the past 55 years, summer days (SU), tropical nights (TR), warm days (TX90), warm nights (TN90), warm spell duration index (WSDI), and growing season length (GSL) in the Yangtze River Delta region have all shown increasing trends, with warm nights (TN90) exhibiting the largest increase at a rate of 8.55 days/decade; extreme value indices also show an upward trend, with monthly minimum temperature minimum (TNn) showing the largest increase at (0.53°C/decade); ice days (ID), frost days (FD), cold days (TX10), cold nights (TN10), and cold spell duration index (CSDI) all show decreasing trends, with cold nights (TN10) showing the largest decrease (-6.06 days/decade); monthly mean diurnal temperature range (DTR) shows a decreasing trend at a rate of 0.11°C/decade. Spatially, all stations show increasing trends for SU, TXn, and TNx; TR, TX90, TN90, TNn, TXx, WSDI, and GSL show increasing trends at 97%, 85%, 98%, 95%, 78%, 92%, and 94% of stations, respectively; all stations show decreasing trends for ID, FD, TX10, and TN10; CSDI and DTR show decreasing trends at 87% and 77% of stations, respectively. Most extreme temperature indices are significantly correlated with latitude, longitude, and altitude. After the abrupt change in climate warming, extreme warm indices increase significantly while extreme cold indices decrease significantly. Overall, the impact of El Niño on extreme temperature indices is greater than that of La Niña.

## Full Text

### Preamble

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#### Correlation Analysis of Variation of Extreme Temperature Events and El Niño Southern Oscillation (ENSO) in Yangtze River Delta Region During 1960-2014

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### Abstract

Based on daily maximum temperature, minimum temperature, and mean temperature data from 65 meteorological stations, this study analyzed the spatiotemporal variation characteristics of extreme temperature events and the influence of ENSO on extreme temperature indices in the Yangtze River Delta region from 1960 to 2014. The results showed that over the past 55 years, extreme warm indices including summer days (SU), tropical nights (TR), warm days (TX90), warm nights (TN90), warm spell duration index (WSDI), and growing season length (GSL) increased significantly, with TN90 showing the largest increase of 8.55 days per decade. Extreme value indices also exhibited upward trends, with monthly minimum temperature minimum (TNn) increasing at a rate of 0.53°C per decade. In contrast, extreme cold indices including ice days (ID), frost days (FD), cold days (TX10), cold nights (TN10), and cold spell duration index (CSDI) decreased significantly by 0.40 days, 4.03 days, 2.56 days, 6.06 days, and 0.33 days per decade, respectively. The diurnal temperature range (DTR) decreased at a rate of 0.11°C per decade. Spatially, 97%, 85%, 98%, 95%, 78%, 92%, and 94% of stations showed increasing trends for SU, TX90, TN90, TNn, TXx, WSDI, and GSL, respectively, while 87% and 77% of stations showed decreasing trends for CSDI and DTR. Most extreme temperature indices were significantly correlated with latitude, longitude, and altitude. After detected abrupt climate changes, extreme warm indices increased significantly while extreme cold indices decreased. Overall, the effect of El Niño on extreme temperature indices was greater than that of La Niña.

**Keywords:** extreme temperature indices; spatial distribution; climate change; ENSO

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## 1. Data Sources

Meteorological data were obtained from the National Meteorological Information Center of the China Meteorological Administration. The Yangtze River Delta region in this study includes Anhui Province, Jiangsu Province, Zhejiang Province, and Shanghai Municipality administratively. Daily mean temperature, maximum temperature, and minimum temperature data from 65 meteorological stations in this region from 1960 to 2014 were selected. Data quality control was performed by excluding stations with missing data exceeding 3 days per month or 15 days per year. Due to station relocations and changes in observation methods, inhomogeneity issues existed in the climate series. The RHtest method was used to homogenize data from stations that had experienced relocations.

ENSO data were represented by the Oceanic Niño Index (ONI) sea surface temperature anomaly data from the Climate Prediction Center (CPC) of the National Oceanic and Atmospheric Administration (NOAA). Based on the climatic characteristics of the study area, the Yangtze River Delta region was divided into three climatic zones: Zone I (southern temperate sub-humid region) including northern Anhui and Jiangsu; Zone II (northern subtropical humid region) including central and southern Anhui and Jiangsu and north-central Zhejiang; and Zone III (mid-subtropical humid region) including central and southern Zhejiang.

[Figure 1: see original paper] Distribution of meteorological stations in the Yangtze River Delta region

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## 2. Research Methods

Extreme temperature indices adopted were those defined by the Expert Team on Climate Change Detection and Indices (ETCCDI), jointly established by the World Meteorological Organization (WMO) Commission for Climatology and the Climate Variability and Predictability (CLIVAR) program. The RClimDex software was used to calculate 16 extreme temperature indices for the 65 meteorological stations in the Yangtze River Delta region. Linear trend analysis was applied to examine temporal trends in extreme temperature indices. The Mann-Kendall (M-K) method was used for significance testing of trends and abrupt change detection. Continuous wavelet analysis was employed to study periodic characteristics. Spatial interpolation used the inverse distance weighting (IDW) method.

Based on Li Xiaoyan et al.'s research on ENSO classification standards, event intensity was quantified. El Niño event years were classified as extremely strong (5), strong (4), moderate (3), weak (2), and very weak (1). La Niña event years

were classified as extremely strong (-5), strong (-4), moderate (-3), weak (-2), and very weak (-1). Years influenced by El Niño events were defined as El Niño years and their lag-1 years.

Definition of extreme temperature indices

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### 3. Results

#### 3.1 Interannual Variation Trends

The interannual variation trends of 16 extreme temperature indices in the Yangtze River Delta region showed that ice days (ID), frost days (FD), cold days (TX10), cold nights (TN10), and cold spell duration index (CSDI) decreased significantly, with rates of -0.40 days, -4.03 days, -2.56 days, -6.06 days, and -0.33 days per decade, respectively. Warm days (TX90), warm nights (TN90), summer days (SU), tropical nights (TR), warm spell duration index (WSDI), and growing season length (GSL) increased significantly, with TN90 showing the largest increase at 8.55 days per decade. Among extreme value indices, monthly minimum temperature minimum (TNn) increased most significantly at 0.53°C per decade, while monthly maximum temperature minimum (TXn), monthly maximum temperature maximum (TXx), and monthly minimum temperature maximum (TNx) showed increasing trends of 0.35°C, 0.53°C, and 0.27°C per decade, respectively. Diurnal temperature range (DTR) decreased at a rate of 0.11°C per decade.

All three climatic zones showed consistent trends with the entire region, though with some differences. Zone I showed the most significant decreasing trends for cold indices, while Zone III showed the most significant increasing trends for warm indices. Comparison with national and Yangtze River Basin trends revealed that the Yangtze River Delta experienced more pronounced increases in warm indices and decreases in cold indices, likely due to rapid urbanization and increased anthropogenic heat emissions.

Comparison of interannual variation trends and significance tests of extreme temperature indices in the Yangtze River Delta and other regions

#### 3.2 Spatial Variation

The spatial distribution of extreme temperature index trends showed that all stations exhibited decreasing trends for ID, FD, TX10, and TN10, with larger decreases in the northern region. For SU, TR, TX90, TN90, WSDI, and GSL, 97%, 85%, 98%, 95%, 78%, and 94% of stations showed increasing trends, respectively, with more pronounced increases in the northern and central parts of the delta. TXn, TNn, TXx, and TNx showed increasing trends at most stations, while CSDI and DTR decreased at 87% and 77% of stations, respectively.

[Figure 2: see original paper] Spatial distribution of interannual variation trends of extreme temperature indices in the Yangtze River Delta

### 3.3 Abrupt Change Analysis

Mann-Kendall test results indicated that all 16 extreme temperature indices experienced abrupt changes. Extreme cold indices (ID, FD, TX10, TN10, CSDI) and DTR showed transitions from increasing to decreasing trends around the mutation points. Extreme warm indices (TR, TX90, TN90, WSDI, GSL) showed transitions from decreasing to increasing trends. Most extreme value indices shifted from low to high values. The majority of abrupt changes occurred around 1996, indicating a strong response to global warming.

Summary of abrupt change analysis of extreme temperature indices in the Yangtze River Delta

### 3.4 Periodic Variation Analysis

Wavelet analysis revealed that most extreme temperature indices exhibited periodic oscillations. Ice days (ID) showed significant oscillations at 4-year, 6-year, 11-year, and 17-year scales. Frost days (FD) showed main periods of 5-year, 11-year, and 21-year scales. Most indices had primary periods of 5-6 years and 11 years, with some showing longer periods of 21-28 years.

[Figure 3: see original paper] Wavelet variance diagrams of ID and FD in the Yangtze River Delta

Summary of periodic analysis of extreme temperature indices in the Yangtze River Delta

### 3.5 Relationship with Geographic Location

Correlation analysis showed that most extreme temperature indices were significantly correlated with latitude, longitude, and altitude. ID, FD, TN10, and TX90 were negatively correlated with latitude, while SU, TX10, and TN90 were positively correlated with latitude. TR, TN90, TXx, TNx, WSDI, and GSL were positively correlated with longitude. ID and FD were positively correlated with altitude, while TR, TN90, TNx, WSDI, and GSL were negatively correlated with altitude.

Correlation coefficients between extreme temperature indices and geographic parameters in the Yangtze River Delta

### 3.6 Correlation with Regional Climate Change

The correlation between extreme temperature indices and regional mean temperature showed that most indices had good correlations with mean temperature. ID, FD, TX10, TN10, and CSDI were negatively correlated, while SU, TR, TX90, TN90, WSDI, and GSL were positively correlated. After the abrupt

change point (1996), the warming trend accelerated, with warm indices increasing significantly and cold indices decreasing significantly.

Mean trends per decade of extreme temperature indices in categorized latitude ranks

Correlation coefficients between extreme temperature indices and mean temperature in the Yangtze River Delta

Changes of mean temperature and extreme temperature indices during 1960-1996 and 1996-2014

### 3.7 Correlation with ENSO

From 1960 to 2014, 23 El Niño events and 15 La Niña events occurred. Statistical analysis showed that 85% of El Niño years and 69% of the years following El Niño events had positive anomalies for most warm indices and extreme value indices. In contrast, 68% of La Niña years and 50% of the years following La Niña events had positive anomalies for cold indices. The values of most warm indices and extreme value indices were highest in El Niño years or the following year, indicating that El Niño exacerbated warming in the Yangtze River Delta. Cold indices were higher in La Niña years and particularly in the year following La Niña events. The effect of El Niño on extreme temperature indices was greater than that of La Niña, with El Niño's influence occurring in the same year or the following year, while La Niña's influence was primarily in the following year.

[Figure 4: see original paper] Occurrence intensity of El Niño/La Niña events from 1960 to 2014

[Figure 5: see original paper] Relationship between ENSO events and ice days, warm spell duration days anomaly in the Yangtze River Delta

Comparisons of average extreme temperature indices in ENSO years (and lag-1 years) and normal years

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## 4. Conclusions

From 1960 to 2014, extreme warm indices (SU, TR, TX90, TN90, WSDI, GSL) and extreme value indices (TXn, TNn, TXx, TNx) in the Yangtze River Delta increased significantly, while extreme cold indices (ID, FD, TX10, TN10, CSDI) and diurnal temperature range (DTR) decreased significantly. The increasing trend of warm indices was greater than the decreasing trend of cold indices. Spatially, over 92% of stations showed increasing trends for warm indices and decreasing trends for cold indices. Most extreme temperature indices mutated around 1996, with warm indices transitioning from decreasing to increasing and cold indices transitioning from increasing to decreasing. Periodic analysis indicated that most indices exhibited oscillations at 5-6 year and 11-year scales.

Most extreme temperature indices were significantly correlated with latitude, longitude, and altitude. After the abrupt change in mean temperature (1996), warming accelerated significantly. The influence of El Niño on extreme temperature indices was greater than that of La Niña, with El Niño's impact occurring in the same year or the following year.

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## 5. Discussion

The trends of extreme temperature indices in the Yangtze River Delta are consistent with global warming background and findings from many regional studies. The pronounced warming trend in the delta region, particularly the stronger increase in minimum temperature-based indices compared to maximum temperature-based indices and the significant decrease in diurnal temperature range, further validates the asymmetric nature of surface temperature rise. This is likely related to urbanization effects and increased anthropogenic heat emissions. However, station relocations, instrument changes, and urbanization may introduce biases in the temperature series. Future studies should adjust station temperature data to eliminate urbanization effects for better analysis of regional extreme temperature trends.

ENSO influences the Yangtze River Delta climate by affecting the East Asian monsoon system and the Pacific subtropical high. During El Niño winters, anomalous southerly winds and weaker East Asian winter monsoons lead to cold and wet conditions, while La Niña events produce anomalous northerly winds and stronger winter monsoons resulting in warm and dry conditions. The complex mechanisms of ENSO's influence on regional extreme temperatures require further investigation of the relationship between ENSO and atmospheric circulation patterns. Additionally, other factors such as climate system internal variability, urban greenhouse gases, and atmospheric composition changes also contribute to extreme temperature events and warrant further research.

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