Variations and Regional Differences of Extreme Temperature Events in Coastal China, 1961–2014 (Postprint)

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Abstract

Based on a daily-scale temperature dataset from 156 surface meteorological stations for the period 1961–2014, the spatiotemporal variation characteristics of extreme temperature events in China's coastal regions were analyzed using methods including trend analysis, wavelet analysis, Mann–Kendall test, cumulative anomaly, Pettitt test, and principal component analysis. The results indicate that extreme temperature warm indices in China' s coastal areas and its subregions exhibit an upward trend, while cold indices and diurnal temperature range show a downward trend, with the interannual trend rate of nighttime indices being significantly greater than that of daytime indices. Except for the multi-year mean values of relative indices, extreme high-value indices, and cold (warm) spell duration indices, which show little difference among sub-regions, the multi-year mean values of frost days, ice days, and diurnal temperature range decrease sequentially from north to south; conversely, the multi-year mean values of summer days, tropical nights, extreme low-value temperature indices, and growing season length increase sequentially from north to south. The main interannual periods of extreme temperature indices in each sub-region range between 2–8 years, with no significant decadal oscillation periods. The abrupt changes in extreme temperature indices in each sub-region occurred mainly during the 1980s and 1990s, with the timing of abrupt changes in cold indices and low-value indices being slightly earlier than that in warm indices and high-value indices. After the abrupt change, extreme warm events and temperature extreme value events entered a frequent occurrence stage, while extreme cold events entered a relatively infrequent stage. In the principal component analysis, extreme temperature indices with high loadings on the first principal component show good indicative significance for both daily mean temperature and daily maximum (minimum) temperature, and the pairwise correlations among such extreme indices are also strong; extreme temperature indices with low loadings show relatively weak indicative significance for daily mean temperature and daily

maximum (minimum) temperature, and their correlations with other extreme temperature indices are also weak.

Full Text

Preamble

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Analysis of Spatiotemporal Variations and Regional Differences in Extreme Temperature Events in the Coastal Area of China During 1961-2014

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Abstract

Based on daily temperature datasets from 156 meteorological stations, this study employed a suite of statistical methods—including trend analysis, wavelet analysis, Mann-Kendall test, cumulative anomaly analysis, Pettitt test, and principal component analysis—to investigate the spatiotemporal variations of extreme temperature events in China' s coastal region from 1961 to 2014.

Trend analysis revealed an upward trend in warm extremes and a downward trend in cold extremes, as well as in diurnal temperature range (DTR) across the entire coastal area. The decadal trend rates of nighttime extreme indices were significantly higher than those of daytime extremes. Multi-year averages of frost days (FD0), ice days (ID0), and DTR decreased from north to south, while those of summer days (SU25), tropical nights (TR20), minimum value of daily maximum temperature (TNx), minimum value of daily minimum temperature (TNn), and growing season length (GSL) increased from north to south. In contrast, relative indices (cool days TX10p, cool nights TN10p, warm days TX90p, warm nights TN90p) and duration indices showed little variation between sub-regions and the entire coastal area.

The primary periods of extreme temperature indices varied from 2 to 8 years across sub-regions, with no significant decadal oscillation periods detected. Mutation of extreme temperature indices occurred mainly during the 1980s and 1990s in all sub-regions, with cold extremes and minimum temperature indices mutating earlier than warm extremes and maximum temperature indices. Following these mutations, extreme warm events and temperature extreme value events entered a frequent occurrence stage, while extreme cold events became relatively rare.

Principal component analysis showed that extreme temperature indices with high loadings in the first principal component exhibited strong correlations with each other and demonstrated good indicative power for daily average and daily maximum (minimum) temperatures. Conversely, indices with low loadings in the first principal component showed weak correlations with other extreme indices and poor indicative power for daily average and daily maximum (minimum) temperatures.

Keywords: extreme temperature; spatiotemporal variation; regional difference; coastal area of China

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Introduction

The IPCC Fifth Assessment Report indicates that global climate change is more severe than previously understood. Compared with average temperatures, extreme temperature events are more sensitive to global climate change, and their accelerating frequency and intensity pose enormous challenges and serious threats to ecological environments and sustainable socio-economic development, attracting increasing attention. Since the 1950s, cold nights over more than 70% of global land areas have significantly decreased while warm nights have increased substantially. Studies in South America, Portugal, India, Mongolia, Georgia, and various regions of China all reveal warming trends through changes in extreme temperature indices.

China' s coastal region, a transitional zone between the Eurasian continent and the western Pacific, experiences complex and variable natural conditions due to large-scale material migration and energy exchange between land and sea. With dense populations, rapid economic development, and intensive industries and infrastructure, the region' s ecological environment is continuously deteriorating and its vulnerability increasing. Under global climate change, extreme climate events such as droughts, storm surges, and coastal erosion occur frequently. Extreme temperature events in South China have shown a significant upward trend over the past century, dominated by extreme warm events. However, existing studies have not fully integrated geographic characteristics and climate type variations to analyze regional differences in extreme climate change features. This study analyzes spatiotemporal variation characteristics of extreme temperature events in China' s coastal region, focusing on comparative regional difference analysis to better understand patterns and provide references for scientific adaptation and mitigation of climate anomalies.

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1. Data and Methods

1.1 Study Area and Data Sources

Using provincial administrative boundaries, China' s coastal provinces and regions were designated as the study area (excluding Taiwan, South China Sea islands, and maritime areas). Based on the China Meteorological Administration' s meteorological geographical zoning, the region was divided from north to south into: Northeast coastal, North China coastal, Huang-Huai coastal, Jiang-Huai coastal, Jiangnan coastal, and South China coastal areas [Figure 1: see original paper].

Meteorological data were obtained from the National Meteorological Information Center of the China Meteorological Administration. Based on data continuity and completeness criteria (historical records exceeding 50 years), daily maximum, minimum, and average temperature data from 156 stations were selected. Missing values were processed using the RClimDex software package for quality control, outlier detection, and standard deviation screening.

1.2 Extreme Temperature Indices

Following the ETCCDI standard, 16 extreme temperature indices were calculated, categorized into four types: relative indices, absolute indices, extreme value indices, and other indices . The decadal trend rate of each index was calculated using linear regression to analyze temporal trends and spatial patterns. Continuous wavelet analysis was applied to examine periodicity, with wavelet variance used to test cycle significance. Mann-Kendall test, cumulative anomaly analysis, and Pettitt test were employed to detect change points in extreme temperature indices. Principal component analysis was conducted to explore relationships among indices.

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2. Spatial Distribution of Extreme Temperature Indices

2.1 Relative Indices

Spatial distribution of decadal trend rates for relative indices across China' s coastal region shows that over 56% (94%) of stations exhibited significant decreasing (increasing) trends in cool days TX10p (warm days TX90p). Cool days showed decreasing trends across the entire coastal area, with larger decreases at stations in North China coastal northern areas, Jiang-Huai coastal, and Jiangnan coastal northern areas. Warm days showed increasing trends at over 93% of stations, with larger increases in Jiangnan coastal northern and South China coastal southern areas [Figure 2: see original paper].

Cool nights TN10p showed decreasing trends at most stations, with larger decreases concentrated in Northeast and North China coastal areas. Warm nights

TN90p showed increasing trends across the entire coastal region, with stations in southern Jiang-Huai coastal areas showing particularly large increases.

2.2 Absolute Indices

For absolute indices, approximately 97% of stations showed decreasing trends in frost days (FD0) and ice days (ID0), with about 62% passing significance tests. Stations north of the Yangtze River showed relatively large decreases in frost and ice days. Approximately 78% of stations showed increasing trends in summer days (SU25) and tropical nights (TR20), with about 35% passing significance tests. These stations were uniformly distributed across the coastal region [Figure 3: see original paper].

In South China coastal and southern Jiangnan coastal areas, 14 stations showed ice day trends of 0 d/10a (no change). Except for North and South China coastal areas where ice day trends were non-significant, absolute indices in other subregions all passed significance tests.

2.3 Extreme Value Indices

The vast majority of stations showed increasing trends in extreme value indices. In order of daily maximum temperature extreme high values (TXx), daily minimum temperature extreme high values (TNx), daily maximum temperature extreme low values (TXn), and daily minimum temperature extreme low values (TNn), the proportions of stations with increasing trends were approximately 79%, 98%, 97%, and 25% respectively, with 72%, 14%, and varying proportions passing significance tests [Figure 4: see original paper].

Stations with larger increases in extreme temperature indices were mainly distributed in coastal areas north of the Yangtze River.

2.4 Other Indices

For other extreme temperature indices, 78% (97%) of stations showed increasing (decreasing) trends in warm spell duration (WSDI) and cold spell duration (CSDI), with 35% (62%) passing significance tests. Stations with significantly increasing WSDI were mainly in Northeast and North China coastal northern areas, while decreasing stations were in southern Jiangnan and South China coastal areas. Stations in Jiangnan and South China coastal areas showed relatively larger decreases in CSDI [Figure 5: see original paper].

Growing season length (GSL) showed increasing trends at 97% of stations, mainly distributed north of South China coastal area, with larger increases at stations north of the Yangtze River. Diurnal temperature range (DTR) showed decreasing trends at 84% of stations, with more pronounced decreases at stations north of the Yangtze River. Only 16% of stations showed increasing DTR trends, scattered sporadically across the coastal region.

3. Temporal Variation Characteristics

3.1 Interannual Trends

Multi-year averages and decadal trend rates for extreme temperature indices in China' s coastal region and sub-regions are shown in . Across the entire coastal region, extreme temperature indices showed clear trends, all passing significance tests at the 95% confidence level.

For relative indices, cool days TX10p and cool nights TN10p decreased at rates of -1.18 d/10a and -3.47 d/10a respectively, while warm days TX90p and warm nights TN90p increased at rates of 1.72 d/10a and 3.3 d/10a. Night index trends were significantly larger than day index trends.

For absolute indices, frost days and ice days decreased at -2.12 d/10a and -0.83 d/10a, while summer days and tropical nights increased at 2.4 d/10a and 3.07 d/10a.

For extreme value indices, TXx, TNx, TXn, and TNn showed increasing trends of 0.12, 0.22, 0.24, and 0.48°C/10a respectively, with TNn showing the most pronounced increase.

For other indices, warm spell duration increased at 1.61 d/10a while cold spell duration decreased at -1 d/10a. Growing season length increased at 3.1 d/10a, while DTR decreased at -0.14°C/10a.

Sub-regional trends were consistent with the entire region, though multi-year averages and trend rates varied. South China coastal showed the smallest trend rate for cool days (non-significant), while Jiang-Huai coastal showed the largest decrease rate for frost days (-5.41 d/10a). Ice day trends were larger north of the Yangtze River. Summer days and tropical nights showed similar trend rates across sub-regions. Extreme low temperature indices showed increasing multi-year averages from north to south, with trend rates generally larger than those for extreme high temperature indices.

3.2 Periodic Characteristics

Given large north-south climate differences, periodicity analysis was conducted by sub-region. Using South China coastal relative indices as an example [Figure 6: see original paper], cool days showed significant interannual cycles of approximately 2.8 years and 13.2 years, with strong wavelet energy in the 1960s, 1980s, and 1990s. Cool nights showed first and second peak periods of about 3.9 and 2.3 years, with strong influence periods in the 1970s and 1990s. Warm days showed a main period of 3.3 years, with strongest oscillations in the 1980s and early 21st century. Warm nights showed significant periods between 1.9-3.5 years, with 2.9-4 years being the strongly concentrated influence period during 1987-2012.

Primary periods varied by sub-region and index . Northeast and North China coastal areas showed slightly smaller primary periods. Huang-Huai coastal had the longest primary period for cool days. South China coastal ice days showed a 5.6-year period. Temperature extreme high value indices generally had longer primary periods north of the Yangtze River. Temperature extreme low value indices showed the longest periods in Jiangnan and South China coastal areas for TNn. Warm spell duration primary periods decreased from 7.9 years in Northeast coastal to 4.7 years in South China coastal.

All sub-regions showed primary periods of less than 8 years, with no significant decadal oscillation periods, possibly due to the relatively short study period limiting detection of decadal-scale cycles.

3.3 Mutation Characteristics

Mutation test results for South China coastal relative indices [Figure 7: see original paper] show that cool days underwent a mutation around 1997-1998, transitioning from a high to low occurrence stage. Cool nights and warm days mutated around 1987-1988 and 1993-1994 respectively, transitioning to low and high occurrence stages. Warm nights mutated around 1996-1997 to a high occurrence stage.

Mutation years and trends for each sub-region are summarized in . Analysis shows that 8 indices mutated in the 1980s, 20 in the 1990s, and 6 in the 2000s, indicating significant mutation of extreme temperature events during 1980-2000. Cold indices mainly mutated in the 1980s-1990s, transitioning from high to low occurrence. Warm indices mainly mutated in the 1990s, transitioning from low to high occurrence. Extreme low temperature indices mutated earlier (1980s) than extreme high temperature indices (1990s). After mutation, extreme warm events and temperature extreme value events entered a frequent occurrence stage, while extreme cold events became relatively rare.

3.4 Consistency of Temperature Index Changes

To assess whether extreme temperature indices consistently reflect temperature changes, principal component analysis (PCA) and correlation analysis were conducted . The first three principal components explained 80.2% of variance. Cold indices (cool days, cool nights, frost days, ice days, cold spell duration) showed high loadings in the first component (57.0% variance). Warm indices (warm days, warm nights, summer days, tropical nights, growing season length) showed high loadings in the second component (13.5% variance). Diurnal temperature range showed high loading in the third component (9.7% variance).

Correlation analysis revealed that all extreme indices correlated significantly with daily average temperature. Warm indices showed strong positive correlations, cold indices showed strong negative correlations, and DTR showed negative correlation. Most inter-index correlations were significant, except for DTR which showed weak correlations with other indices.

Sub-regional PCA and correlation analysis extracted 2-3 principal components per region, with first component variance contributions exceeding 81%. High-loading indices were consistent across regions: mainly warm indices (warm days, warm nights, tropical nights) and cold indices (cool days, cool nights, frost days). Low-loading indices included DTR, extreme high temperature values, warm spell duration, and growing season length. High-loading indices showed strong correlations with daily mean and maximum temperatures, while low-loading indices showed weak indicative power and weak inter-index correlations.

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4. Conclusion

Based on 1961-2014 data from China' s coastal region, this study reveals:

(1) Consistent trends across the entire coastal area and sub-regions: warm indices increased while cold indices and DTR decreased. Night index trend rates were significantly larger than day index rates. Multi-year averages of relative indices and duration indices were similar across sub-regions. Frost days, ice days, and DTR decreased from north to south, while extreme low temperature indices and growing season length increased from north to south.

(2) Primary periods varied by sub-region, ranging from 2-8 years with no significant decadal oscillations. Most mutations occurred in the 1980s-1990s, with cold and low-value indices mutating earlier than warm and high-value indices. After mutation, extreme warm events and temperature extreme value events became more frequent, while extreme cold events became less frequent.

(3) PCA showed that high-loading cold and warm indices in the first principal component were well-correlated and effectively indicated daily mean and maximum/minimum temperature changes. Low-loading indices showed weak indicative power and weak correlations with other indices.

(4) Extreme temperature events are becoming increasingly frequent in China' s coastal region, revealing ongoing climate warming. Combined with high-intensity human activities, this poses significant challenges to sustainable development. Enhanced monitoring, early warning, and disaster prevention capabilities are urgently needed.

References

[1] IPCC. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, 2012.

[2] Whan K, Zscheischler J, Orth R, Shongwe M, Rahimi M, Asare E, Seneviratne S I. Impact of soil moisture on extreme maximum temperatures in Europe. Weather and Climate Extremes, 2015, 9: 57-67.

[3] Dai J, Kesternich M, Löschel A, Ziegler A. Extreme weather experiences and climate change beliefs in China: An econometric analysis. Ecological Economics, 2015, 116: 310-321.

[4] Gao Y, Feng Q, Liu W, Lu A G, Wang Y, Yang J, Chen A F, Wang Y M, Su Y B, Liu L, Ma Q Q. Changes of daily climate extremes in Loess Plateau during 1960-2013. Quaternary International, 2015, 371: 5-21.

[5] Alexander L V, Zhang X, Peterson T C, Caesar J, Gleason B, Tank A M G, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Kumar K R, Revadekar J, Griffiths G, Vincent L, Stephenson D B, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre J L. Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research, 2006, 111(D5): D05109.

[6] De los Milagros Skansi M, Brunet M, Sigro J, Aguilar E, Groening J A A, Bentancur O J, Geier Y R C, Amaya R L C, Jacome H, Ramos A M, Rojas C O, Pasten A M, Mitro S S, Jimenez C V, Martinez R, Alexander L V, Jones P D. Warming and wetting signals emerging from analysis of changes in climate extreme indices over South America. Global and Planetary Change, 2013, 100: 295-307.

[7] De Lima M L P, Santo F E, Ramos A M, De Lima J J M P. Recent changes in daily precipitation and surface air temperature extremes in mainland Portugal, in the period 1941-2007. Atmospheric Research, 2013, 127: 195-209.

[8] Cinco T A, De Guzman R G, Hilario F D, Wilson D M. Long-term trends and extremes in observed daily precipitation and near surface air temperature in the Philippines for the period 1951-2010. Atmospheric Research, 2014, 145-146: 12-26.

[9] Rao B B, Chowdary P S, Sandeep V M, Rao V U M, Venkateswarlu B. Rising minimum temperature trends over India in recent decades: Implications for agricultural production. Global and Planetary Change, 2014, 117: 1-8.

[10] Dashkhhuu D, Kim J P, Chun J A, Lee W S. Long-term trends in daily temperature extremes over Mongolia. Weather and Climate Extremes, 2015, 8: 26-33.

[11] Keggenhoff I, Elizbarashvili M, Amiri-Farahani A, King L. Trends in daily temperature and precipitation extremes over Georgia, 1971-2010. Weather and Climate Extremes, 2014, 4: 75-85.

[12] Deng H J, Chen Y N, Shi X, Li W H, Wang H J, Zhang S H, Fang G H. Dynamics of temperature and precipitation extremes and their spatial variation in the arid region of northwest China. Atmospheric Research, 2014, 138: 346-355.

[13] Li Z X, He Y Q, Wang P Y, Theakstone W H, An W L, Wang X F, Lu A G, Zhang W, Cao W H. Changes of daily climate extremes in southwestern China during 1961-2008. Global and Planetary Change, 2012, 80-81: 255-272.

[14] Guan Y H, Zhang X C, Zheng F L, Wang B. Trends and variability of daily temperature extremes during 1960-2012 in the Yangtze River Basin, China. Global and Planetary Change, 2015, 124: 79-94.

[15] Liang K, Bai P, Li J J, Liu C M. Variability of temperature extremes in the Yellow River basin during 1961-2011. Quaternary International, 2014, 336: 52-64.

[16] Jiao N Z, Chen D K, Luo Y M, Huang X P, Zhang R, Zhang H B, Jiang Z J, Zhang F. Climate change and anthropogenic impacts on marine ecosystems and countermeasures in China. Advances in Climate Change Research, 2015, 6(2): 118-125.

[17] Torrence C, Compo G P. A practical guide to wavelet analysis. Bulletin of the American Meteorological Society, 1998, 79(1): 61-78.

[18] Wei F Y. Modern Climate Statistical Diagnosis and Prediction Technology. Beijing: China Meteorological Press, 2007: 63-66.

[19] You Q L, Kang S C, Aguilar E, Pepin N, Flügel W A, Yan Y P, Xu Y W, Zhang Y J, Huang J. Changes in daily climate extremes in China and their connection to the large scale atmospheric circulation during 1961-2003. Climate Dynamics, 2011, 36(11-12): 2399-2417.

Note: Figure translations are in progress. See original paper for figures.