Historical Trends in Florida Temperature and Precipitation

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February 24, 2010
UF WI Symposium
Gainesville, Florida
Main Points

- Precipitation and temperature statistics at 32 stations in Florida analyzed for trends using non-parametric techniques
- ↑ number of wet days during the dry season – POR
- ↓ May precipitation throughout the state – POR and especially post-1950. *May* be linked to changes in start of the wet season.
- Urban heat island effect – urban (and drained) areas
  - ↑ Tave and ↑ number of dog days for wet (warm) season especially post-1950
  - Decrease in DTR (↑ Tmin > ↑ Tmax)
  - ↑ Annual maximum of Tave and Tmin for all seasons in POR and especially post-1950
Data for 32 NWS and COOP stations obtained from the office of the state climatologists located at FSU.

Longest and most complete daily precipitation and temperature records (1892-2008).

Raw data obtained and analyzed for trends.
### Variables

#### Statistics used for trend detection

<table>
<thead>
<tr>
<th>Variable</th>
<th>Averages (magnitude and duration each by season and by month)</th>
<th>Extremes (by season)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Total precipitation Number of wet days</td>
<td>Number of days of extreme values (&gt; 1-in-2). Maximum seasonal value Number of heavy precipitation events (&gt; 1-in-5) of duration 2, 3, 5, and 7 days</td>
</tr>
<tr>
<td>Daily temperature (Average, Maximum, Minimum, Temperature Range)</td>
<td>Average temperature Number of dog days (&gt; 80F) Annual Temperature Range</td>
<td>Number of days of extreme values (&gt; 1-in-2). Maximum and minimum seasonal values Number of extreme events (&gt; 1-in-5) of duration 2, 3, 5, and 7 days</td>
</tr>
</tbody>
</table>

**Seasons:** Entire year, Wet Season (MJJ+ASO), Dry Season (NDJ+FMA), NDJ, FMA, MJJ, ASO
### Trend Detection Methods

- **Ordinary Least Squares (Linear Regression)**
  - Parametric method – Assumes residuals $\sim N(0, \sigma)$. Required for hypothesis testing of trends.
  - Sensitive to outliers (lower $R^2$) and influential points (extreme values near beginning and end of dataset that greatly affect the slope of the regression line and may increase $R^2$). The leverage effect can yield incorrect results.

- **Mann-Kendall Test and Theil-Sen Regression**
  - Non-parametric test
  - Resistant to outlier effects, influential data, censored data, non-normal data
  - Assumes data is iid.

- **Key issue:** Distinguishing between trend and persistence (autocorrelation) in the timeseries.
  - + serial correlation can overestimate probability of a trend
Mann-Kendall Test (Mann, 1945 & Kendall, 1938, 1962, 1975)

H₀: The data \( x_i \) are a sample of \( n \) independent and identically distributed random variables (i.e. no trend (\( \tau = 0 \)))

For \( n > 10 \), \( Z_s \sim N(0,1) \).

\[
S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k)
\]

\[
\text{sgn} (x_j - x_k) = \begin{cases} 
1 & \text{if } x_j - x_k > 0 \\
0 & \text{if } x_j - x_k = 0 \\
-1 & \text{if } x_j - x_k < 0 
\end{cases}
\]

\( x_j \) and \( x_k \) are sequential timeseries values.

An exact distribution for \( S \) exists and is used in the case when there are no ties (Best and Gipps, 1974).

In the case of ties, and for large \( n \) a normal approximation is used:

\[
Z_s = \begin{cases} 
\frac{S - 1}{\sigma_s} & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
\frac{S + 1}{\sigma_s} & \text{if } S < 0 
\end{cases}
\]

\[
\sigma_s = \sqrt{\frac{1}{18} [n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p-1)(2t_p + 5)]}
\]

\( H_0 \) is rejected if p-value associated with \(|Zs|\) is less than chosen significance level \( \alpha \).
Theil-Sen Regression (Sen, 1968 & Theil, 1950)

For all possible distinct pairs of measurements, \((x_j, x_k)\) for \(t_k > t_j\) compute the simple pairwise slope estimate: 

\[
S_{ij} = \frac{x_k - x_j}{t_k - t_j}
\]

Estimate of the slope is 

\[
\beta_1 = \text{median}(S_{ij})
\]

Intercept based on Conover (1980) method is 

\[
\beta_0 = \text{median}(X) - \beta_1 \cdot \text{median}(t)
\]

Methods assume data is iid.
Zhang’s Pre-Whitening method (2000) was used to pre-whiten the timeseries (remove serial autocorrelation). See Wang and Swail (2001).

Seasonal Mann-Kendall test and Theil-Sen regression performed on monthly values. For autocorrelated monthly data, used the Modified Seasonal Mann-Kendall test from Hirsch and Slack (1984). The Seasonal test assumes homogeneity in trends across seasons (months), which was first tested using test by van Belle and Hughes (1984).
Block Maxima & Minima

Generalized Extreme Value Distribution

\[ G(z) = \exp\left\{-\left[1 + \frac{\zeta(z - \mu)}{\sigma}\right]^{-\frac{1}{\xi}}\right\} \]

\{ \begin{align*} \zeta &> 0 \\ \mu &\in \mathbb{R} \text{ (location)} \\ \zeta &\in \mathbb{R} \text{ (shape)} \\ \sigma &> 0 \text{ (scale)} \end{align*} \}

H₀: No trend in the location parameter μ (b=0)

2 models fitted:
M₀: μ = Constant
M₁: \( \mu(t) = a + bt \)

Significance of trend b evaluated using the Likelihood Ratio Test, which uses the deviance statistic (Coles 2001):

\[ D = 2\{l_1(M_1) - l_0(M_0)\} \]

\[ D \sim \chi^2 \text{ (df=1)} \]

H₀ is rejected if p-value associated with D is less than chosen significance level α.
Results

Table 1: Statistics used for trend detection

<table>
<thead>
<tr>
<th>Annual Precipitation - POR</th>
<th># of Wet Days Dry Season - POR</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (Neg)</td>
<td>1 (Neg)</td>
</tr>
<tr>
<td>1 (Pos)</td>
<td>7 (Pos)</td>
</tr>
</tbody>
</table>

Hydrologic & Environmental Systems Modeling
Results

May Precipitation - POR

May Precipitation – post-1950

Table 1  Statistics used for trend detection

<table>
<thead>
<tr>
<th>May Precipitation - POR</th>
<th>May Precipitation – post-1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Results

Max Precip NDJ – post-1950
Table 1  Statistics used for trend detection

<table>
<thead>
<tr>
<th></th>
<th>Wet Season</th>
<th>Tave</th>
<th>POR</th>
<th>Wet Season</th>
<th>Tave</th>
<th>post-1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>4</td>
<td>10</td>
<td></td>
<td>4</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

Markers sized from +/- 0.0000221 to +/- 0.0057 |
Filled markers are significant at the 0.05 level
Results

Table 1  Statistics used for trend detection

<table>
<thead>
<tr>
<th># of Dog Days – POR</th>
<th># of Dog Days – post-1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>
Results

Table 1  Statistics used for trend detection

<table>
<thead>
<tr>
<th>Annual maxima of Tave - POR</th>
<th>NDJ Maxima of Tave - POR</th>
<th>MJJ Maxima of Tave - POR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tave - POR</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>NDJ Maxima of Tave - POR</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>MJJ Maxima of Tave - POR</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

Markers sized from +/- 0.000512 to +/- 0.0412. Filled markers are significant at the 0.05 level.
Results

Annual maxima of Tave – post-1950

Table 1  Statistics used for trend detection

<table>
<thead>
<tr>
<th>Statistic</th>
<th>NDJ Maxima of Tave – post-1950</th>
<th>MJJ Maxima of Tave – post-1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tave</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>NDJ</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>MJJ</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

Filled markers are significant at the 0.05 level.
Results

Table 1  Statistics used for trend detection

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual maxima of $T_{min}$ - POR</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Annual maxima of $T_{min}$ – post-1950</td>
<td>1</td>
<td>16</td>
</tr>
</tbody>
</table>
Results

Table 1  Statistics used for trend detection

Annual maxima of Tmax – post-1950
Table 1  Statistics used for trend detection

- Ft. Lauderdale +1.8° F
- Ft. Myers +2.1° F
- Arcadia -0.4° F

Population for 21 km x 21 km grid cell around station

Post-1 950

Ft. Lauderdale +1.8° F

Post-1 950

Ft. Myers +2.1° F

Arcadia -0.4° F

Grid-based population for USHCN stations (Owen & Gallo, 2000)
Population for 21 km x 21 km grid cell around station

Grid-based population for USHCN stations
(Owen & Gallo, 2000)
Results

Belle Glade +2.6°F
Arcadia -1.9°F
Results

Median Deviation of Annual Tave for 32 stations

Median Dev of Wet Season Precip for Central FL
References


Pielke R.A. Sr. et al. 2007. Unresolved issues with the assessment of multicadal global land surface temperature trends. J Geophys Res 112:D24S08


Extra slides
Results

Table 1  Statistics used for trend detection

<table>
<thead>
<tr>
<th>Wet Season Tave - POR</th>
<th>Wet Season Tave – post-1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tave</td>
<td>Tave</td>
</tr>
<tr>
<td>- POR</td>
<td>- post-1950</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>
Table 1: Statistics used for trend detection

<table>
<thead>
<tr>
<th>Location</th>
<th>Temperature Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ft. Lauderdale</td>
<td>+1.4° F</td>
</tr>
<tr>
<td>Ft. Myers</td>
<td>+2.4° F</td>
</tr>
<tr>
<td>Arcadia</td>
<td>-1.9° F</td>
</tr>
</tbody>
</table>

Grid-based population for USHCN stations (Owen & Gallo, 2000)