Summer Precipitation Variability over the SE U.S. Analyzed from Atmospheric Moisture Budget

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SE U.S. summer precipitation

2009 Flood
Mableton, GA

2007 Drought – Worst in 100 years
Lake Lanier
Intensified variability of the summer rainfall

\( \chi^2 \) test:
Intensified precipitation variability is significant

<table>
<thead>
<tr>
<th></th>
<th>1st 30 years (1948–1977)</th>
<th>2nd 30 years (1978–2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet (&gt; 1 Std)</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Dry (&lt; -1 Std)</td>
<td>2</td>
<td>5</td>
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Wang et al. 2010
What factors affect the SE US summer precipitation?

All the factors can interact with each other at various spatial & temporal scales. Thus, identifying which factors drive the intensified rainfall variability is complex and difficult.

One possible simplification is to categorize these factors using certain criteria.

Meso-scale and Synoptic-scale systems (Baigorria et al. 2007; Knight and Davis 2007, 2009; Shepherd et al. 2007; Barlow 2011)

NASH circulation (Henderson et al. 2007; Katz et al. 2003; 2011; 2012; L. Li et al. 2012)

ENSO (Mo et al. 2008)

PDO (L. Li et al. 2012)

Atmo. Internal variability (Seager et al. 2009)

Anthropogenic forcing (Chen et al. 2003; Mearns et al. 2003; Liang et al. 2006; Christensen et al. 2007; W. Li et al. 2011)

Soil Moisture (Koster et al., 2004, Wu et al., 2007)

Atl. SST (Wang et al. 2010); AMO (Citrus, 2008)
Research Approach:
Atmospheric Moisture Balance

Seasonal Mean: $F_{in} = F_{out}$

(Brubaker et al., 1993)

\[ w g (P, E) = \nabla \cdot \int_{0}^{p_s} q \vec{V} \, dp \]

Trenberth and Guillemot 1995
Seager et al., 2010
Research Approach:

Atmospheric Moisture Balance

Precipitation = Evaporation + Moisture Transport

SE U.S. Summer Precipitation (P)

Moisture Transport

\[ \nabla \cdot \int_0^{p_s} q \vec{V} \, dp \]

Evaporation (E)

Synoptic-Scale Eddy

Thermo-dynamic (q)

Dynamic (V)

Large-scale Circulation

Thermo-dynamic (q)

Dynamic (V)

Thermo-dynamic (q_s - q_a)

Dynamic (surface wind speed)
Data and Methods

• **Data:**
  - **Precipitation**
    • CPC U.S. Unified Precipitation and PRec/L
  - **Atmospheric Reanalysis Datasets**
    • NCEP/NCAR; ERA-40; JRA-25 and NARR
    • Averaged over June-July-August (JJA) season

• **Methods:**
  - **Analysis of atmospheric moisture balance**
    • Partition of seasonal mean field and synoptic scale eddy
      \[ q = \bar{q} + q' \quad \vec{V} = \bar{V} + \vec{V}' \quad (\text{bar is seasonal mean; prime is 6-hr deviation}) \]
      \[
      \int_0^{p_s} \nabla \cdot \left( q \vec{V} \right) dp = \int_0^{p_s} \nabla \cdot \left( \bar{q} \bar{V} \right) dp \quad \int_0^{p_s} \nabla \cdot \left( q' \vec{V}' \right) dp \quad q_s \vec{V}_s \nabla p_s
      \]
      *Mean flow*  *Eddy*
  
- **Wavelet analysis** *(temporal evolution of periodicity)*
SE U.S. Moisture Budget (Climatology)

JJA Climatology:
Magnitude: \( E > \) Moisture Transport

1948-2007 JJA climatology of precipitation, moisture flux convergence and evaporation (mm/day)
Moisture Budget (Interannual variation)

Interannual Variation

- **Mean Flow > Eddy**

- **Moisture Transport > E**
  std dev 0.73mm/d > 0.41 mm/d

Total moisture transport vs that associated with JJA mean flow and synoptic eddies. The red lines are the least square fitting lines.

Time series of JJA mean precipitation, moisture transport and evaporation anomaly over the SE U.S. (Error bar represents one standard error among reanalysis datasets)
Moisture Budget $\rightarrow$ Interannual Variability

2-4 yr Variability:
- Moisture Transport $> E$
- JJA Mean-flow is the main contributor

“Morlet” wavelet

Local wavelet power spectrum of a) precipitation, b) evaporation, c) moisture transport and d) JJA mean component of moisture transport in 1948-2007
Thermodynamic (q) vs Dynamic (V)

\[
\bar{q} = \bar{q}_c + \bar{q}_a \\
\bar{V} = \bar{V}_c + \bar{V}_a
\]

\[
q\bar{V} = (\bar{q}_c + \bar{q}_a)(\bar{V}_c + \bar{V}_a)
\]

\( q_c \) and \( V_c \): 60-yr climatology; \( q_a \) and \( V_a \): deviation from the climatology

\[
\int_0^{p_s} \nabla \cdot (q\bar{V}) dp
\]

\[
= \int_0^{p_s} \nabla \cdot (q_c\bar{V}_c) dp + \int_0^{p_s} \nabla \cdot (q_a\bar{V}_a) dp
\]

\[
+ \int_0^{p_s} \nabla \cdot (q_c\bar{V}_a) dp + \int_0^{p_s} \nabla \cdot (q_a\bar{V}_c) dp
\]
Precipitation = Evaporation + Moisture Transport

\[ \nabla \cdot \int_0^{p_s} q \vec{V} \, dp \]

SE U.S. Summer Precipitation (P)

Moisture Transport

Synoptic-Scale Eddy

Dynamic (V)

Large-scale Circulation

Thermo-dynamic (q)

Dynamic (V)

Evaporation (E)

Thermo-dynamic (q_s - q_a)

Dynamic (surface wind speed)
JJA mean precipitation rate (shaded, unit: mm day\(^{-1}\)), 850hPa subtropical high ridge line (dashed contour) and moist of 850hPa geopotential height is 20-gpm, and the bold cur velocity less than -0.01Pa s\(^{-1}\) is stippled.
Composite US summertime precipitation anomaly (left), moisture flux anomaly (vector, right) and 500mb vertical velocity anomaly (contour, right).
Moisture Transport & Western Ridge

Increases in NW and SW types of western ridge during recent 30 years (*L. Li et al. 2012*)

- Intensifies variability in moisture divergence/convergence over the SE US
- Intensifies precipitation variability

Composite 850hPa 1560 geopotential height isoline upon the dynamic component of moisture divergence
Conclusions

- The SE US summer precipitation variability is mainly controlled by atmospheric dynamics.
- NASH western ridge position has a close relationship with the summer precipitation of its variability.
Thank you
**Fig. 1** a) spatial patterns of the first EOF of JJA mean precipitation over SE U.S. (91°W-76°W, 25°N-36.5°N) based on Prec/L data during the 1948-2007; b) the normalized PC1 time series corresponding to the spatial pattern (bar, values are shown in the left axis), and areal-averaged SE U.S. summer precipitation (black curve, units: mm day$^{-1}$, values are shown in the right axis).
ENSO & SE U.S. summer precipitation

- **NINO1.2**
- **NINO3**
- **NINO4**
- **NINO3.4**
- **Combined ENSO**

**Graphs:**

- **a)**
- **b)**
- **c)**

**Legend:**
- Blue: Precipitation
- Red: Moisture Transport

**Months:**
- DJF
- JFM
- FMA
- MAM
- AMJ
- MJJ
- JJA