Perspectives on warm season convection in complex terrain.....

D. Gochis (NCAR)
Climatological Context

Fundamentals of warm vs. cold season orographic precipitation

Focus on diurnal cycle

Some characteristics of extreme, warm-season hydrometeorological events in complex terrain

FRONT-PORCH 2013 study in Front Range convection and hydrometeorology
Major Mountain Chains w/ Pronounced Warm Season Convective Regimes
Baroclinic vs. Eq. Barotropic regimes...
Major Moisture Flux Pathways into the N. American Monsoon

- Caribbean Low-Level Jet
- Great Plains Low-Level Jet
- Gulf of California LLJ
- Rio Grande Rift Gap Flow
Basic Global Climatology: Wintertime
The many atmospheres of mountain regions: Ekhart (1948)

Free Atmosphere

Mountain Atmosphere

Valley Atmosphere
‘enhanced’ diurnal cycles/ ‘TAF’

Slope Atmosphere-
Radiative flux divergence,
Sensible/latent heat transfers,
Momentum effects

\[ \frac{dq}{dx} \]

\[ \frac{d\theta}{dx} \]
Cold vs. Warm season differences...

- Dynamic regime: baroclinic vs. eq. barotropic
- Climatological differences in static stability
  - In summer: $R_i > 1$, $F_r \sim < 1$
- Amplification of the diurnal cycle in summer
  - Local thermally driven circulations can be dominant over large-scale wind field
  - Local heat and moisture fluxes can play a large(r) role in modifying the regional atmosphere
- PBL depth and freezing level are much higher in summer than during winter
  - Higher LCL -> potential for sub-cloud evaporation
  - Diabatic processes (latent heat and radiation) can have significant feedback to cloud systems…
Basic Global Climatology

- Phase locking with diurnal cycles.. (of precipitation and moist thermodynamics...)
Thermally-forced terrain circulations...

Images courtesy Zardi and Whiteman, 2012
Background: Terrain circulations...

- **Formalization:**

\[
\begin{align*}
\frac{\partial u}{\partial s} + u \frac{\partial u}{\partial s} + w \frac{\partial u}{\partial n} &= -\frac{1}{\rho_0} \frac{\partial (p - p_a)}{\partial s} - g \frac{d}{\theta_0} \sin \alpha - \frac{\partial u \partial w'}{\partial n} \\
\frac{\partial w}{\partial s} + u \frac{\partial w}{\partial s} + w \frac{\partial w}{\partial n} &= -\frac{1}{\rho_0} \frac{\partial (p - p_a)}{\partial n} + g \frac{d}{\theta_0} \cos \alpha \\
\frac{\partial \theta}{\partial s} + u \frac{\partial \theta}{\partial s} + w \frac{\partial \theta}{\partial n} &= -\frac{1}{\rho_0 c_p} \frac{\partial R}{\partial n} - \frac{\partial w' \theta'}{\partial n} \\
\frac{\partial u}{\partial s} + \frac{\partial w}{\partial n} &= 0
\end{align*}
\]

Local Press. Perturbation

Buoyancy-reduced Gravity

Sensible Heat Production

Gochis et al., AMS New Orleans, 2012
The North American Monsoon Research Advances:

- Johnson et al. (2010) J. Climate Special Issue on ‘TRMM Diabatic Heating’
- The diurnal cycle of convective flows and diabatic heating directly support the conceptual model of precipitation
- NERN supplied T/RH for mid- and high-elevation locations
The NAME Event Rain gauge Network (NERN 2002-2007)
Defining the Diurnal Cycle of Rainfall
Character: Frequency, Intensity, Spatiality

2002-2004 Jul-Aug Diurnal Cycle of Hourly Precipitation Frequency (NERN)

2002-2004 Jul-Aug Diurnal Cycle of Hourly Precipitation Intensity (NERN)

### 2002-04 Hour of Maximum Precipitation Frequency

**Times listed in local solar time**

**Legend**

- States
- 0204_mxhrfrq

**Hr. of Max. Freq.**
- 16-17
- 17-18
- 18-19
- 19-20
- 20-21
- 21-22
- 22-23
- 23-0
- 0-1
- 1-2

**2002-2004 Jul-Aug Diurnal Cycle of Hourly Precipitation Frequency (NERN)**

<table>
<thead>
<tr>
<th>Time of Day (LST)</th>
<th>Network Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-500</td>
<td>0.00</td>
</tr>
<tr>
<td>500-1000</td>
<td>0.05</td>
</tr>
<tr>
<td>1000-1500</td>
<td>0.10</td>
</tr>
<tr>
<td>1500-2000</td>
<td>0.15</td>
</tr>
<tr>
<td>2000-2500</td>
<td>0.20</td>
</tr>
<tr>
<td>2500-3000</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**NERN Team:** D. Gochis, J. Rodriguez, C. Watts, J. Garatuza

*Gochis et al., MWR 2004, J. Clim, 2007*
Conclusions:

- **General:**
  - The North American Monsoon circulation is a distinct driver of N. American warm season climate exerting significant control on hydroclimatic behavior
  - The elevated and complex topography of western N. America is a key feature of the NAM climate system serving as an elevated heat source, orographic barrier, moisture sink and organizing mechanism for complex eco-hydrological processes
  - **Modeling systems must adequately represent key physiographic features** (orography and local moisture sources) to produce viable hydroclimatic simulations

- **Controls on Precipitation:**
  - Diurnal cycle is a fundamental mode of circulation, stability, cloud and hydroclimatic variability and is tightly coupled to orography
  - Satellite QPE products contain significant frequency and intensity biases that map to terrain features and severely alias land surface hydrology models

- **Controls on Runoff:**
  - Seasonal hydrologic “conditioning” of watersheds is the first order driver with terrain and event character (e.g. hurricanes) influencing IAV and ISV behavior

- **Controls on land surface-atmosphere fluxes:**
  - Physiographic features such as soil depth and terrain gradients are important controls on surface energy partitioning
Basic Global Climatology

- Phase locking with diurnal cycles.. (of precip and moist thermodynamics…)

- Source regions for long-lived propagating events (MCSs)…
Convection within and in the lee of topography:

Western North America

A B CFR

C D SMO

A Wet Soils
   Evergreen Forest

B Rocky Mountains  Foothills  Great Plains

C Coastal Plain  Foothills  Sierra Madre Occ.

D Dry Soils
   Deciduous Shrubs

Courtesy E. Vivoni
Major Mountain Chains w/ Pronounced Warm Season Convective Regimes
Issues for Water Vapor Cycling:

1. What are the key source, transport and discharge mechanisms for atmospheric water vapor?

Figure 4. Relationship among mesoscale convective complex (MCC) population centres, elevated terrain, and prevailing mid-level flow.
Major Mountain Chains w/ Pronounced Warm Season Convective Regimes
Modeling Issues...

- EXPID: E001
  - Total Precipitation (mm/day) JJA (1)
  - Begin: JUN 1982
  - End: AUG 1982
  - Mean: 3.01365
  - Std: 3.05321

- GPCP Version-2.1 satellite/gauge JJA (1) (Actual)
  - Begin: JUN 1982
  - End: AUG 1982
  - Mean: 2.73767
  - Std: 2.67541

- Difference (Top–Middle)
  - Mean: 0.275993
  - Std: 2.28119

W. Chao, 2012, submitted JAS
Characteristics of some ‘Extreme Events’:

- !!! Limited by ‘sustained moisture convergence’ !!!
- Rapid City, S.D. (1972)
- Big Thomspson, CO (1976)
- Rapidan, VA (1995)
- Ft Collins CO (1997)
- Liguria, IT (2011)
- Tabasco, MX, R. Grijalva (multiple…)
Characteristics of some ‘Extreme Events’:
FRONT PROCH – 2013:

- **Task 1-Physical Process Studies:** Conduct hydrometeorological process research into the controls on warm season convection initiation, evolution and its hydrological responses in complex terrain.

- **Task 2-Radar Retrieval Research:** Perform basic research with multi-parameter microwave radar systems on the spatially and temporally continuous retrieval of precipitation, wind, humidity and hydrometeor structures.

- **Task 3-Real-time Demonstrations:** Demonstrate real-time, end-to-end, hydrometeorological (e.g., precipitation and streamflow) nowcasting capabilities through assimilation of high resolution data into both NWP-based and extrapolation-based prediction systems.

- **Task 4-Collection of Radar Data Sets for Classroom Use:** Obtain radar data sets which will serve as the basis of web-accessible modules designed to illustrate key mesoscale storm structures for upper level undergraduate and graduate students.