Ingredients-based climatology and future projections of extreme precipitation events using a NWP framework

Jason Caldwell
Reclamation, Flood Hydrology
rcaldwell@usbr.gov

Team Members
Victoria Sankovich, John England (Reclamation)
Martyn Clark, Naoki Mizukami, Kyoko Ikeda (NCAR)
Kelly Mahoney (CIRES)

S&T Project ID: 6917

Research Question

- *Using a numerical weather prediction (NWP) framework, what impact does climate change have on the atmospheric conditions and geographical dependency of extreme rainfall events in the Colorado Front Range?*

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Project Goals

(1) Identify atmospheric and geographic forcing of extreme rainfall events in the Colorado Front Range

(2) Evaluate the effects of climate change on these forcings and the resulting extreme precipitation events in the Colorado Front Range

(3) Examine scale dependencies using NARCCAP and WRF model output

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Motivation

Extreme precipitation events drive decisions related to water resources:

* Dam safety
* Flood risk and mitigation
* Reservoir operations.

Storm events modulated by:

* Thermal/moisture characteristics
* Predicted to change in future
* Interaction with topography

PRIOR RESEARCH:

* CFR PACE Project (Mahoney et al., 2010)
* Colorado Headwaters Project

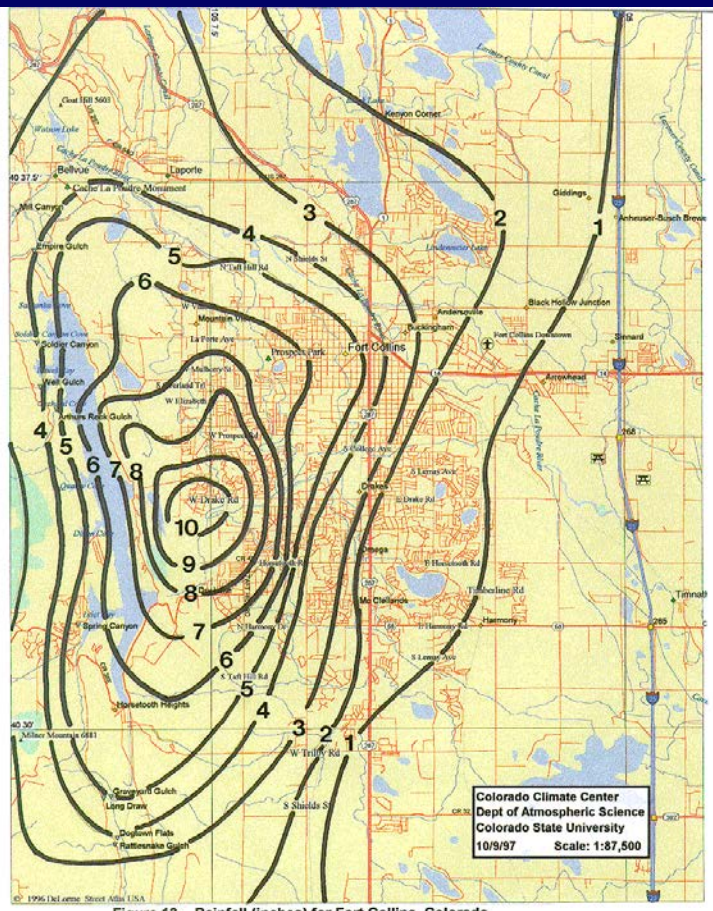

Figure 13. Rainfall (inches) for Fort Collins, Colorado, for 5:30-11:00 p.m. MDT for July 28, 1997

Source: Doeken and McKee
http://ccc.atmos.colostate.edu/~odie/rain.html

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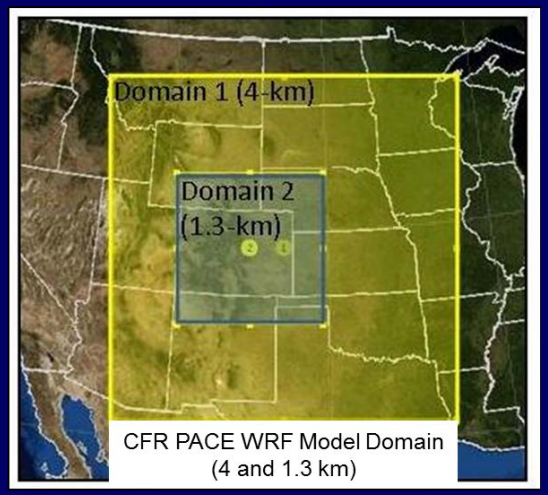
Data

CFR PACE project

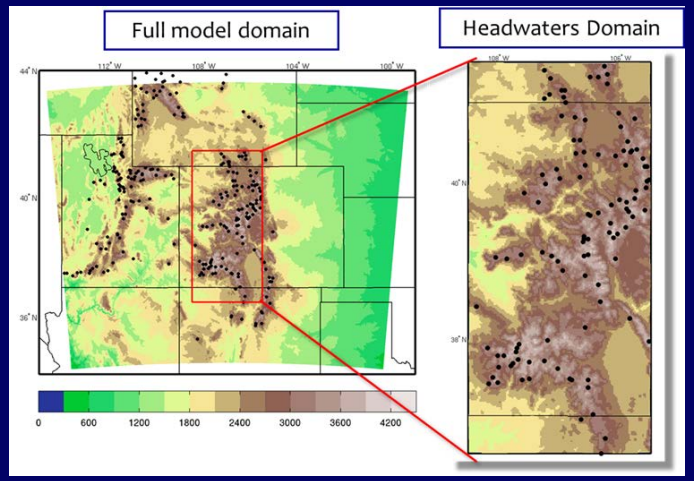
- *Assess potential for changes in warm season extreme precipitation*
- *Focus in the Colorado Front Range*
- *Identified ten extreme rainfall events*
- *Examined changes in atmospheric physics*
- *PROVIDES:*
  - ** downscaled NARCCAP simulations at 1.3- and 4-km*



CFR PACE WRF Model Domain
(4 and 1.3 km)

NCAR Colorado Headwaters Project

- *Historical and climate-perturbed simulations for the period 2000-2008*
- *Identify top 20 storms during the period*
- *Evaluating model and scale dependency*
- *PROVIDES:*
  - ** historical/future simulations at 4-km*



FY12 FOCUS ON CHP DATA

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Approach

- Collect and extract extreme storm events from downscaled NARCCAP and WRF simulations (FY12)
- Identify ingredients contributing to extreme precipitation events in the Colorado Front Range using statistical methods (FY12)
- Evaluate temporal and spatial variability in ingredients-based predictors of extreme precipitation (FY13)

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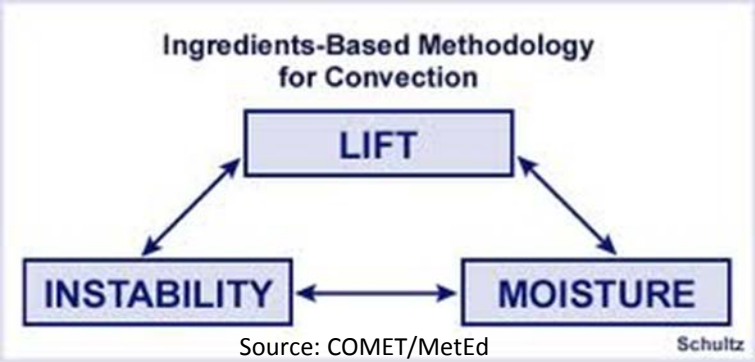
Approach

Doswell et al. (1996) outline ingredients-based approach for flash flooding



Source: COMET/MetEd

Ingredients include:

→ *Moisture availability*
→ *Precipitation efficiency*
→ *Storm motion*

Identify forcing mechanisms responsible for extreme precipitation

- *How do these variables change under future climates?*
- *Does this affect the risk for more frequent or intense storms?*
- *What are the implications for dam safety and operations?*
- *Is the change uniform across the western US?*
- *Can we use this information to inform storm maximization efforts?*

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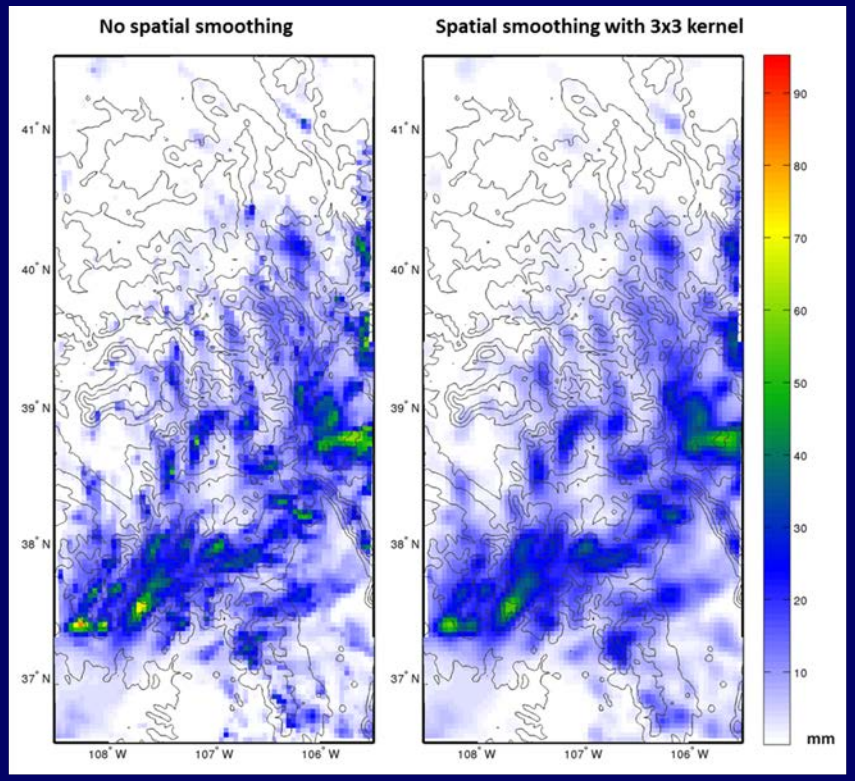
Task: Collect/Extract Data

CO Headwaters Project:

- Hourly, 4-km grids
- Oct 2000 – Sept 2008
- Daily, total liquid precip
  - * Warm Season: Jun-Sept
  - * All Season: all months

Spatial/Temporal Smoothing:

- 1x1 and 3x3 Kernels
- 1- and 12-hour moving average
- Focused on 3x3 with 1-hr smoother



Spatial smoothing effect on rainfall grid. The original rainfall grid (left) and 3x3 kernel filtered rainfall grids on July 26th 2007.

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Task: Collect/Extract Data

Top 20 Events:

- Historical (+/- 1 day) WRF model output
    - * Total liquid precipitation
    - * Meteorological variables
        - Moisture (RH, q)
        - Winds (dir, speed)
        - Heights
        - Temperature
    - * Underlying topography
        - Elevation, aspect*, slope*

3x3	1hr		
Date	Rain	long	lat
--	mm/day	deg	deg
7/8/2006	76.86	-105.53	40.47
7/8/2006	73.72	-105.53	40.44
8/30/2003	58.33	-105.50	39.35
7/28/2007	56.55	-108.27	37.37
7/23/2004	52.66	-105.52	38.52
7/6/2006	52.47	-106.01	36.64
8/4/2007	52.47	-106.96	36.50
8/4/2007	52.27	-106.91	36.50
7/6/2006	51.77	-106.05	36.65
7/9/2006	51.18	-105.66	38.70
8/7/2008	50.94	-105.51	41.41
7/20/2007	50.80	-105.75	38.45
7/28/2007	50.59	-108.23	37.37
7/6/2006	50.38	-106.05	36.68
8/6/2006	50.13	-106.11	39.29
8/7/2008	49.93	-108.45	39.17
7/6/2006	49.74	-105.96	36.68
7/22/2002	49.61	-107.23	36.72
7/28/2007	49.40	-108.27	37.40
8/9/2001	49.32	-105.54	40.04

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Task: Identify Ingredients

Traditional models:

*Linear regression (normal, continuous)

LINEAR REGRESSION MODELS LACK THE ABILITY TO CAPTURE NON-NORMAL DISTRIBUTIONS

Generalized Linear Models

* Relate response of dependent variable to linear combination of predictors

* Response of dependent variable assumed to be a realization from any exponential family distribution

$$G(E(Y)) = \eta = f(X) + \varepsilon = X\beta^T + \varepsilon$$

G(.)	*link function*
X	*set of predictors/indep. Variables*
E(Y)	*expected value of response variable*
ε	*error*
β	*model parameters*

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Task: Identify Ingredients

Use BIC to select best subset of predictors (initial total predictors = 37)

- Resolves issue of over-fitting by adding predictors

Further resolution of best subset by significance of Betas

Steps:

(1) Model the occurrence/non-occurrence (logistic)

(2) Model the magnitudes (gamma)

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Task: Identify Ingredients

MODELING FRAMEWORK

-Spatial domain for each storm
-Storms treated independently

Weather Variables:
SLP, RH, HT, QC, T, U, V, W
Geographic Variables:
Lon, lat, elev, aspect
Pressure Levels:
1000, 850, 700, 500, 250

Identify the Top 50 Precipitation Threshold Value

Set pixels
< Pthresh = 0
>=Pthresh =1

Model using GLM logistic

Predict the probability of occurrence

Top 50 probabilities considered as “1”s

Extract weather variables at the predicted “1”s

Model magnitude using Top 50 Precipitation Values

Predict the magnitude at those locations

Compare predicted locations and magnitudes

Storm-by-Storm Focus

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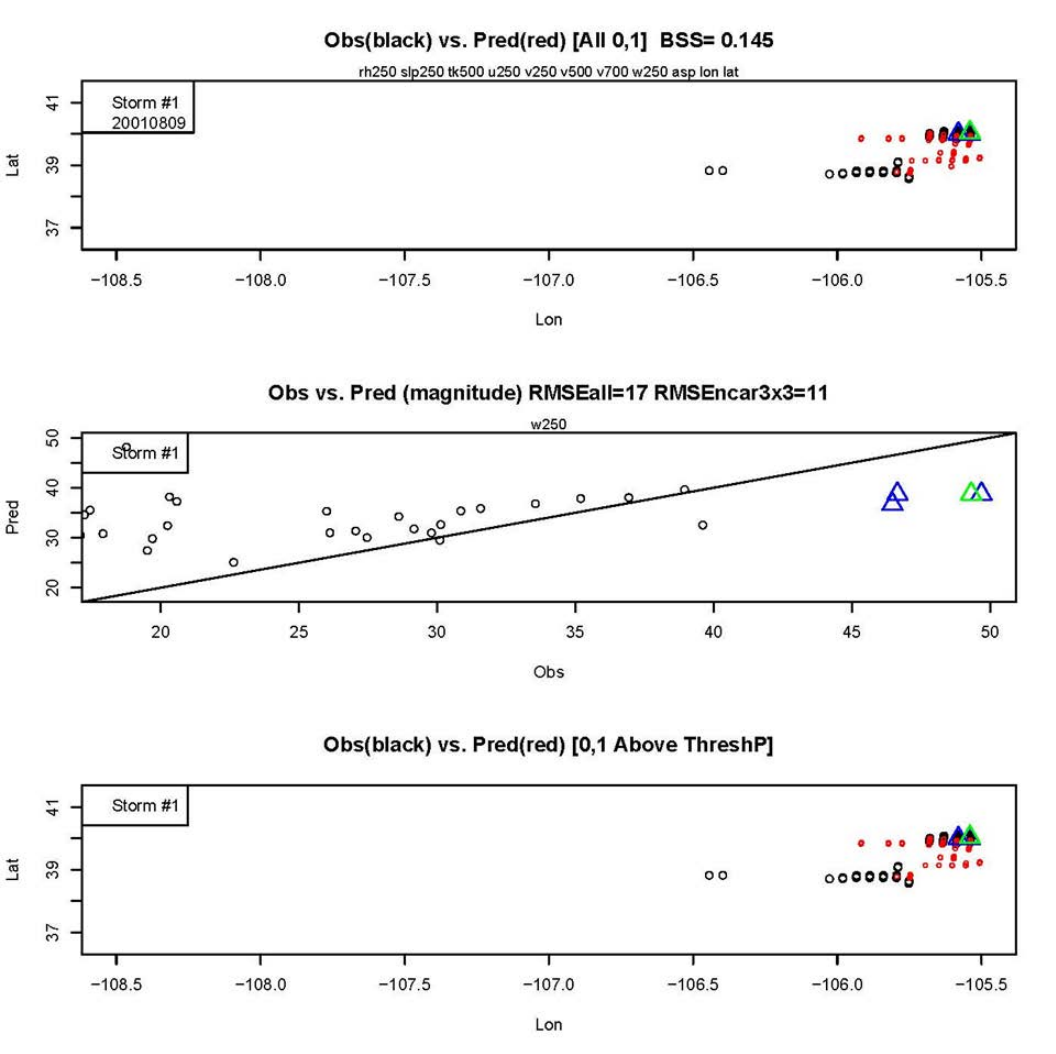
Task: Identify Ingredients

August 9, 2001

- Poor performance
  - Wrong locations (0,1)
  - Lower actual precipitation at those locations
  - Results in underestimates in magnitude



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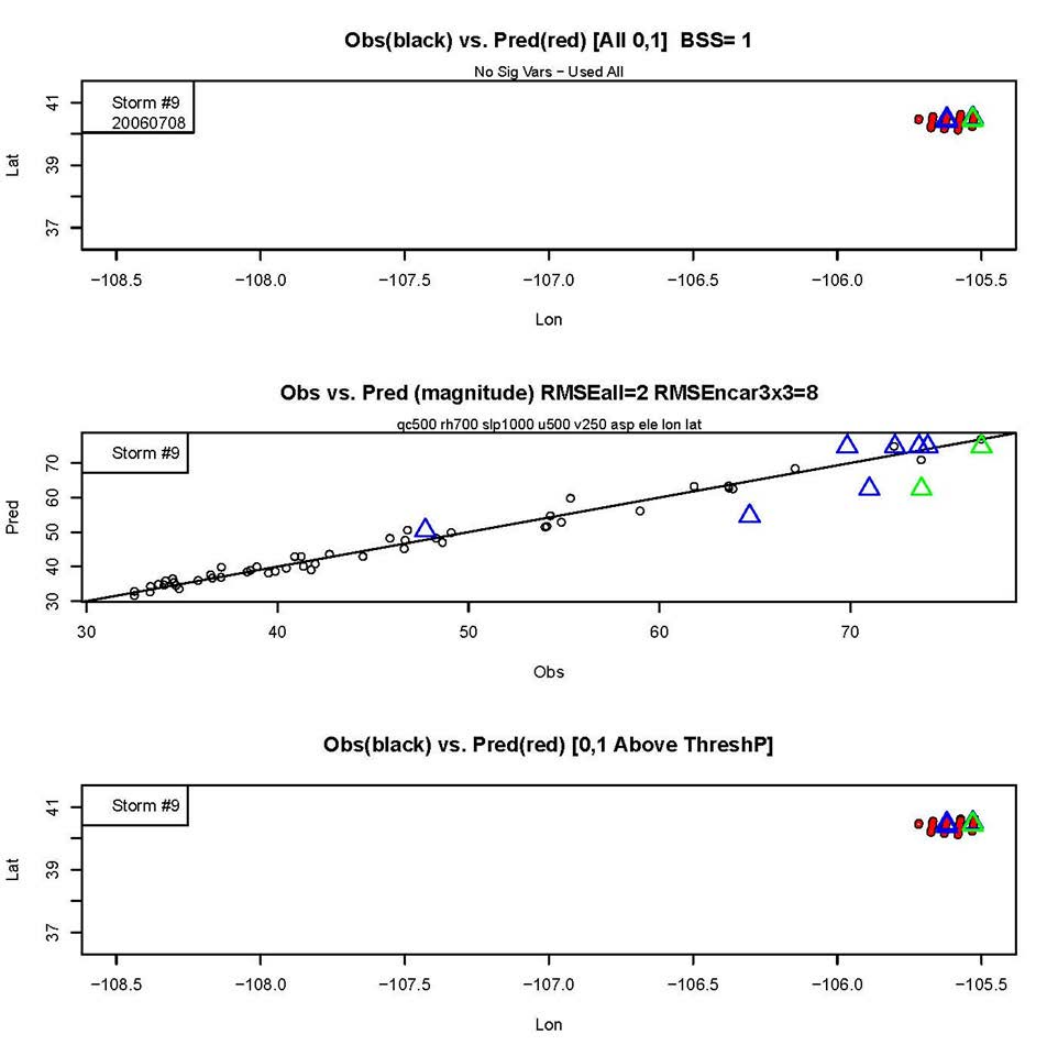
Task: Identify Ingredients

July 8, 2006

- Best performance
  - Exact locations (0,1)
  - Precipitation magnitudes modeled well



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Task: Identify Ingredients

Summary of Skill Scores

Storm #	Date	Events3x3	BSS	RMSEall	RMSE3x3
1	20010809	1	0.15	17	11
2	20020722	1	0.23	18	7
3	20030824	0	0.32	9	
4	20030830	1	0.50	12	11
5	20040717	0	0.14	9	
6	20040723	1	0.44	17	11
7	20050725	0	0.08	11	
8	20060706	4	0.75	6	6
9	20060708	2	1.00	2	8
10	20060709	1	0.44	15	2
11	20060806	1	0.68	9	3
12	20070720	1	0.48	10	11
13	20070726	0	0.18	15	
14	20070727	0	0.07	20	
15	20070728	3	0.36	16	6
16	20070730	0	0.54	10	
17	20070803	0	0.39	11	
18	20070804	2	0.61	9	3
19	20070805	0	0.53	10	
20	20070815	0	0.38	11	
21	20080807	2	0.15	24	5
		20	0.40	12	7
		Total	Average	Average	Average

KEY FINDINGS:

- Location is relatively well-predicted
  - All events BSS>0 (better than climo)
  - Max = 1.0, Min = 0.07, Mean = 0.40
- Magnitude also well-predicted, in general
  - Mean RMSE = 12 mm (0.05”) all storms
  - Mean RMSE = 7 mm (0.03”) 3x3 storms

ISSUES:

- Definition of threshold may skew results
- Low variance in observations → near zero correlation
- Predicted 1s in regions of lower precipitation amounts → underestimation

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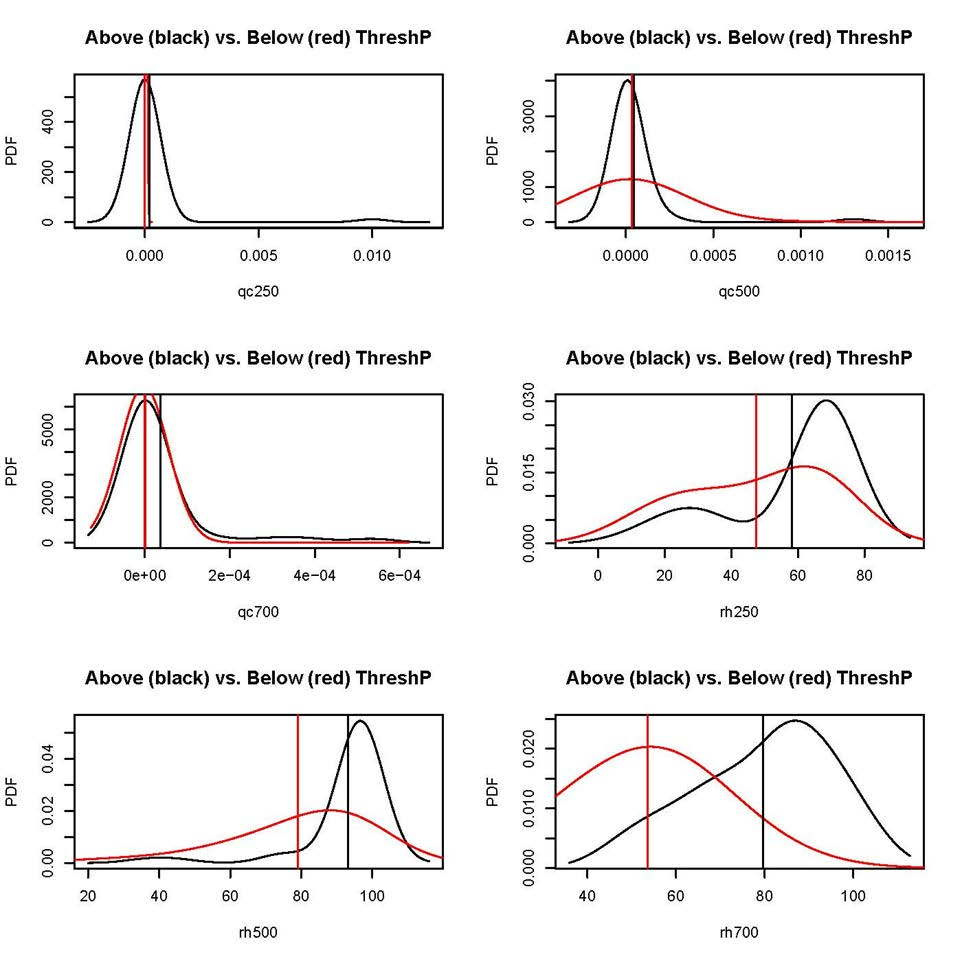
Task: Identify Ingredients

EVALUATION OF MOISTURE:

- ***Slight increase in cloud moisture at 700hPa***
- ***Increased relative humidity (10-20%) at/above 700hPa***
- ***POTENTIALLY INDICATES:***
  - ***Higher moisture aloft in extreme storms***
  - ***Higher precipitation efficiency in cloud layer***



Black = Above Thresh; Red = Below Thresh

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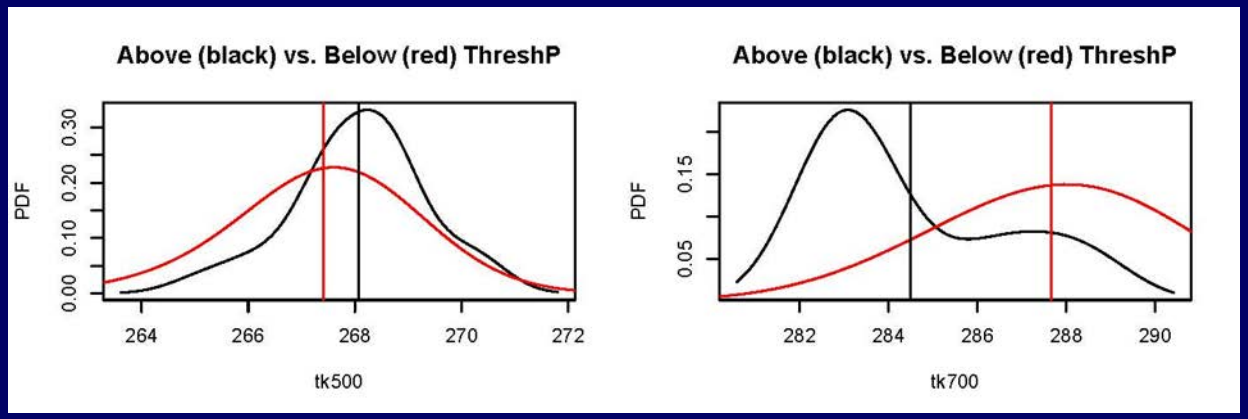
Task: Identify Ingredients



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<u>EVALUATION OF TEMPERATURE:</u>

- ***Slightly warmer temperatures aloft (500hPa, 250hPa)***
- ***Cooler temperatures at 700hPa***
- ***POTENTIALLY INDICATES:***
  - ***Latent heat release aloft***
  - ***Precipitation production in cloud layer***

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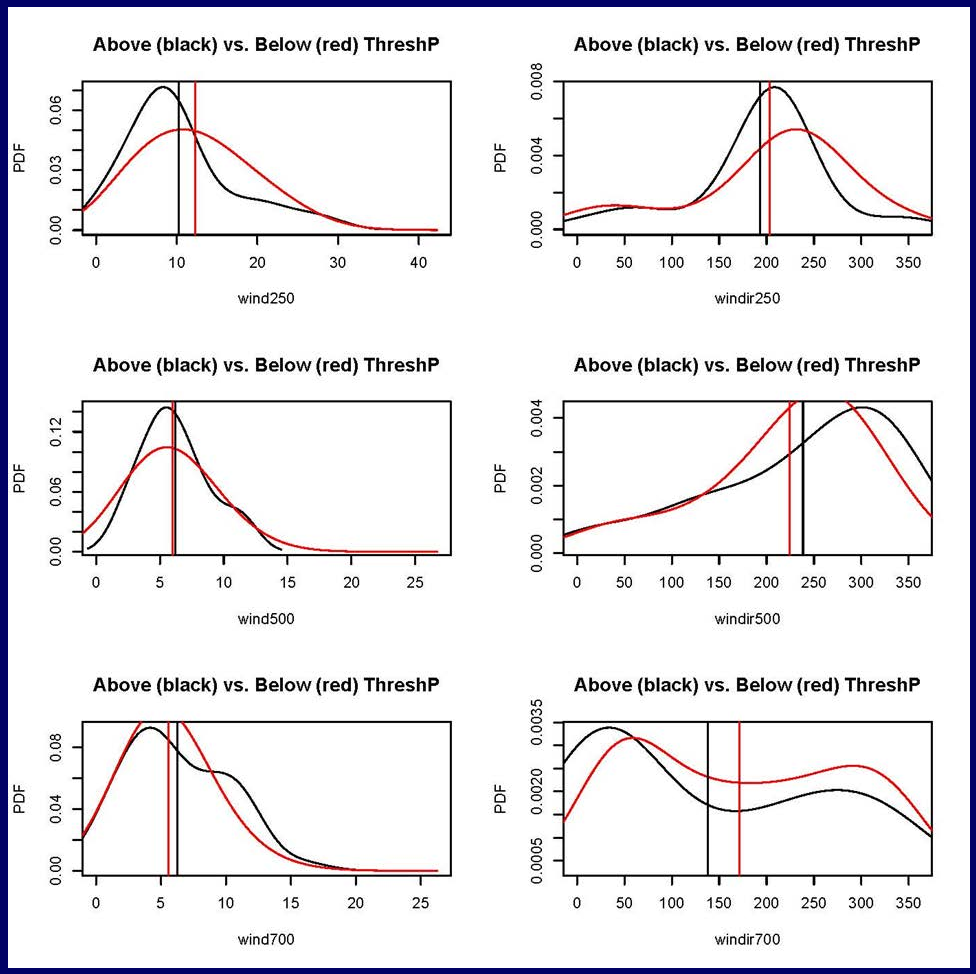
Task: Identify Ingredients

EVALUATION OF WINDS:

- ***Stronger easterly flow at 700hPa***
- ***Same magnitude but more westerly flow at 500hPa***
- ***Weaker more southerly flow at 250hPa***
- ***POTENTIALLY INDICATES:***
  - ***Increased moisture at low-levels***
  - ***Shear 700-500hPa***
  - ***Slower storm motion***



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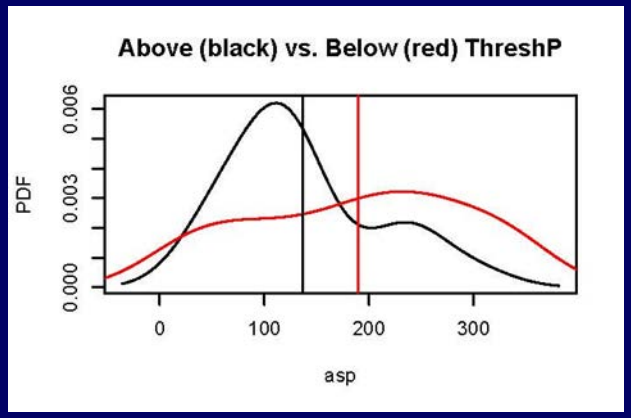
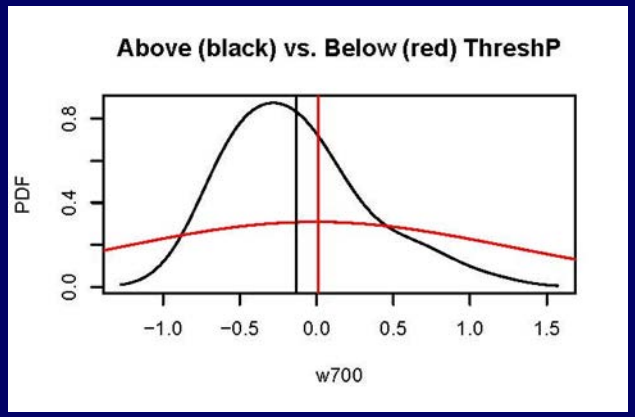
Preliminary Findings

EVALUATION OF OTHER VARIABLES:

- ***Higher sea level pressure (2-3 hPa)***
- ***Southeast facing terrain based on azimuth of aspect preferred for heaviest rain***
- ***Elevation of heavy rain ~200m higher at mean of 2800m***





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Summary & Future Work

Statistical modeling approach is acceptable but requires refinement → Local Polynomial (Clark and Slater, 2006)

Storm-by-storm insufficient for capturing climatological perspective → lump all storms to increase sample size

Raw meteorological variables fail to tell the whole story → Need to generate additional variables (e.g., Qflux, IPW)

Spatial perspective completed → Use temporal application

Robust, flexible framework developed → Apply to PACE WRF and climate change perturbation runs to examine spatial and temporal variability and dependencies

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Questions/Comments?

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