Weather Modification Benefit Cost Analysis and a Look into the 2015 Weather Pattern

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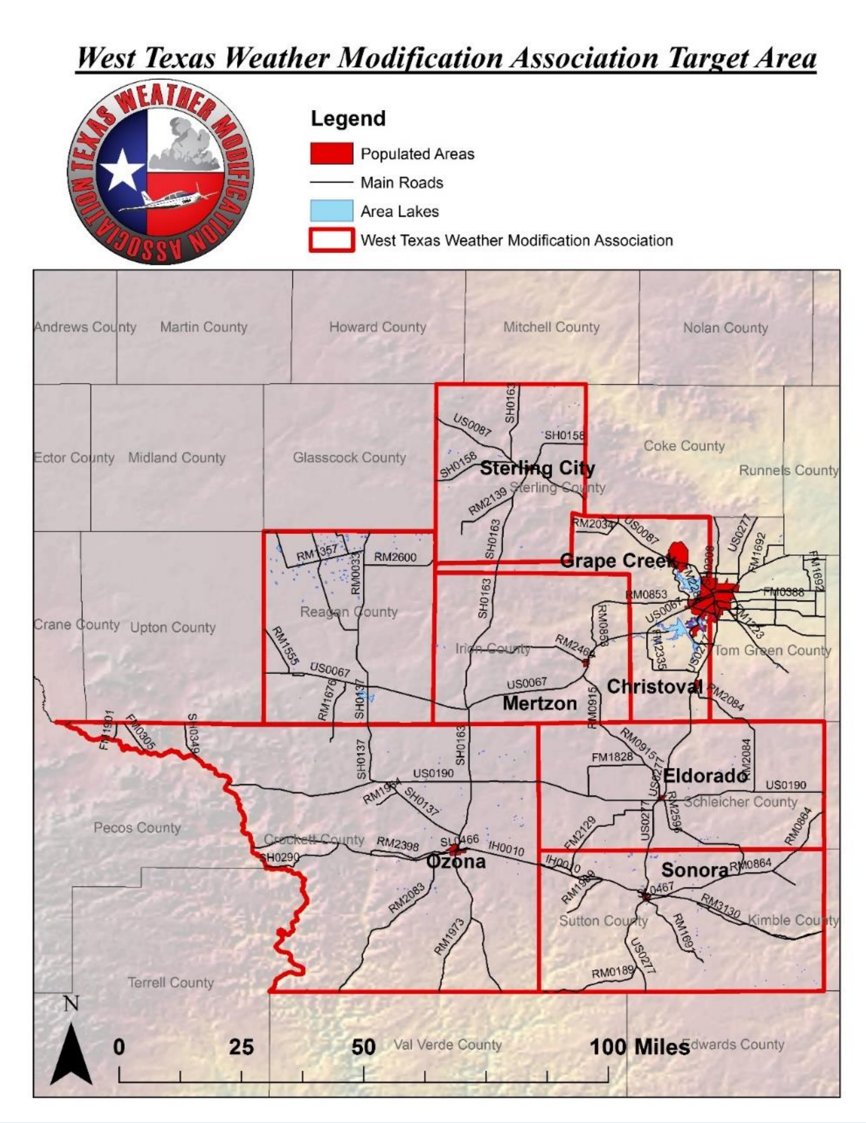
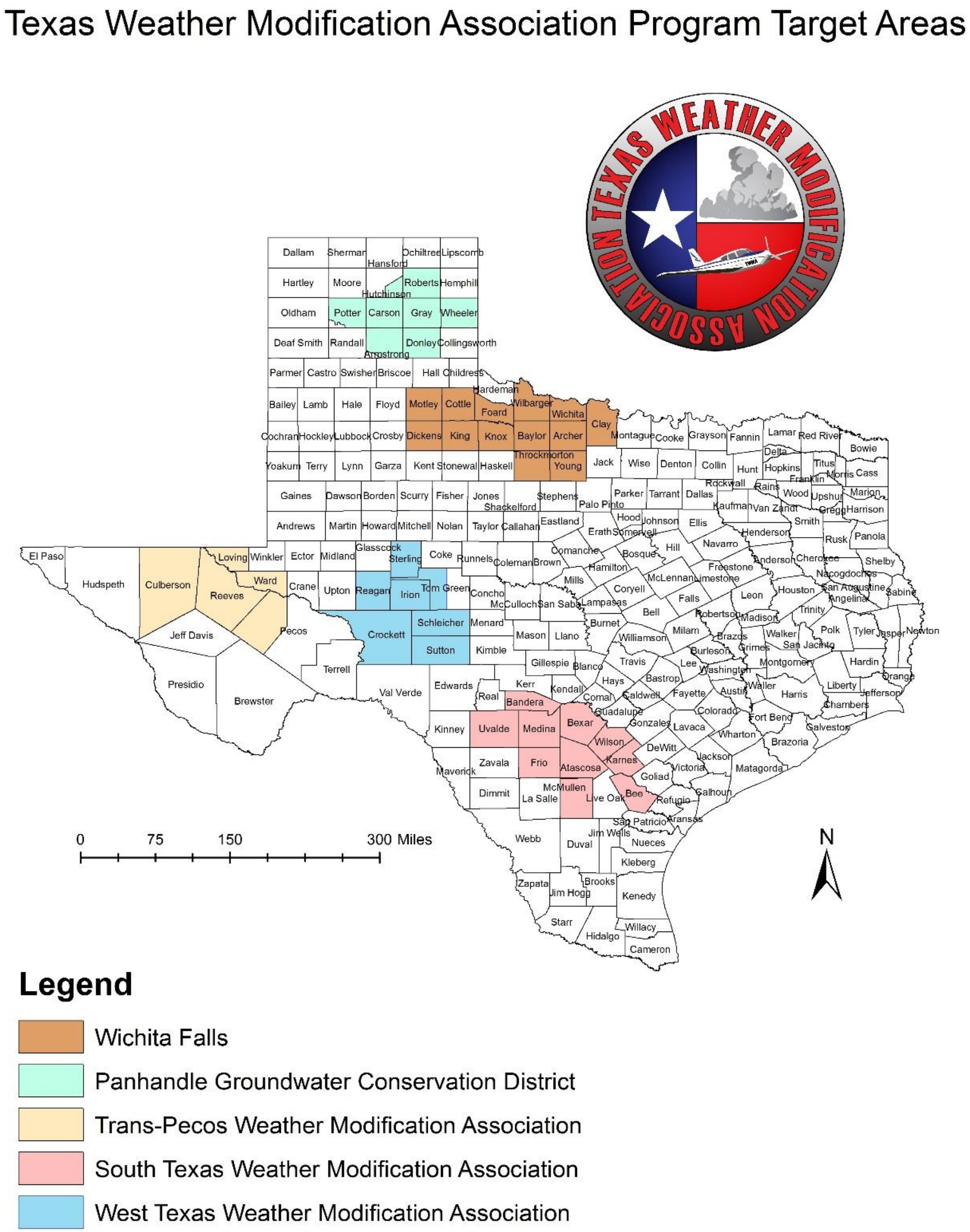
Groundwater Management #7 Groundwater Symposium – 18 April 2015 – San Angelo, TEXAS

What to Expect

- Target Areas of the WTWMA/TWMA
- Quick Background on Weather Modification
  - Who, what, when, where and why?
- Analysis
- Benefit-Cost Analysis
- A look into the rest of 2015

Target Areas



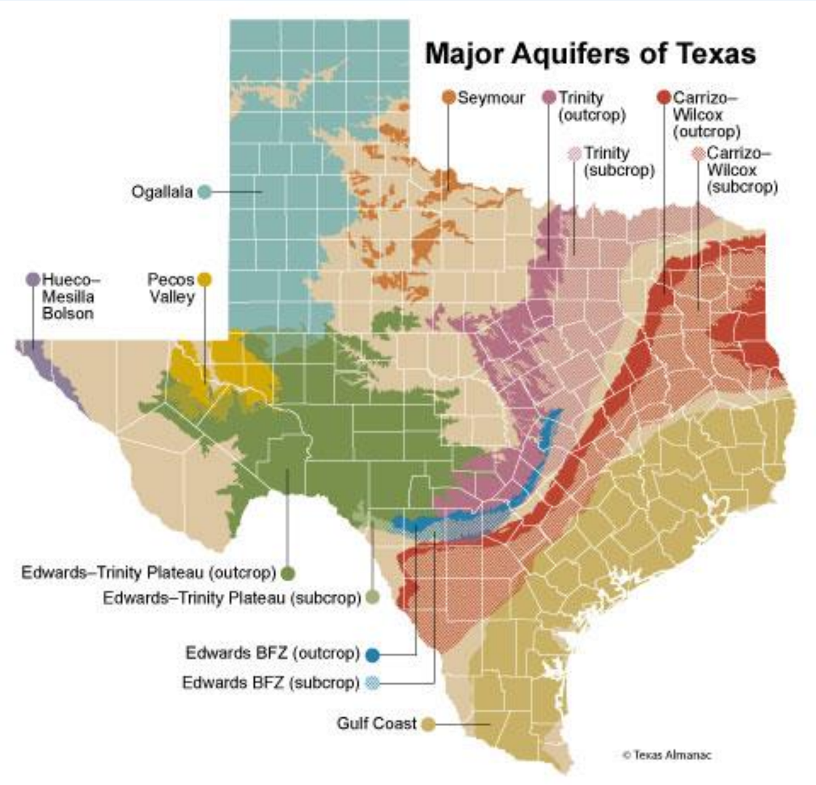


Why Modify the Weather?

- Demand for water increases while the supply decreases
- Clouds in Texas are very vulnerable to particulates, especially those in West Texas
  - Impacts from dust, smoke, sulfates and other small aerosols
- Texas is very susceptible to drought
- ENSO conditions impact Texas more so than any other state in terms of changing weather patterns
  - La Nina
  - El Nino

Program Goals

- Help increase water supply for:
  - Drinking water
  - Irrigation
  - Area Lakes, Rivers and Reservoirs
  - **Aquifer Recharge**
- While reducing:
  - Need to irrigate
  - Groundwater Consumption



Methodology

- Base Seeding via aircraft using two different types of flares
  - Glaciogenic Flares (Silver Iodide)
  - Hygroscopic Flares (Calcium Chloride)

- Flares are similar to roadside flares.
  - Burn in place (BIP)
  - Particles volatilize reforming to the sizes/distributions favorable for seeding

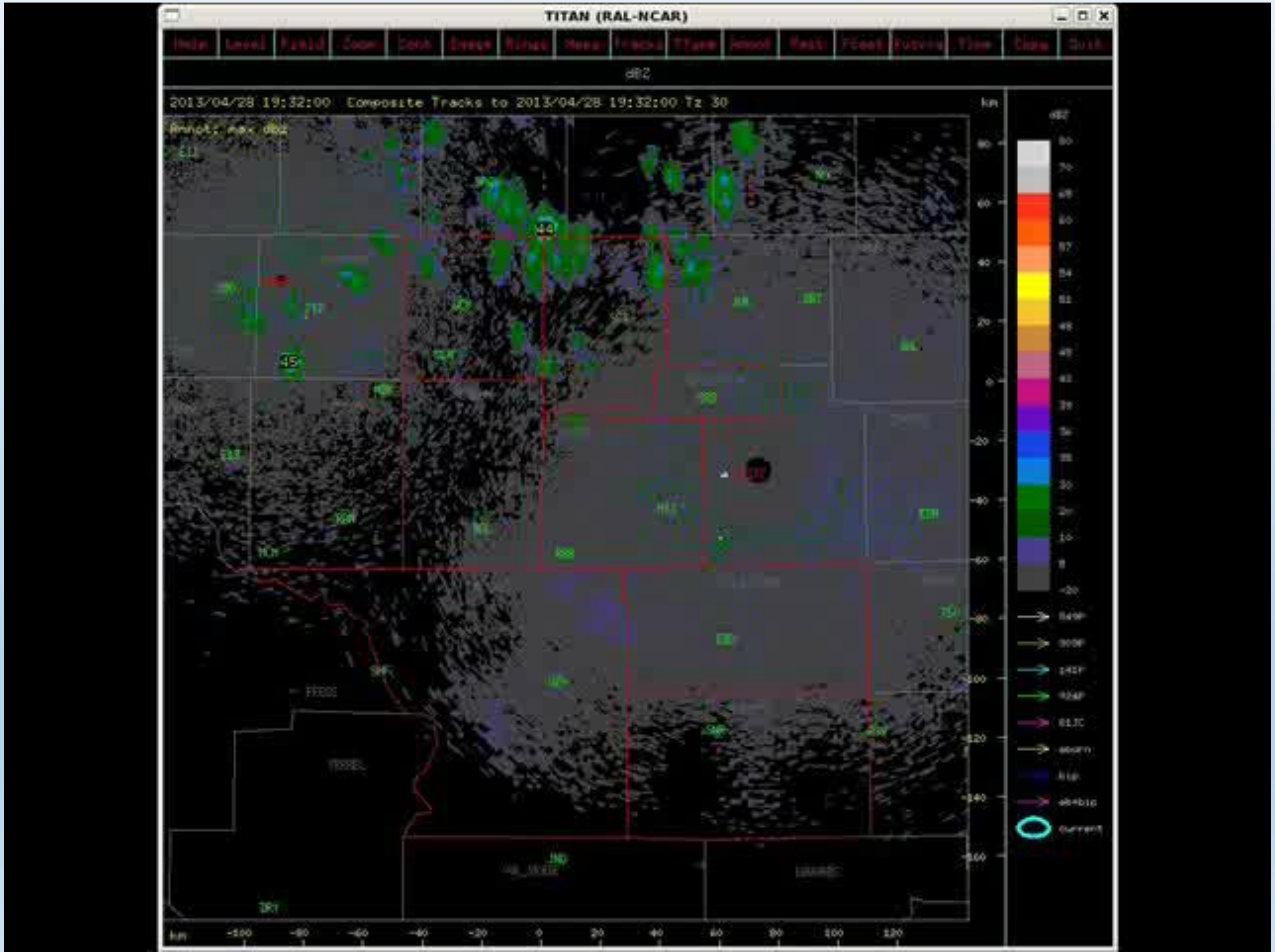
Methodology

- Storms must be convective in nature
  - 1. to ensure the possibility of super cooled water
  - 2. to ensure the chances of strong enough inflow reliable enough to transport material
- Rely on inflow at the cloud base to transport material into the cloud
- Must have “VFR” flight conditions
  - Allows us to target clouds on an as-need basis

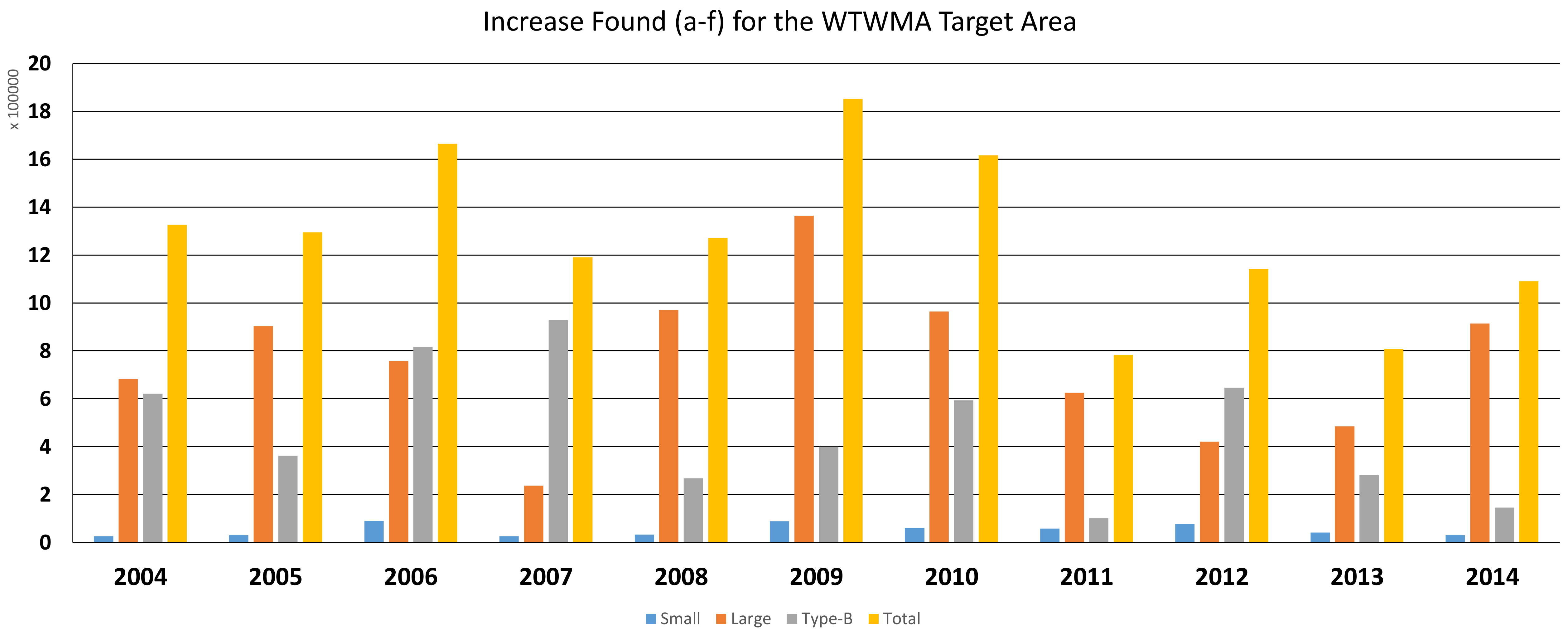
Example

- 28 April 2013
- Forecast models suggested scattered showers north of a line from San Angelo to Big Lake
- Areas further south were expected to be dry
- Cloud bases near 12,000 feet, ICA values strongly positive indicating very “sick” clouds
- Hygroscopic Seeding was aggressively used, along with some dual-seeding as clouds grew vertically

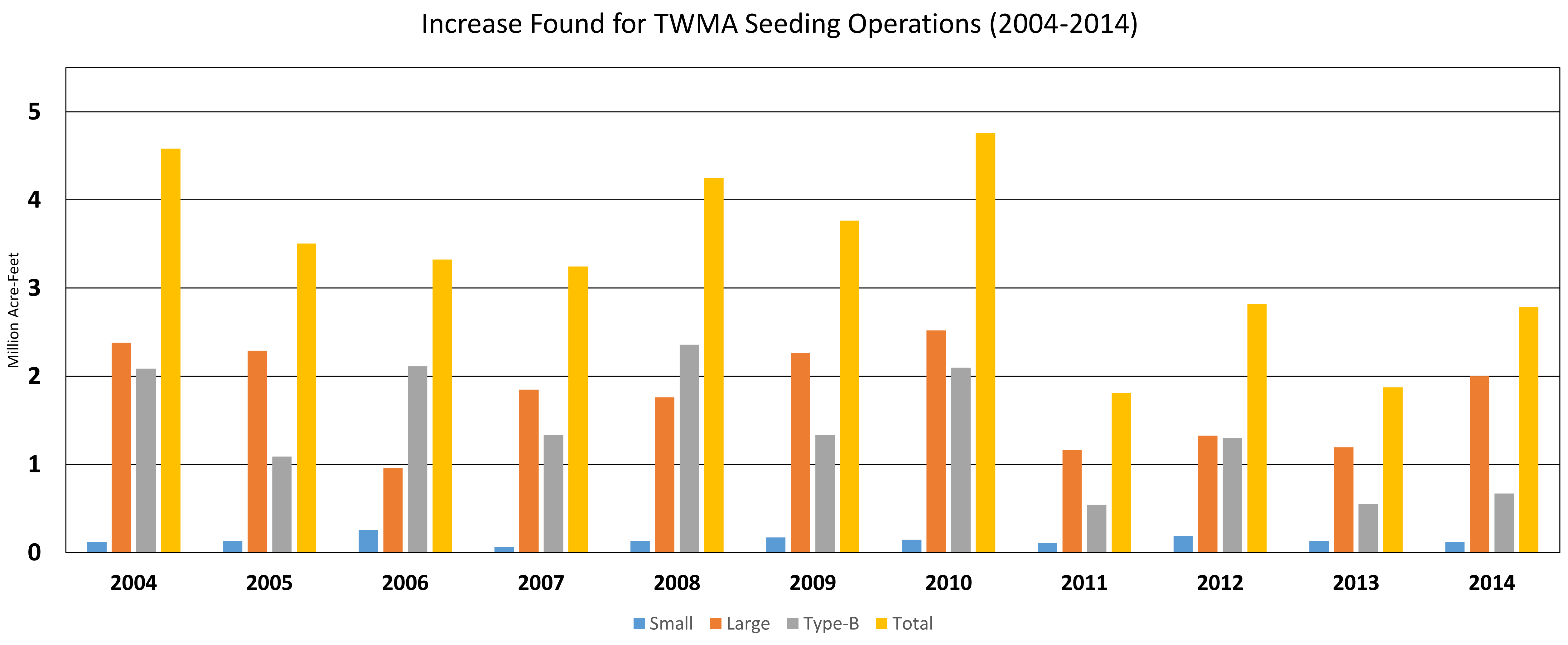
Example (28 April 2013)



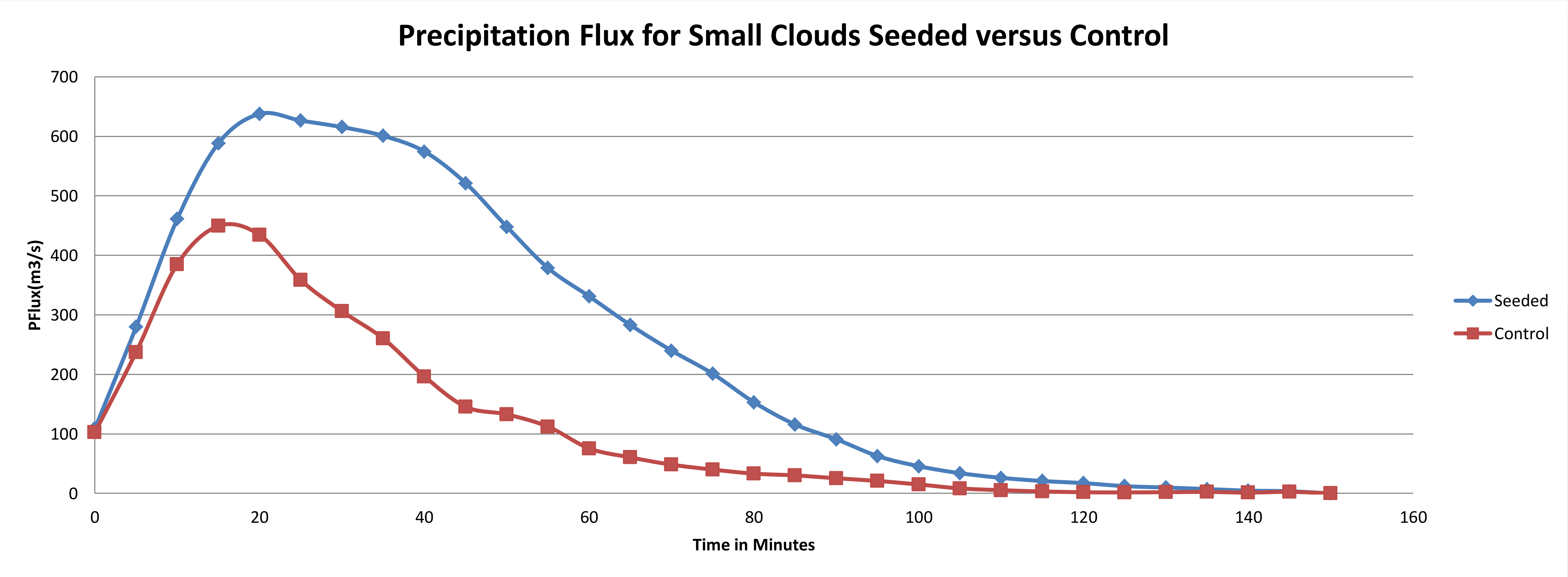
Analysis for the WTWMA



Analysis for the TWMA



9 Year Analysis on Small Clouds

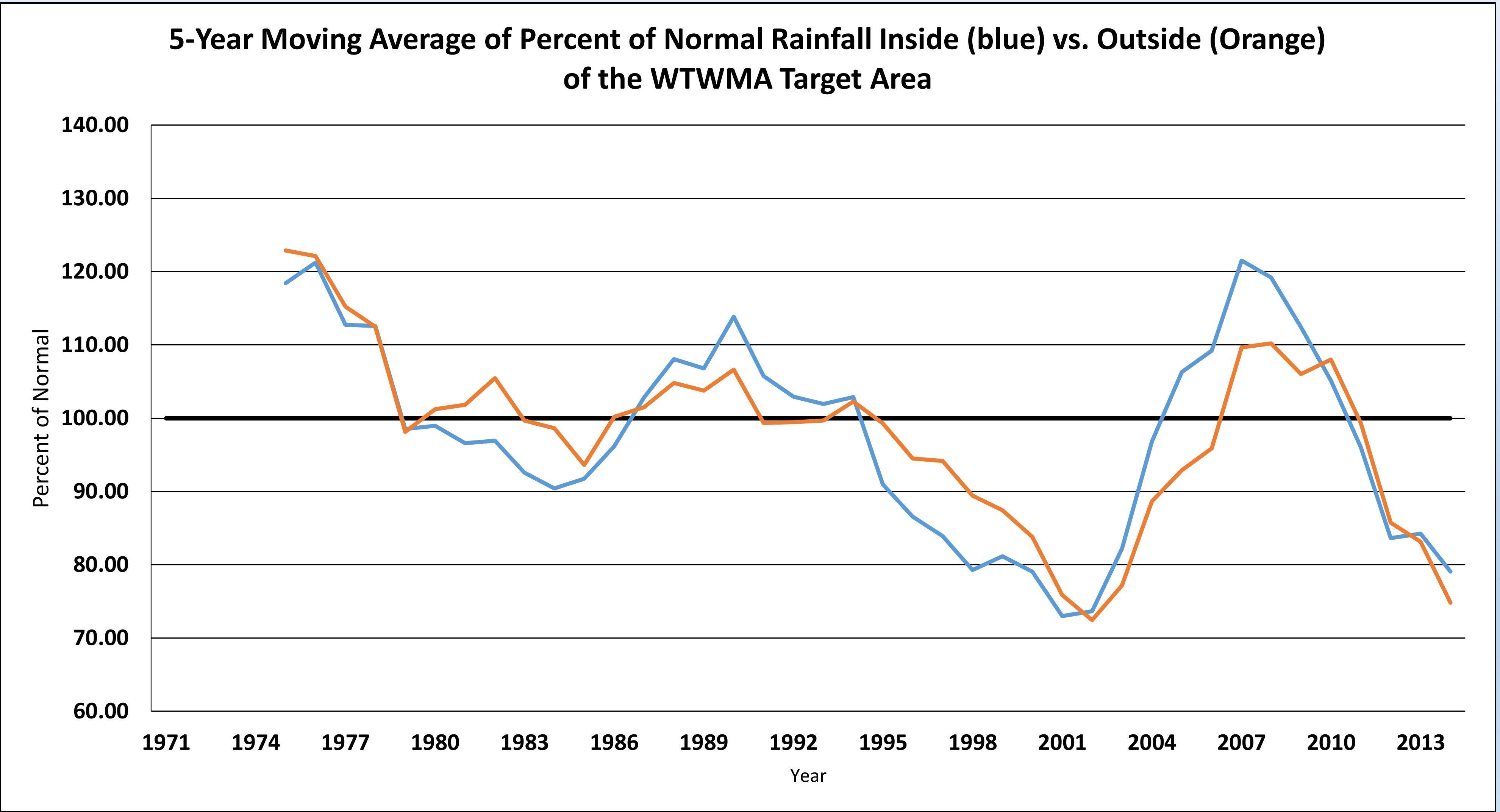


Credit: Dr. Arquimedes Ruiz-Columbiè, TTU

Precipitation Analysis

- Percent of Normal rainfall was compared within the target area to areas outside of the target area.
- Weather Modification began in West Texas in 1996 (first operational year)
- In 2004, meteorologist began using high resolution radar data. Therefore I have called the 2004-2012 the "modern era" of weather modification

Outside vs. Inside of the Target Area



2004-2014:

Inside = 100.35% of Normal

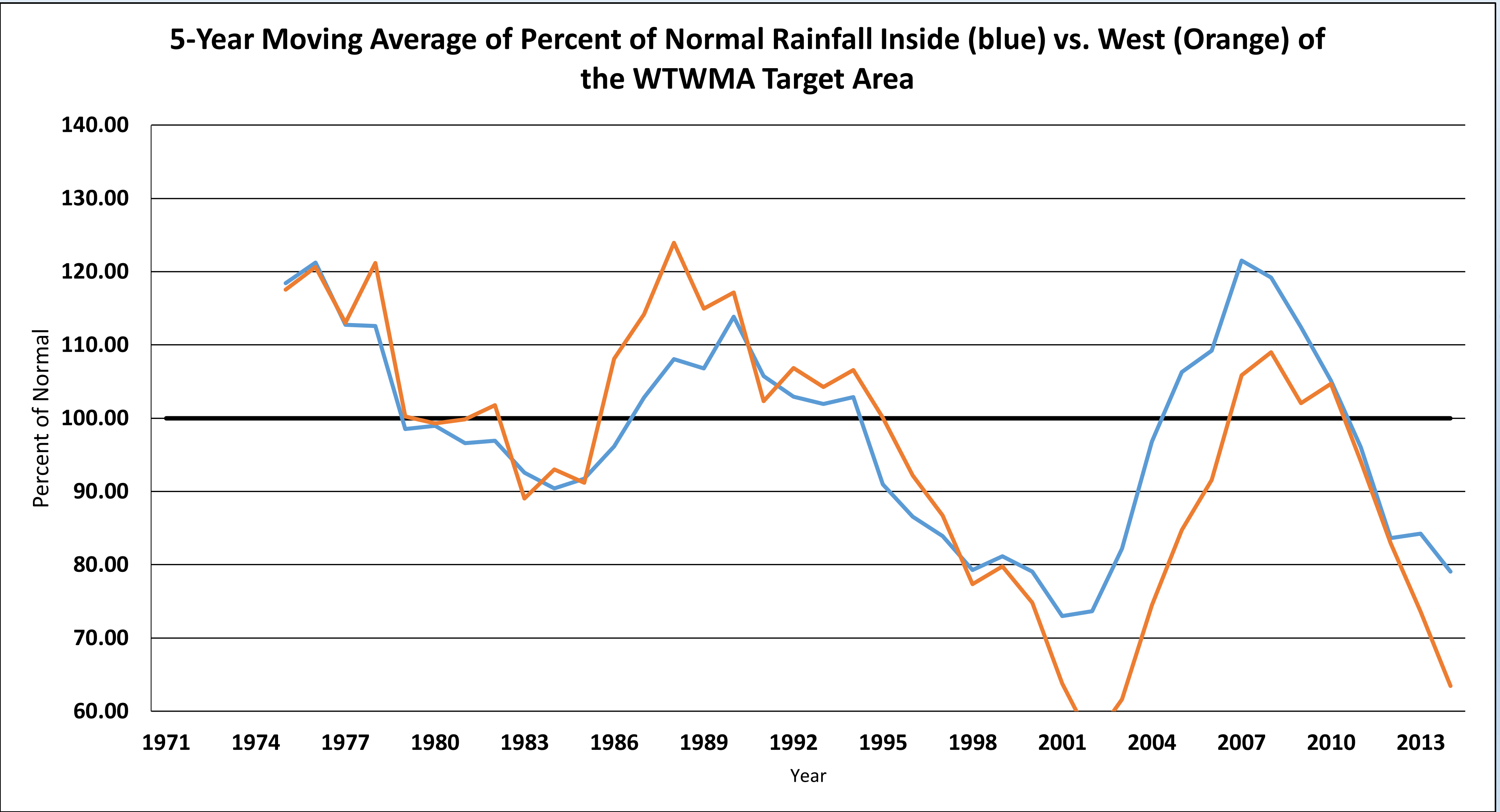
Outside = 95.01% of Normal

1996-2014:

Inside = 92.72% of Normal

Outside = 88.75% of Normal

Target Area versus Outside (West)



2004-2014:

Inside = 100.35% of Normal

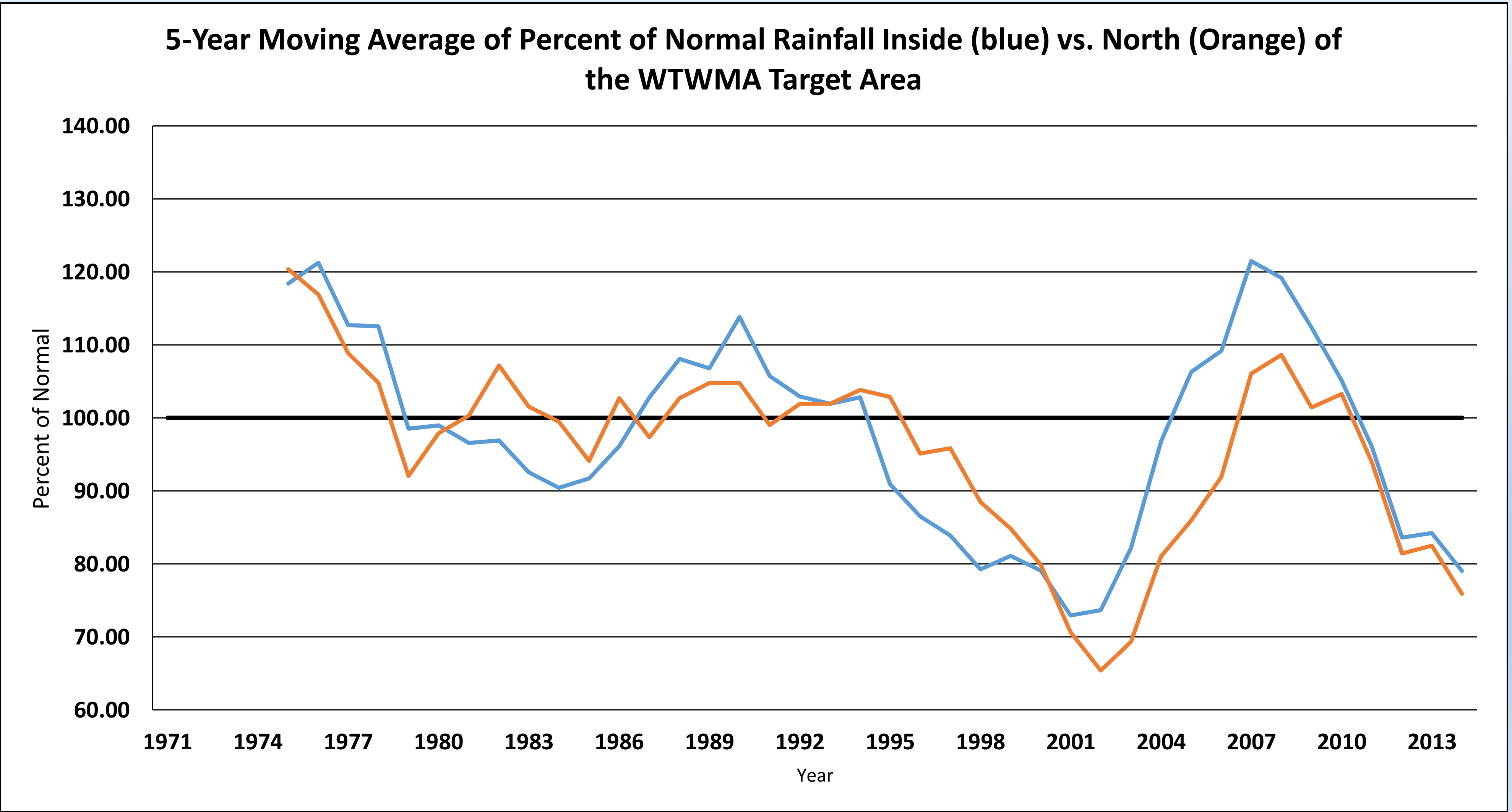
Outside = 79.86% of Normal

1996-2014:

Inside = 92.72% of Normal

Outside = 87.73% of Normal

Target Area versus Outside (North)



2004-2014:

Inside = 100.35% of Normal

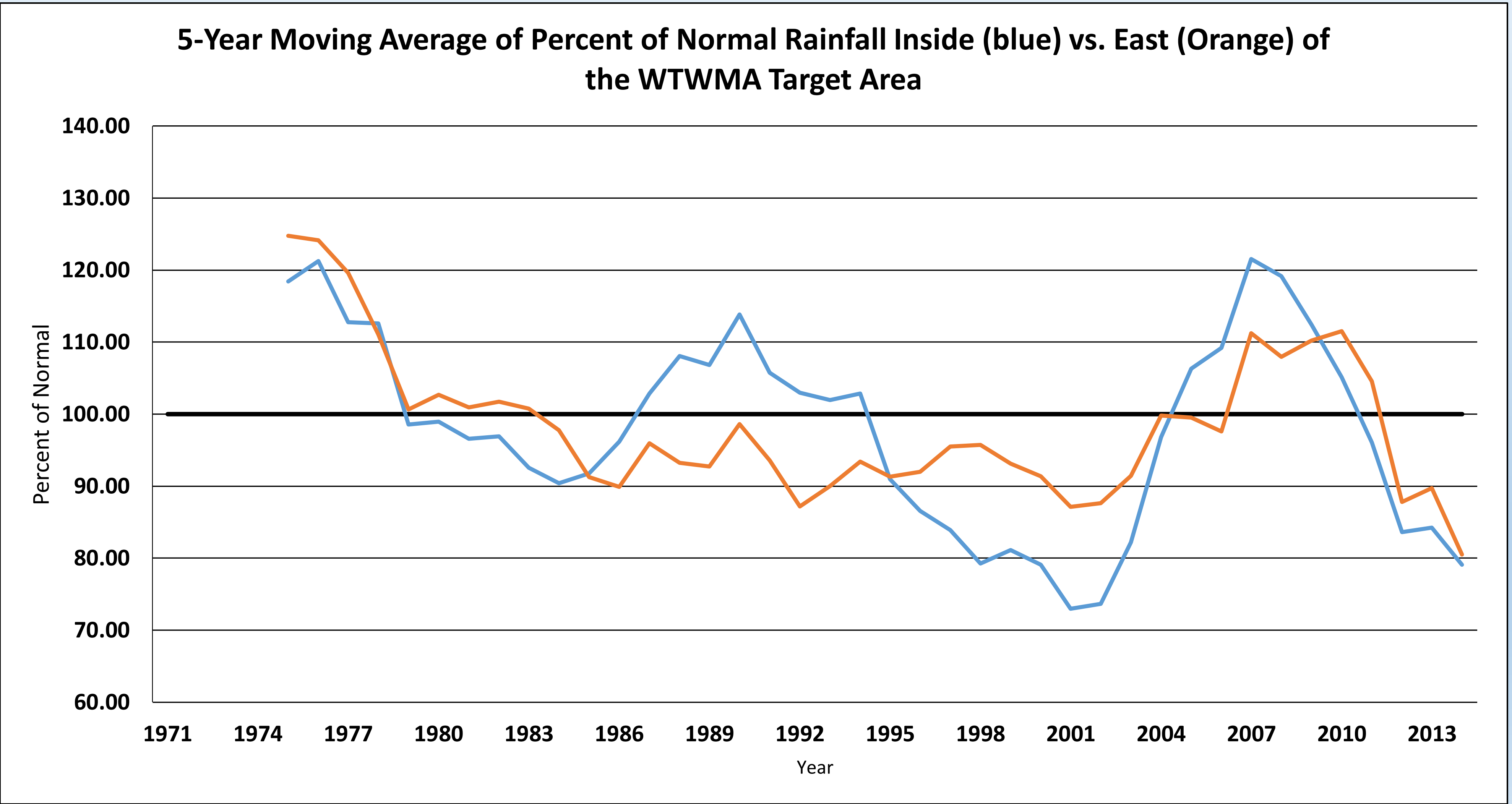
Outside = 92.06% of Normal

1996-2014:

Inside = 92.72% of Normal

Outside = 84.86% of Normal

Target Area versus Outside (East)



2004-2014:

Inside = 100.35% of Normal

Outside = 95.68% of Normal

1996-2014:

Inside = 92.72% of Normal

Outside = 97.68% of Normal

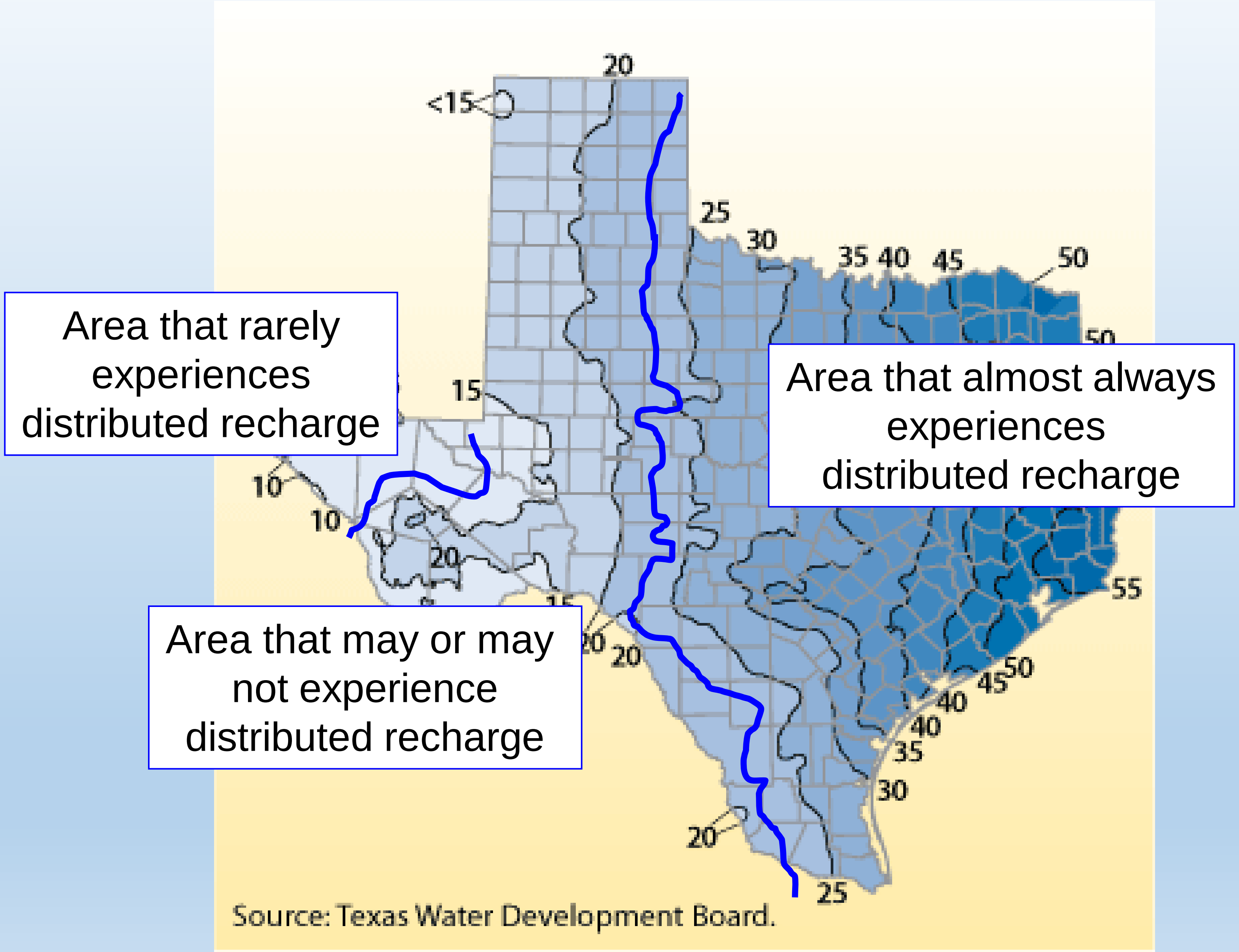
Aquifer Recharge

- Studies done by Green and Bertettie of the Southwest Research Institute indicate 16.5” of precipitation annually is needed for aquifer recharger across the Edwards-Trinity Aquifer

- Weather Modification could be the difference between seeing or not seeing recharge in a given time period

- An important benefit received from Weather Modification as additional rainfall is the only way to increase recharge

Texas Can be Sub-Divided by Area into Three Categories of Recharge



Source: Green, Bertettie, Southwest Research Institute (2010)

The impacts of Weather Modification on Recharge in West Texas

- The annual precipitation increase from weather modification was taken away from the annual rainfall.

- This allowed for a difference of recharge to be calculated. Then…

- Using:

$$\mathbf{R = 0.15(P-16.50)}$$

- The amount of Recharge due to weather modification can be calculated
  - County by county, year by year.

The impacts of Weather Modification on Recharge in West Texas

- Once recharge was found the Thornthwaite equation for Potential Evapotranspiration

$$\text{PET} = 16\left(\frac{L}{12}\right)\left(\frac{N}{30}\right)\left(\frac{10T_{\alpha}}{5}\right)^{\alpha}$$

Where L = average day length of moth

Where N = number of days in each month

Where Ta = Average Daily Temperature of the month being calculated

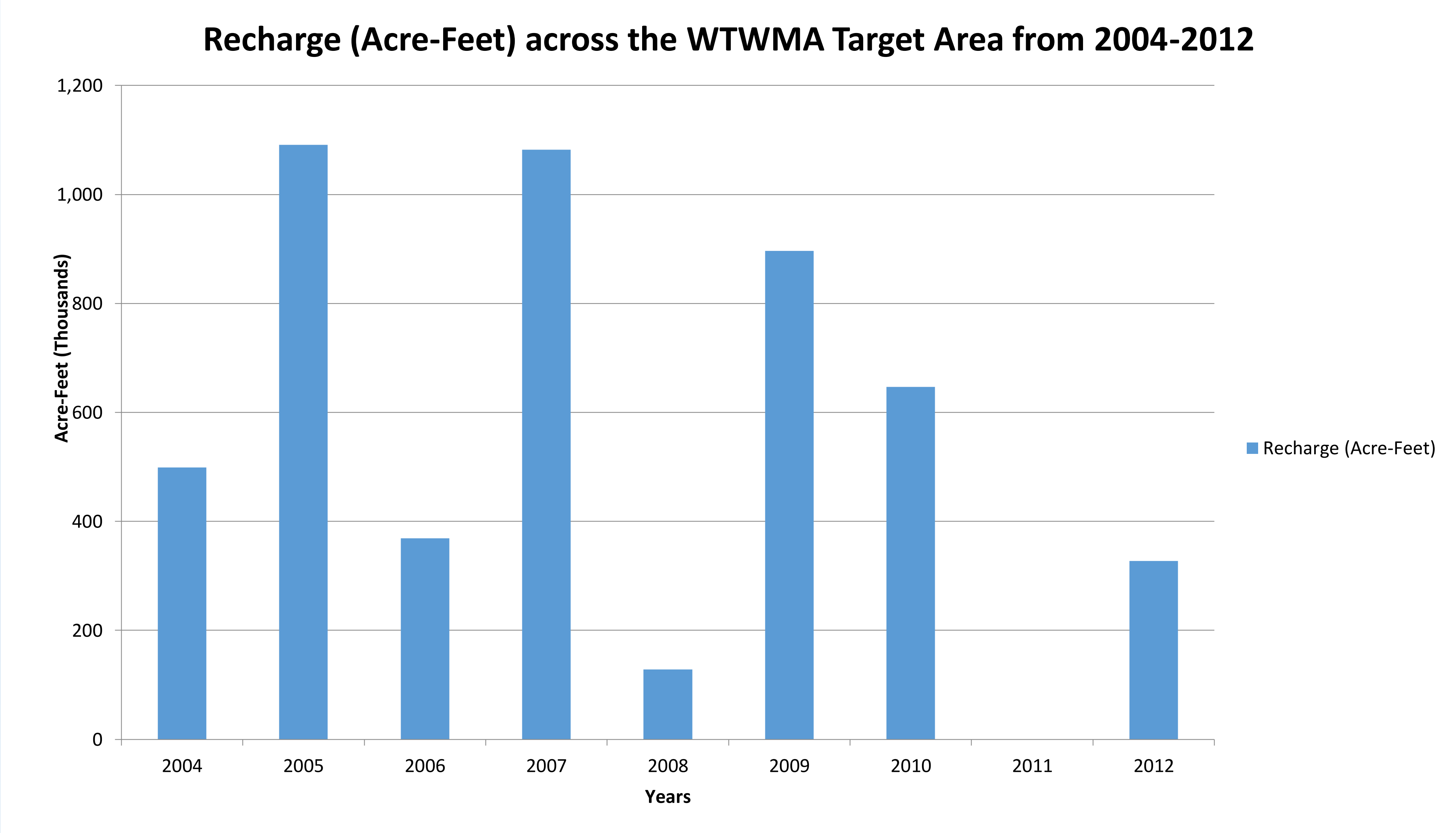
Where a = $(6.75 \times 10^{-7})I^3 - (7.71 \times 10^{-5})I^2 + (1.792 \times 10^{-2})I + 0.49239$

Where I = $\sum_{I=1}^{12}\left(\frac{Ta}{5}\right)^{1.514}$

The impacts of Weather Modification on Recharge in West Texas

- Estimated Recharge across the WTWMA target area over the last 9 years is:
  - 1 million acre-feet
    - Or ~100k acre-feet per year
- Nearly 10% of increases from weather modification in West Texas is expected to recharge into area aquifers

Annual Recharge across the WTWMA Target Area due to Rain Enhancement



Benefit Cost Analysis (Johnson 2014)

- Benefits Include
  - Increased Ag Production
  - Decreased surface and groundwater consumption
  - Improved Opportunities for Economic Stability and Future Growth
  - Enhanced Landscape Appearance
  - Increased Reservoir Levels
  - Replenishment of Aquifers
  - Improved Habitat Conditions for Wildlife
  - Increased Lake and River Levels
  - Fire Suppression

Not all benefits cut and dry

- Some benefits are difficult to quantify and are subjective

- However, increased ag production, reductions in irrigation activity and resulting economic impact can be objectively calculated.

  - These are the benefits analyzed in this study which leaves plenty of room for additional benefits
    - Especially in terms of groundwater recharge, lake/river/reservoir replenishment

Impact of additional rainfall to dryland crop acreage…

- Four predominate agricultural commodities within the 31 county study area:
  - Corn
  - Wheat
  - Sorghum
  - Cotton

For the WTWMA Target Area

County	Increased Dryland Revenues
Crockett	$2,371
Glasscock	$2,084,673
Irion	$6,641
Reagan	$727,440
Schleicher	$436,032
Sterling	$30,365
Sutton	$4,896
Tom Green*	$1,378,197
TOTAL	**$4,651,015**

*totals for Tom Green County only account for 45% of the county (roughly the area covered by the WTWMA target area)

Impact of additional rainfall to irrigated crop acreage

- Across the 31 county study area, one additional inch during the Mar-Oct period would result in saving 38,592 acre-feet, or 463,107 acre-inches, of water
- Irrigation Cost across the study area range from $3.30 to $7.00 per acre-inch.

For the WTWMA Target Area

County	Cost Savings to Irrigated Acreage
Crockett	$0
Glasscock	$86,943
Irion	$79
Reagan	$35,932
Schleicher	$3,161
Sterling	$2,603
Sutton	$831
Tom Green*	$122,163
TOTAL	**$251,712**

*totals for Tom Green County only account for 45% of the county (roughly the area covered by the WTWMA target area)

Impact of additional rainfall to increased grazing land revenues

- The 31 county target area supports:
  - 1.06 million head of beef cows
  - 184k goats
  - 221k sheep
- Increased moisture = increased grazing forages
  - Would lead to increased stocking rates, higher daily gain rates for livestock, improved body condition scores for females leading to improved fertility, and/or heavier weaning/sale weights

For the WTWMA Target Area

County	Increased Grazing Land Revenues
Crockett	$305,216
Glasscock	$73,275
Irion	$90,767
Reagan	$119,362
Schleicher	$160,019
Sterling	$114,526
Sutton	$185,280
Tom Green*	$65,695
TOTAL	**$1,114,139**

*totals for Tom Green County only account for 45% of the county (roughly the area covered by the WTWMA target area)

Total of Benefits Analyzed

County	Dryland Crop	Irrigation Savings	Increased Grazing Land	DIRECT EI
Crockett	$2,371	$0	$305,216	$307,587
Glasscock	$2,084,673	$86,943	$73,275	$2,244,891
Irion	$6,641	$79	$90,767	$97,486
Reagan	$727,440	$35,932	$119,362	$882,733
Schleicher	$436,032	$3,161	$160,019	$579,212
Sterling	$30,365	$2,603	$114,526	$147,894
Sutton	$4,896	$831	$185,280	$191,007
Tom Green*	$1,378,197	$122,163	$65,695	$1,566,055
TOTAL	**$4,651,015**	**$251,712**	**$1,114,139**	**$6,016,866**

*totals for Tom Green County only account for 45% of the county (roughly the area covered by the WTWMA target area)

Benefits Cont.

- Benefits are not felt only at the local level, but also at a statewide level.
- Impact Analysis for Planning (IMPLAN) output multipliers were used for certain commodities/benefits to estimate the statewide impact
- Multipliers not used for irrigation savings
  - See report for specific multipliers used

Statewide Economic Impact

County	Direct Economic Impact	Statewide Economic Impact
Crockett	$307,587	$691,373
Glasscock	$2,244,891	$4,750,952
Irion	$97,486	$218,070
Reagan	$882,733	$1,867,927
Schleicher	$579,212	$1,258,655
Sterling	$147,894	$322,374
Sutton	$191,007	$427,508
Tom Green*	$1,566,055	$3,220,707
TOTAL	**$6,016,866**	**$12,757,566**

*totals for Tom Green County only account for 45% of the county (roughly the area covered by the WTWMA target area)

Benefit-Cost Ratio

- Using the expenses of the program over the last 5 years and comparing that of the benefits described, the ratio is:
  - Direct Economic Impact: 1:16
  - Statewide Impact: 1:34
    - For every dollar being put into the WTWMA, $16-$34 dollars is returned assuming one inch of additional rainfall is produced

Comparisons to Other Programs

PROGRAM	Direct EI	Statewide EI	Benefit Cost Ratio (D)	Benefit Cost Ratio (S)
WTWMA	$6,016,866	$12,757,566	1:16	1:34
STWMA**	$5,691,327	$10,850,560	1:21	1:39
PGCD	$4,877,938	$9,407,140	1:22	1:43
All Combined	**$16,586,131**	**$33,015,266**	**1:19**	**1:38**

Data for SWTREA not added here due to inconsistent target area size and operating years, however, the ratios are as follows: 2009 through 2011 – 1:9, 1:18, 2012 – 1:7, 1:14

Of the 31 counties analyzed:

- Tom Green, Glasscock and Carson Counties are the top 3 in increased revenue from dryland crops from weather modification.
- Carson, Uvalde and Tom Green Counties are the top 3 in savings from irrigation due to weather modification.
- Webb, Crockett and Medina are the top 3 in increases from grazing land due to weather modification.
- Overall, the top three counties receiving benefits from weather modification are:
  - Tom Green
  - Glasscock
  - Carson

What is NOT included?

- Recharge Enhancement
  - Jennings, Green 2014 found $100,000 a-f/year of enhanced recharge due to weather modification over the last 10 years
- Enhanced Spring/River Flow
  - Leads to better wildlife management and lake/reservoir runoff

- These are areas that should be studied in the future. Some ideas have already in the works.

2015 Outlook

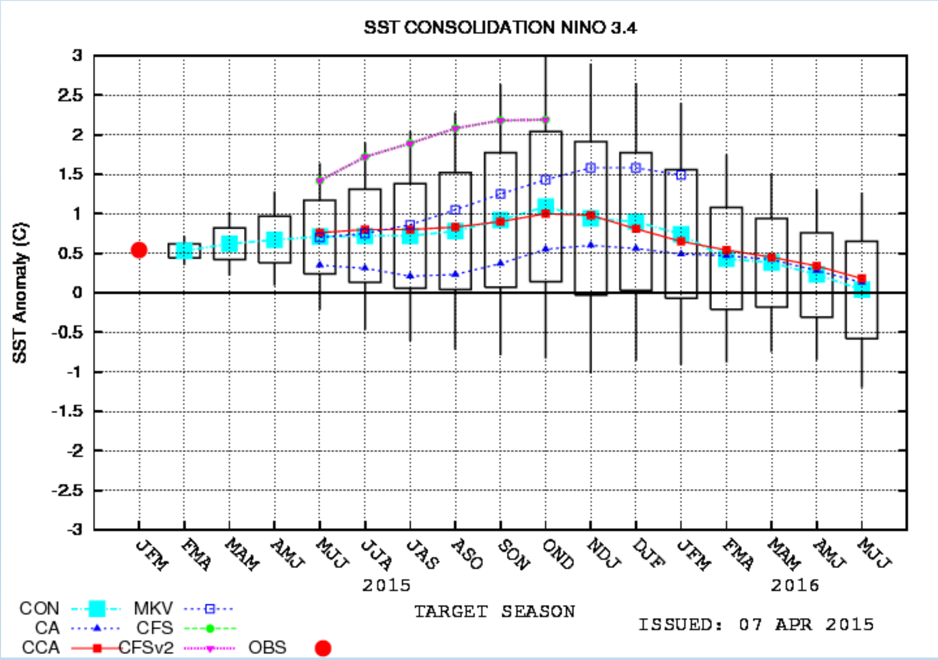
- Has been a rather wet spring
  - Precipitation (through MARCH) totals across the region have been pretty solid
- Top 5 (within WTWMA target area)
  - San Angelo 7NW – 6.16”
  - Mertzon – 6.01”
  - Sterling City – 5.65”, 5.62”
  - Sonora Average – 5.34”
  - Ozona 32SW – 5.01
- Bottom 3 (excluding those with missing data)
  - Barnhart – 2.75”
  - Ozona 15SSW – 3.76”
  - Eldorado – 3.83”

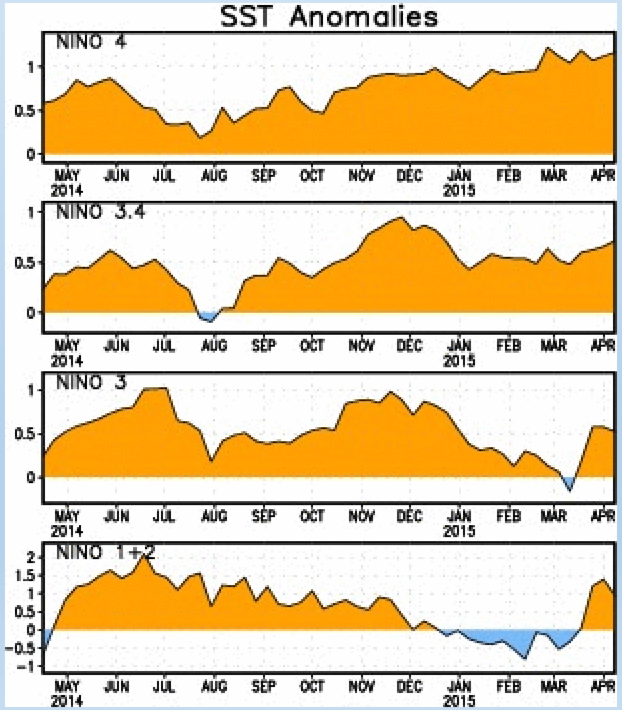
2015 Outlook

- Generally, wet springs correlate to wet summer/falls
  - The correlation is weak (0.33), but it is there.
  - During El Nino Years, the Average 1st QTR precipitation at SJT is 3.65”
    - This year, we have totaled up 3.97” so far.
    - During these same El Nino years, the average annual precipitation for SJT is 22.28”
      - Almost a safe bet to expect 1-2” of above average rainfall this year.

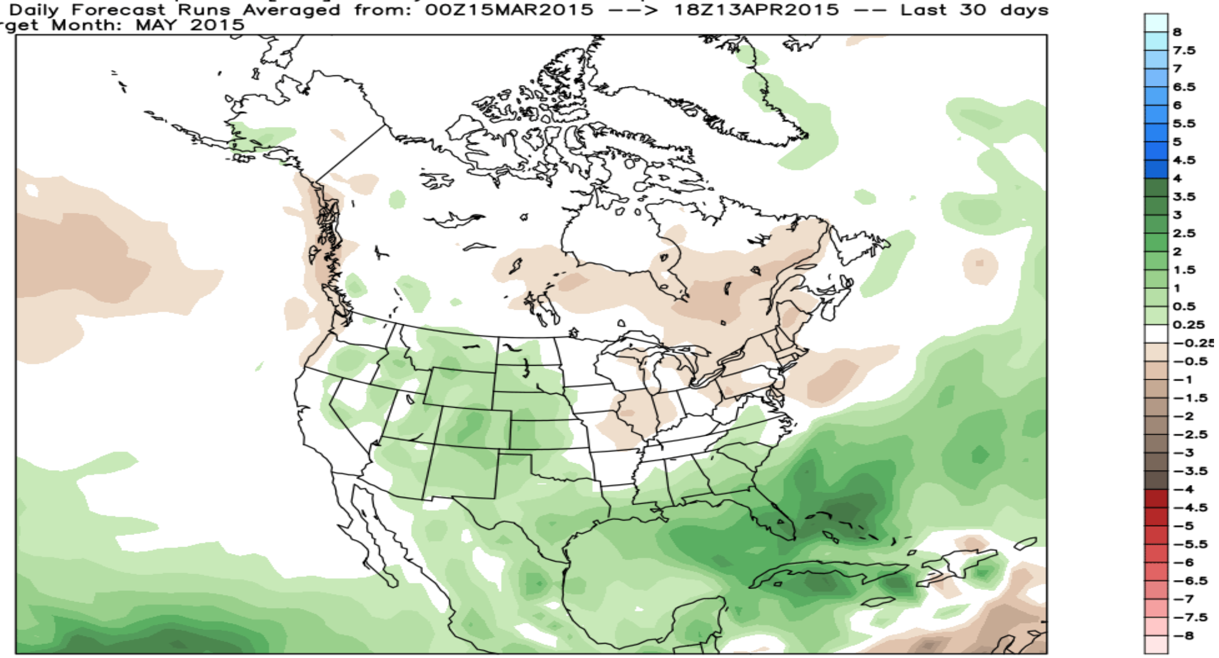
ENSO Outlook

- ENSO conditions continue to not only stay in an El Nino, but strengthen. This should translate to continued above normal precipitation



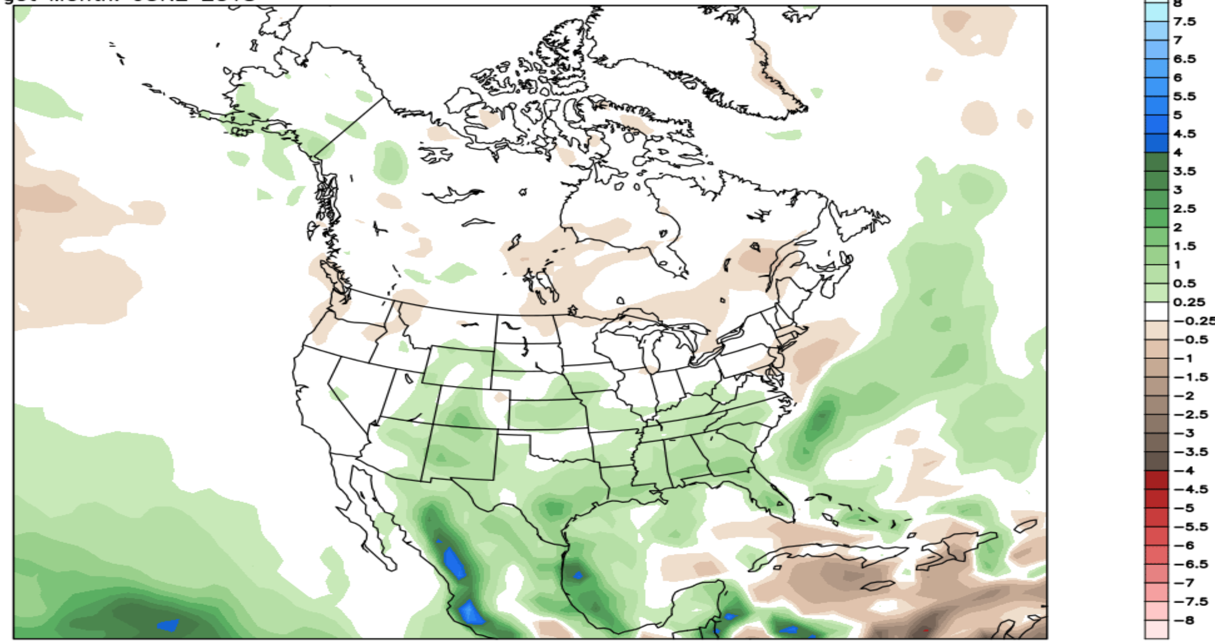


NCEP CFSv2 Precipitation [inch] Monthly Mean Forecast Departure
4x Daily Forecast Runs Averaged from: 00Z15MAR2015 --> 18Z13APR2015 -- Last 30 days
Target Month: MAY 2015



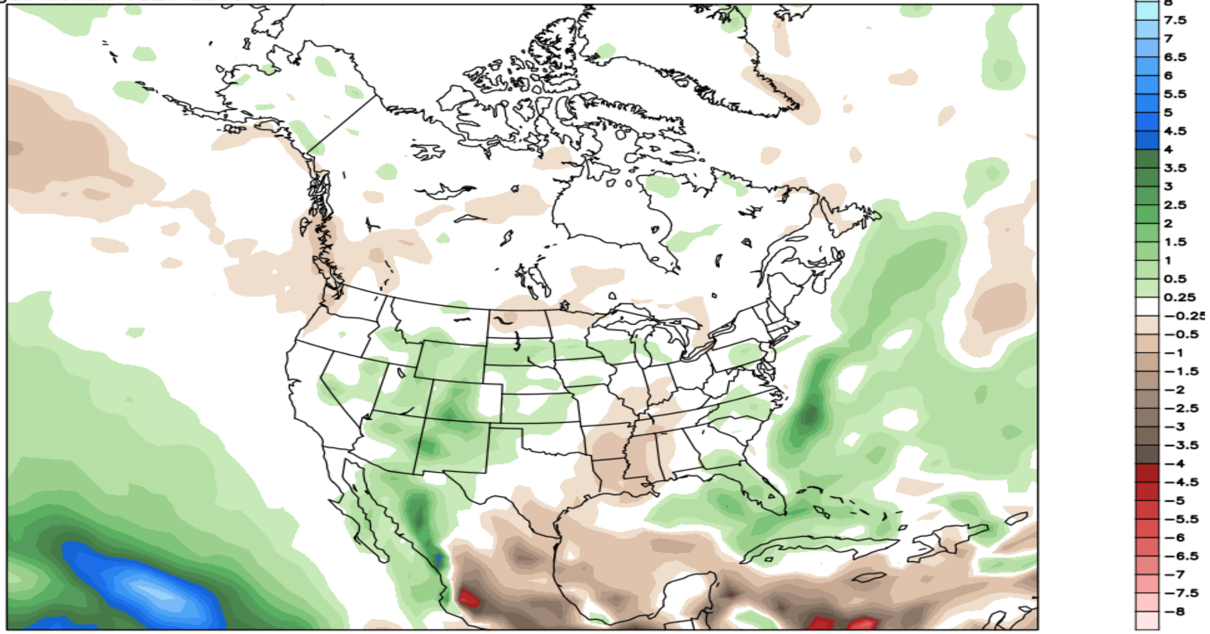
Precipitation (shaded) -- Monthly Average Departure
NCEP CFSv2 384x190 Surface Flux Thinned Gaussian Forecast Grid

NCEP CFSv2 Precipitation [inch] Monthly Mean Forecast Departure
4x Daily Forecast Runs Averaged from: 00Z15MAR2015 --> 18Z13APR2015 -- Last 30 days
Target Month: JUNE 2015



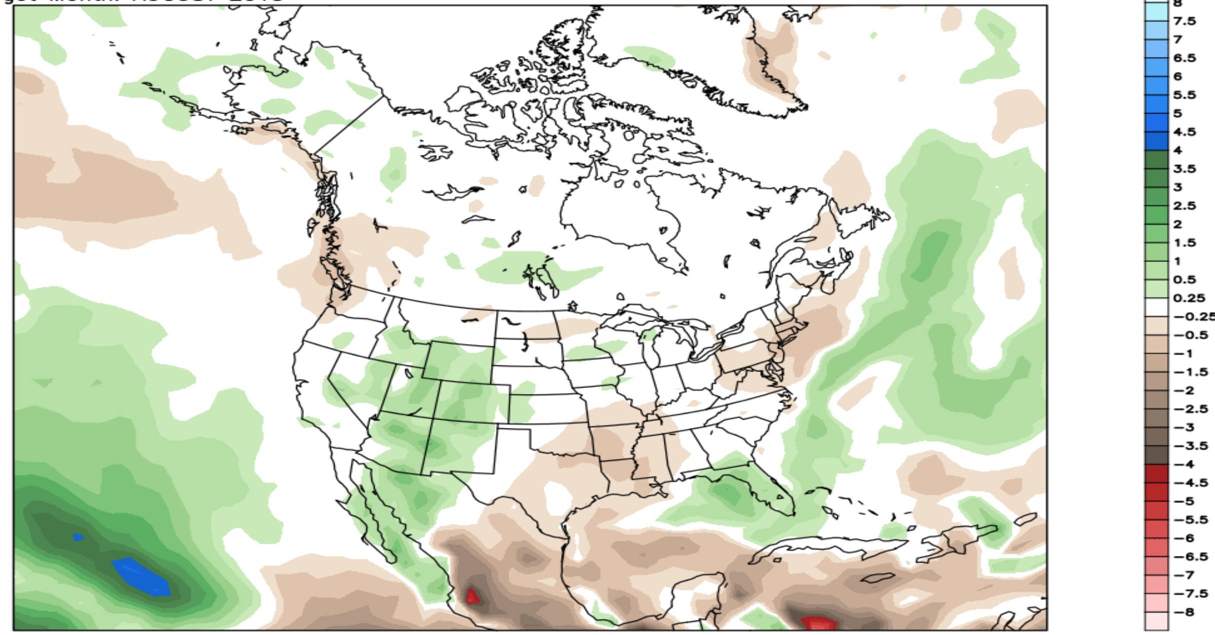
Precipitation (shaded) -- Monthly Average Departure
NCEP CFSv2 384x190 Surface Flux Thinned Gaussian Forecast Grid

NCEP CFSv2 Precipitation [inch] Monthly Mean Forecast Departure
4x Daily Forecast Runs Averaged from: 00Z15MAR2015 --> 18Z13APR2015 -- Last 30 days
Target Month: JULY 2015



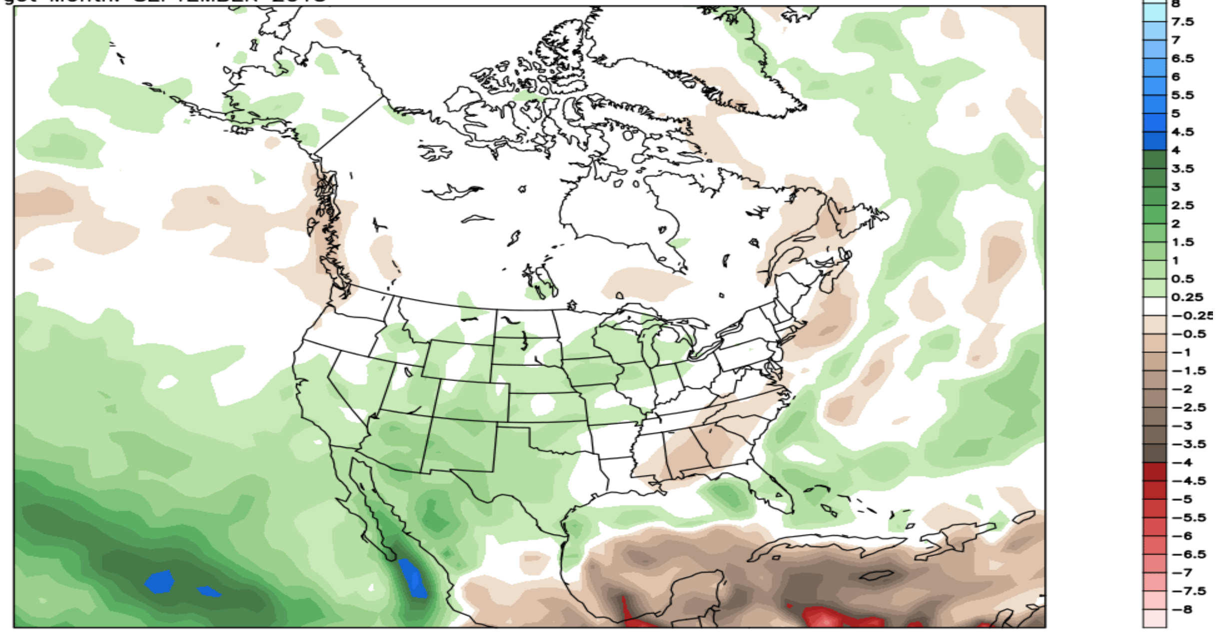
Precipitation (shaded) -- Monthly Average Departure
NCEP CFSv2 384x190 Surface Flux Thinned Gaussian Forecast Grid

NCEP CFSv2 Precipitation [inch] Monthly Mean Forecast Departure
4x Daily Forecast Runs Averaged from: 00Z15MAR2015 --> 18Z13APR2015 -- Last 30 days
Target Month: AUGUST 2015



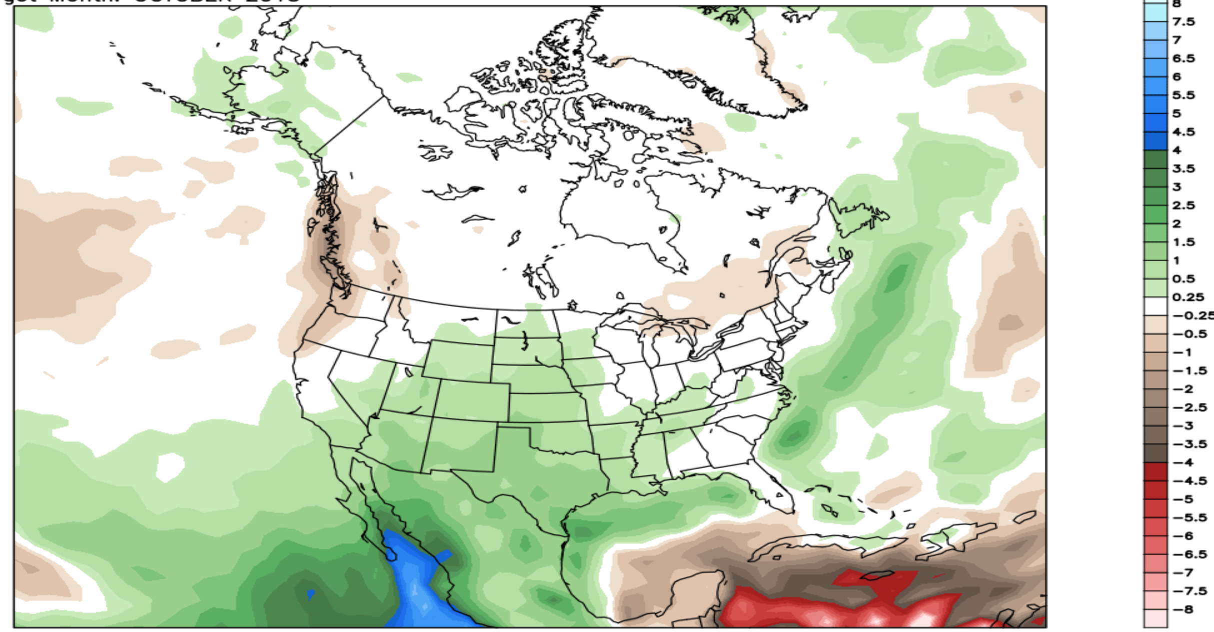
Precipitation (shaded) -- Monthly Average Departure
NCEP CFSv2 384x190 Surface Flux Thinned Gaussian Forecast Grid

NCEP CFSv2 Precipitation [inch] Monthly Mean Forecast Departure
4x Daily Forecast Runs Averaged from: 00Z15MAR2015 --> 18Z13APR2015 -- Last 30 days
Target Month: SEPTEMBER 2015



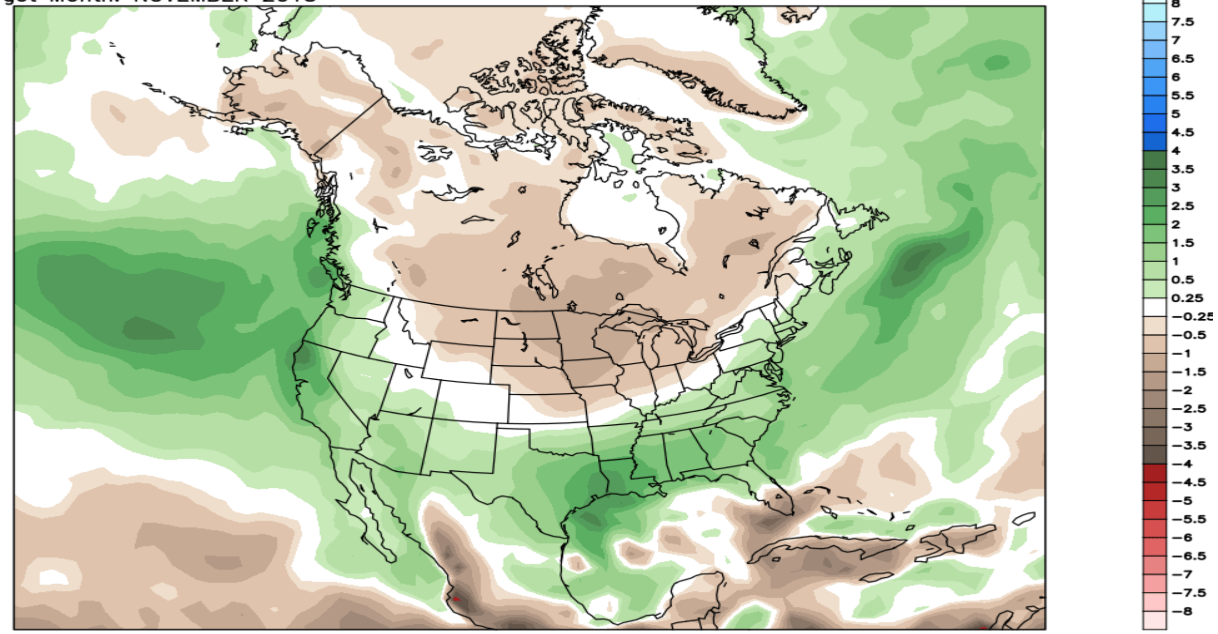
Precipitation (shaded) -- Monthly Average Departure
NCEP CFSv2 384x190 Surface Flux Thinned Gaussian Forecast Grid

NCEP CFSv2 Precipitation [inch] Monthly Mean Forecast Departure
4x Daily Forecast Runs Averaged from: 00Z15MAR2015 --> 18Z13APR2015 -- Last 30 days
Target Month: OCTOBER 2015



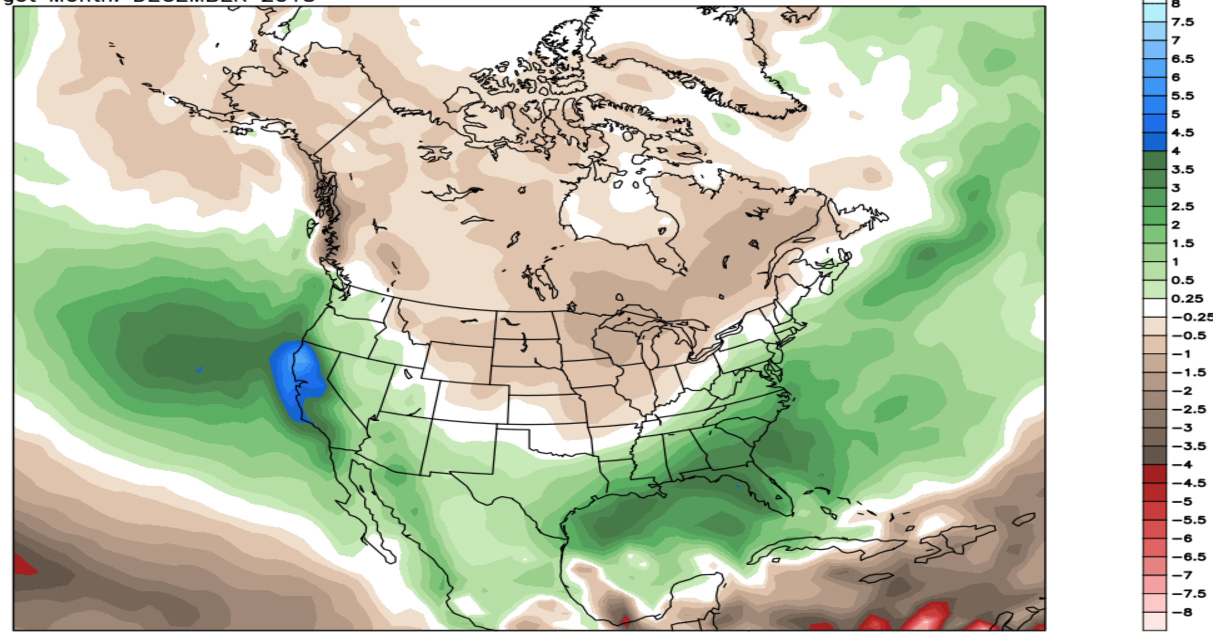
Precipitation (shaded) -- Monthly Average Departure
NCEP CFSv2 384x190 Surface Flux Thinned Gaussian Forecast Grid

NCEP CFSv2 Precipitation [inch] Monthly Mean Forecast Departure
4x Daily Forecast Runs Averaged from: 00Z15MAR2015 --> 18Z13APR2015 -- Last 30 days
Target Month: NOVEMBER 2015



Precipitation (shaded) -- Monthly Average Departure
NCEP CFSv2 384x190 Surface Flux Thinned Gaussian Forecast Grid

NCEP CFSv2 Precipitation [inch] Monthly Mean Forecast Departure
4x Daily Forecast Runs Averaged from: 00Z15MAR2015 --> 18Z13APR2015 -- Last 30 days
Target Month: DECEMBER 2015



Precipitation (shaded) -- Monthly Average Departure
NCEP CFSv2 384x190 Surface Flux Thinned Gaussian Forecast Grid

Forecast:

- The trends are looking good.
  - The previous models were 30 day average runs, however, when the latest, most recent runs were analyzed, the precipitation anomalies are even stronger

- My original forecast of 20-25” continues to look good, but a few heavy rain makers can really skew the totals and push a few folks over the 30” mark by the end of the year.

- I think we have a better chance of exceeding 30” before not reaching 20”.

Questions? Comments? Suggestions?

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http://www.wtwma.com (under construction)

http://www.texasweathermodification.com