THE UNUSUAL NATURE OF WEST COAST NCDC CLIMATE DIVISIONS' SEASONAL PRECIPITATION ANOMALY PATTERNS RELATIVE TO ENSO PHASE FOR THE 2015-16 AND 2016-17 SEASONS, AS COMPARED TO LONG-TERM 1895-96 to 2014-15 CLIMATOLOGICAL TENDENCIES

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1. INTRODUCTION

In a previous study (Fisk, 2016), the existence and character of statistical anomaly patterns in July-June total precipitation were investigated for twelve California, Oregon, and Washington NCDC Climate Divisions located near the Pacific Ocean west of the Cascade Mountains. Period of record was the 1895-96 thru 2014-15 seasons (n=120). The K-Means clustering methodology, integrated with an optimizing add-on functionality called the V-Fold Cross Validation Algorithm was utilized to resolve mean standardized anomaly patterns by cluster, by division. Results produced seven clusters. Following this, through referencing and manipulation of bi-monthly statistics from the online Multivariate ENSO (MEI) Index (Wolter, 2015), a hierarchy of ENSO designations based on mean bi-monthly rankings was constructed: "Strong La Nina", "Other La Nina", "Neutral", "Weak El Nino", "Moderate El Nino", and "Strong El Nino". These designations were then matched up in cross-tabulation fashion with those of the clusters, and from further manipulation of the 42 cross-tab frequencies, a table of Bayesian probabilities was created which estimated the conditional probabilities of given cluster anomaly patterns being realized, given the particular ENSO category. In addition to providing conditional probabilities of expected precipitation regime types up and down the Pacific Coast, the probabilities could be utilized in assessing the anomaly character of future year's seasonal precipitation patterns relative to the Bayesian expectations.

The 2015-16 El Nino was generally regarded as one of the three strongest in history, back to at least the 1870's and the Bayesian probabilities gave a greater than 80 percent chance that Southern California, at least, would be wet or very wet for the rain season, but instead, drought persisted, extending an already protracted regime to its fifth consecutive season.

The succeeding 2016-17 season, a La Nina transitioning in early 2017 to a Neutral, brought heavy rains up and down the entire coast, including, unexpectedly, Southern California – the long drought pattern's effects alleviated to a considerable extent. Uniformly heavy seasonal rains along the entire Pacific Coast, whatever the ENSO phase, are very unusual.

So, making use of the 2016 Clustering/Bayesian results framework, the present study provides a "objective" statistical interpretation of the ensuing 2015-16 and 2016-17 seasons' character, both of which, anecdotally, were considered unusual.

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2. METHODOLOGICAL REVIEW OF THE 2016 STUDY

The following sections (3 to 5) provide a condensed review of the methodology pursued for the 2016 study (text, graphs, and tables). The graphs/tables are the originals with no updates to the Bayesian probabilities, which would be possible, of course, by a new clustering, ENSO ranking, and Bayesian exercise, incorporating the 2015-16 and 2016-17 data. An experimental redo of the cluster analysis by itself which *did* include these two most recent seasons' data produced no changes to the 1895-96 thru 2014-15 cluster memberships.

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3. BAYESIAN ANALYSIS

From *Wikipedia*, Bayesian inference is a method of which Bayes' rule is used to update the probability estimate for a hypothesis as additional evidence is acquired. In this application, the initial hypothesis would be a probabilistic belief, or "Prior Probability", that a given anomaly pattern (cluster) would occur unconditionally (i.e., historical percent frequency of the pattern), updated by a processing of evidence that related the occurrence of the pattern to ENSO phase. The latter could be referred to as "accounting for evidence" and the result, or "impact", multiplied by the "Prior Probability" would produce a "Posterior Probability" that incorporates this new conditional information (the ENSO phase) into a revised probabilistic belief that the given pattern will occur. A desirable outcome would be a marked contrast in magnitudes between the posterior and prior probabilities which would indicate that knowledge about the conditional variable was a significant factor.

4. THE DATA

The 2016 study's data were NCDC accessed precipitation statistics of the July 1895 to June 2015 period. Figures 1 through 3 are maps of the California, Oregon, and Washington Climate Divisions, respectively, included for the study. For California (Figure 1), the three divisions are 1.) "South Coast", 2.) "Central Coast", and 3.) "North Coast". For Oregon (Figure 2), they are 1.) "Coastal Area" , 2.) "Southwestern Valleys", 3.) "Williamette Valley", and 4.) "Northern Cascades". For Washington (Figure 3) they are 1.) "West Olympic Coastal", 2.) "East Olympic Cascade Foothills", 3.) "Puget Sound Lowlands", 4.) "Cascade Mountains West", and 5.) "NE Olympic San Juan". For presentation purposes, all of these 12 titles, by necessity, appeared in abbreviated form.

Also, Figure 4 is a bar chart of the 1895-96 thru 2014-

15 mean July-June precipitation figures, by division, and Figure 5 a similar type bar chart of the standard deviation statistics, by division. With such a wide division-to-division range in overall mean precipitation and variability across the divisons, it was imperative from an interpretation standpoint to express the individual cluster results, division-by-division, in terms of relative or standardized deviations from the overall averages in Figure 4, based on the overall standard deviation statistics depicted in Figure 5.

Figure 1 – Map of California Climate Divisions included in this study – from NCDC.

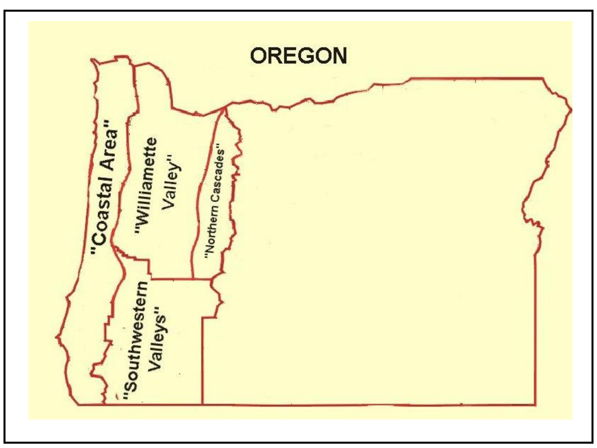

Figure 2 – Map of Oregon Climate Divisions included in this study – from NCDC.

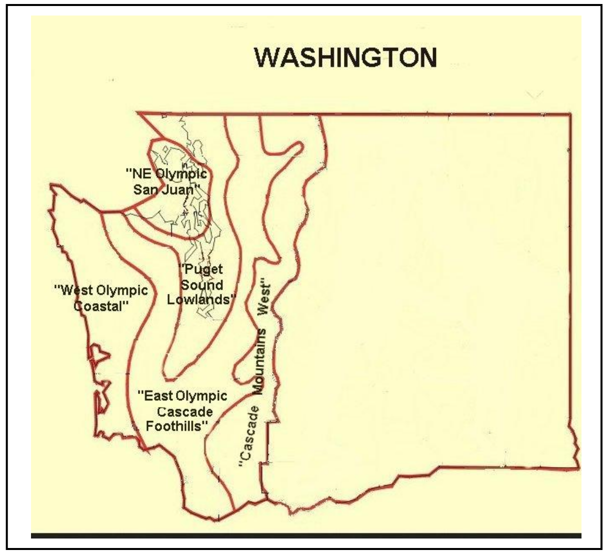

Figure 3 – Map of Washington Climate Divisions included in this study – from NCDC.

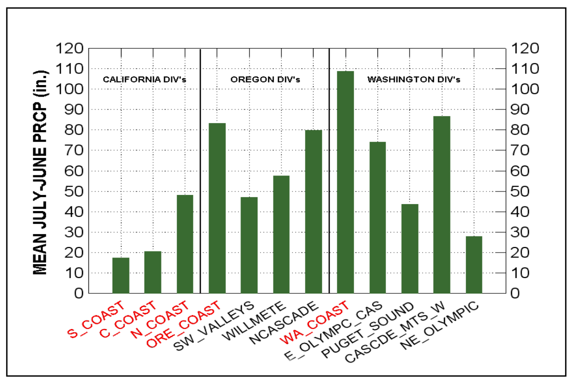

Figure 4 – Mean Seasonal (July-June) Precipitation (in.) For twelve NCDC Near-Coastal California, Oregon, and Washington Climate Divisions (1895-96 thru 2014-15 Period of Record).

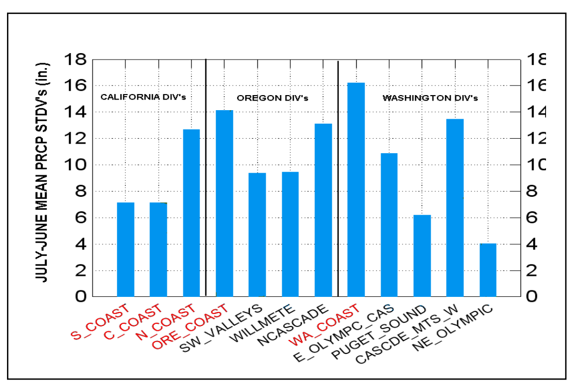

Figure 5 – Seasonal (July-June) Precipitation Series' Standard Deviations (in.) for twelve NCDC Near-Coastal California, Oregon, and Washington Climate Divisions (1895-96 thru 2014-15 Period of Record).

5. 2016 RESULTS

5.1. *– Standardized Anomaly Patterns, by Cluster, By Division*

The K-Means/V-Fold methodology produced seven clusters (patterns), ranging in percent frequency from 23.3% to 4.2%. Figures 6 thru 12, inclusive, present the division-by-division standardized mean anomalies for each of the seven patterns, in descending order of importance. Those divisions shaded in red border directly on the Pacific Ocean.

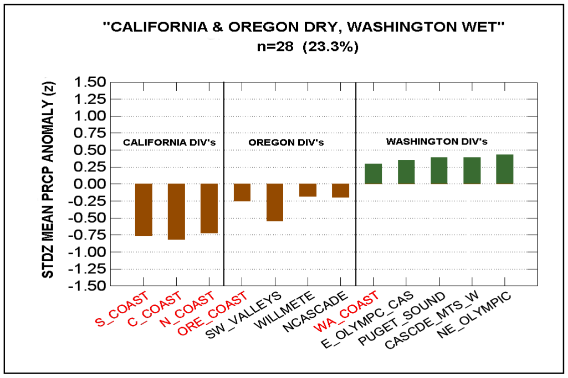

Figure 6 – Standardized Mean Division-by-Division Anomalies for the "California & Oregon Dry, Washington Wet" Pattern - Ranking Mode #1.

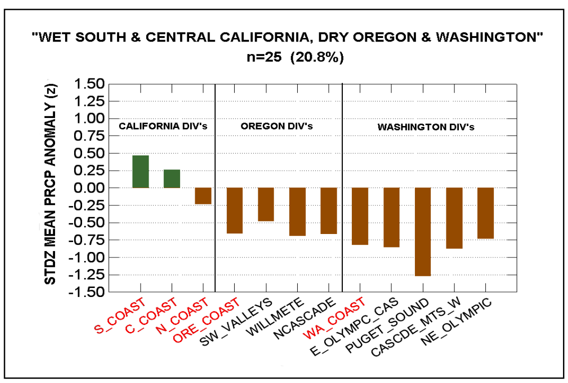

Figure 7 – Standardized Mean Division-by-Division Anomalies for the "Wet South & Central California, Dry Oregon & Washington" Pattern –Ranking Mode #2.

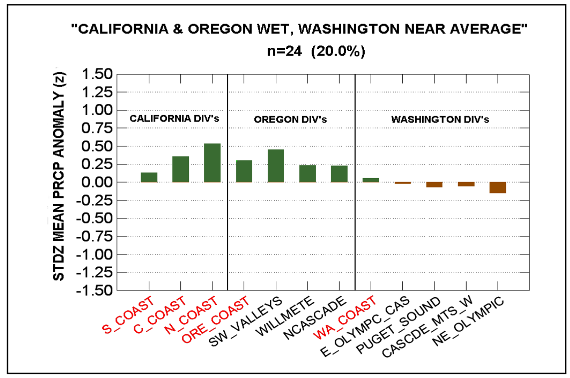

Figure 8 – Standardized Mean Division-by-Division Anomalies for the "California & Oregon Wet, Washington Near Average " Pattern – Ranking Mode # 3.

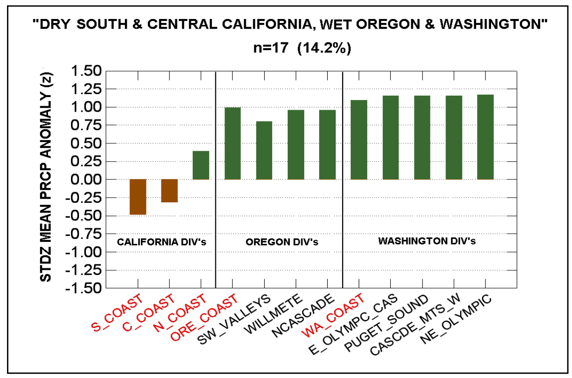

Figure 9 – Standardized Mean Division-by-Division Anomalies for the "Dry South & Central California, Wet Oregon & Washington Pattern" – Ranking Mode # 4.

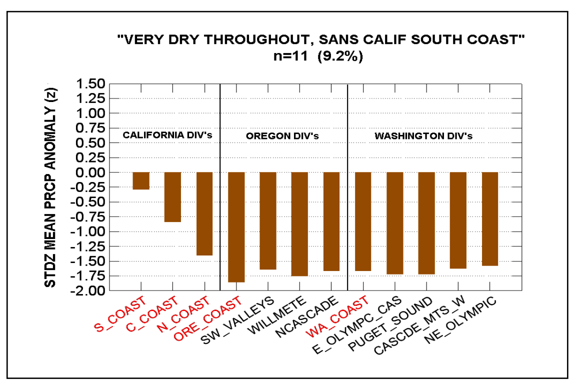

Figure 10 – Standardized Mean Division-by-Division Anomalies for the "Very Dry Throughout, Sans Calif South Coast" Pattern – Ranking Mode # 5.

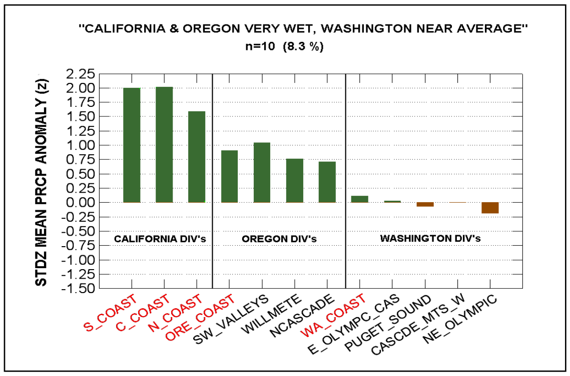

Figure 11 – Standardized Mean Division-by-Division Anomalies for the "California & Oregon Very Wet, Washington Near Average" Pattern – Ranking Mode #6.

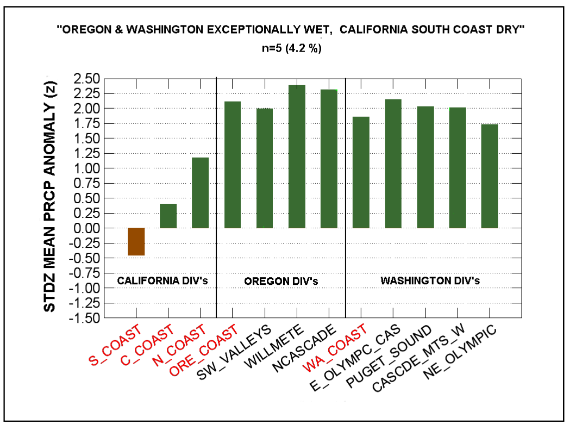

Figure 12 - Standardized Mean Division-by-Division Anomalies for the "Oregon & Washington Exceptionally Wet, California South Coast Dry Pattern" – Ranking Mode #7.

5.2. – Pattern Probabilities Conditioned on El Nino, Neutral, or La Nina occurrences – Bayesian Determinations

While the percent frequencies of the above seven patterns described the unconditional probabilities that they might be approximated individually for a given July-June rain year, ENSO phase ("El Nino, "Neutral", or" La Nina") is a conditional indicator known to significantly influence West Coast rainfall patterns, so the next step was to investigate the modifying influences of ENSO on the baseline prior probabilities of the seven patterns. This was a conditional probability exercise, and the method of choice was Bayesian Analysis.

First, the 1895-96 thru 2014-15 seasons were assigned ENSO episode classification, and for this task, the online MEI ("Multivariate ENSO index") web site was referenced (Wolter, 2015). The current data base consists of standardized index values encompassing two-month running periods, going back to Dec 1949/Jan 1950. A separate legacy data base also has index values covering Dec 1870/Jan 1871 through Nov/Dec 2005. As the NCDC Climate Divisions' history goes back to 1895, both the legacy and current versions of Wolter's data base were utilized.

A strategy was adopted to merge the two, joining the legacy data set up through 1949 (the1950-2005 portion excluded) with the 1950-present data set, the combined data sets' two-month running periods then re-standardized as a single unit. Next, the re-standardized data set was changed into a July-June format (a "season" covering the JunJul to MayJun periods). Then, following an approach that Wolter uses, each of the two-month moving periods were assigned a rank; the individual ranks added and averaged to create a seasonal average rank (based on the 1871-2014 period).

Since West-Coast precipitation tends to decrease markedly late in the season and El Nino episodes have a tendency also to decay in strength in Spring, based on a correlation analysis of the individual two-month ranks with the overall average ranks, the AprMay and MayJun variables were dropped, the new average overall ranks recalculated using the remaining ten periods.

Data for the 1871-72 to 1894-95 seasons were then dropped, leaving those for 1895-96 to 2014-15 intact. The seasonal ranking averages of these were then sorted with the following ENSO classification scheme applied: Rankings 1 to 12: "Strong La Nina", rankings 13-40: "Other La Nina", rankings 41-80: "Neutral", rankings 81-94: "Weak El Nino":, rankings 95-108 : " Moderate El Nino" and finally, rankings 109-120: "Strong El Nino". Thus, there were 12 "Strong" La Nina's, 28 "Other" La Nina's, 40 "Neutrals", 14 "Weak" El Nino's, 14 "Moderate" El Nino's, and 12 "Strong" El Nino's.

Lastly, the Bayesian conditional probabilities were calculated. Since there were seven patterns and six different ENSO phases, 42 separate calculations were required. Table 1 below shows the complete Posterior Probability results.

Pattern #	Name	Posterior P(A|B) "Strong El Nino"	Posterior P(A|B) "Moderate El Nino"	Posterior P(A|B) "Weak El Nino"	Posterior P(A|B) "Neutral"	Posterior P(A|B) "Other La Nina"	Posterior P(A|B) "Strong" La Nina	Prior P(A)
1	"California & Oregon Dry, Washington Wet"	8.3%	0	28.6%	30.0%	28.6%	25.0%	23.3%
2	"Wet South & Central, California, Dry Oregon & Washington"	33.3%	42.9%	14.3%	15.0%	17.9%	16.7%	20.8%
3	"California & Oregon Wet, Washington Near Average"	25.0%	14.3%	21.4%	22.5%	21.4%	8.3%	20.0%
4	"Dry South & Central California, Wet Oregon & Washington"	0.0%	7.1%	0.0%	20.0%	14.3%	33.3%	14.2%
5	"Very Dry Throughout, Sans Calif South Coast"	8.3%	14.3%	28.6%	5.0%	7.1%	0.0%	9.2%
6	"California & Oregon Very Wet, Washington Near Average"	25.0%	21.4%	7.1%	5.0%	3.6%	0.0%	8.3%
7	"Oregon & Washington Exceptionally Wet, California South Coast Dry"	0.0%	0.0%	0.0%	2.5%	7.1%	16.7%	4.2%

Table 1 – Posterior Probability Results for all combinations of ENSO Type vs. Pattern

To interpret, for example, the "Strong El Nino" Posterior Probability column (third from the left), reading down, lists the conditional probabilities that each of the seven patterns would be realized, given a "Strong El Nino" episode. The 33.3% figure, shaded red for the "Wet South & Central California, Dry Oregon &

Washington" pattern is that most likely to happen of the seven, this being noticeably higher than the pattern's 20.8% prior, shown in Column 9. Interestingly, the posterior shown for this pattern relative to a "Moderate" El Nino is an even higher 42.9 %, more than double the prior. Both "Strong" and "Moderate" El Nino's thus seemed to prefer this "Wet South & Central California, Dry Oregon & Washington" configuration.

There were a number of other interesting prior vs. posterior contrasts, these cases shaded in red, so, in summary, conditioning the occurrence probabilities of the seven patterns on ENSO phases did provide the potential for more refined insights into their likelihoods. The range of their priors was 4.2% to 23.3%, that for the posteriors 0.0% to 42.7%.

6. RELATING THE SIMILARITIES OF THE 2015-16 AND 2016-17 ANOMALY PATTERNS TO THOSE OF THE IDEALIZED CLUSTER ANOMALY CONFIGURATIONS

This was accomplished by comparative visual scrutinization of NCDC Climate Division standardized precipitation anomaly charts for the July-June 2015-16 and 2016-17 seasons with those of the Cluster anomaly charts in Figures 6 to 12. Following selection of the most nearly matching cluster configuration, the Table 1 Bayesian table was consulted to yield insights on how atypical the pattern was given the ENSO designation.

6.1. – The 2015-16 Rain Season

Figure 13 depicts the U.S. NCDC Climate Division standardized July-June precipitation anomalies for the very strong El Nino 2015-16 season. The 1895-2000 period was utilized as the "Longterm Average" as it was the only one available that included the earliest seasons back through 1895-96.

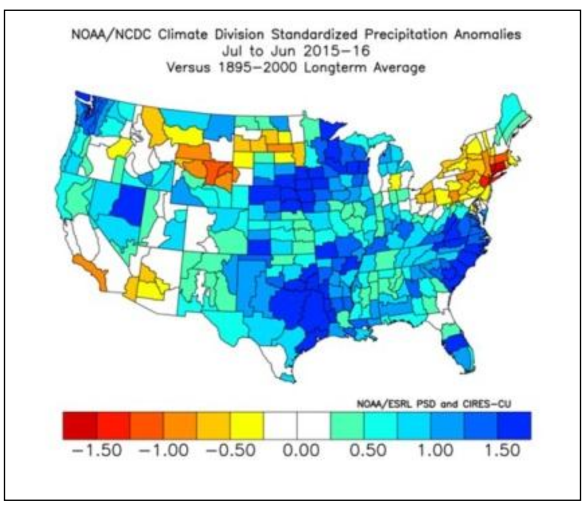

Figure 13. U. S. Climate Divisions' July-June Standardized Precipitation Anomalies for 2015-16.

Examining the twelve divisions of interest, those for Washington indicate anomalously wet conditions (blue to dark blue shadings, some in the +1.50z or greater category). The shadings for Oregon and "North Coast" California were all blue or green, that for "Central Coast" California white (i.e., near average mean anomalies), and those for the "South Coast" California brown, reflecting mean anomalies between -0.75z and -1.00z. Thus. there was a trend from south to north of anomalously dry to excessively wet.

Next, inspection of the clusters' mean anomaly configurations over Figures 6 thru 12 revealed two approximate matches, those of Figure 9 and Figure 12. Both of these display the dry to wet trend, although Figure 9 is closer in standardized anomaly magnitudes. For presentation purposes, Figure 9 is reproduced below as Figure 14, Figure 12 as Figure 15.

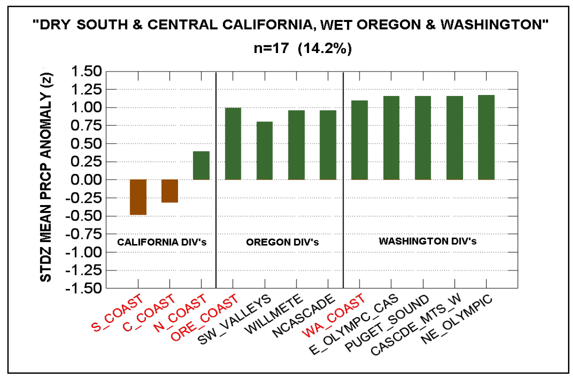

Figure 14 (same as Figure 9) – Standardized Mean Division-by-Division Anomalies for the "Dry South & Central California, Wet Oregon & Washington Pattern" – Ranking Mode # 4.

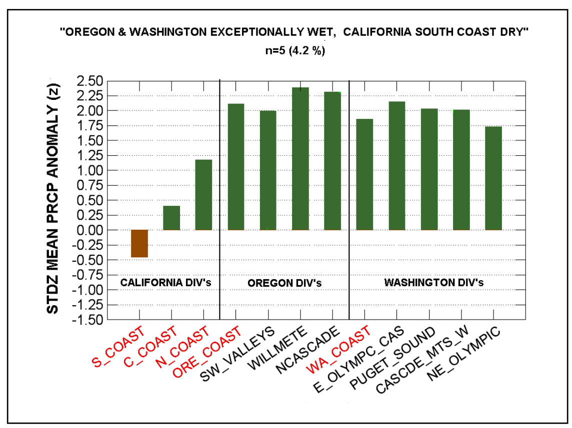

Figure 15 (also Figure 12)- Standardized Mean Division-by-Division Anomalies for the "Oregon & Washington Exceptionally Wet, California South Coast Dry Pattern" – Ranking Mode #7.

Next, referring to the Table 1, Column 3 contains the Bayesian posteriors for “Strong El Nino”. In that column, for each of the modes depicted in Figures 14 and 15 (pattern #4 in row 8, and pattern #7 in row 16, respectively), the posteriors are zero!, indicative that the 2015-16 regime was likely unprecedented over the 1895-96 to 2013-14 period of record, and most likely back farther into the early 1870’s. Since by all accounts the 2015-16 El Nino was one of the strongest in recorded history, it’s categorization as “Strong” could not be regarded as an artifact of the ENSO designation scheme used in the study.

Moreover, in the “Strong La Nina” (Column 8), the posteriors for each of the Figure 14 and 15 configurations are at their relative maximum magnitudes. That for Figure 14 (33.3%) is more than double its prior (14.2%), and that for Figure 15 (16.7%) is almost four times as great as its prior (4.2%). Indeed, from this, the 2015-16 pattern behaved more like a Strong La Nina than a Strong El Nino. The latter, as indicated by the red shaded relative magnitudes in Column 3, are associated with wet conditions in Central and Southern California 83% of the time on a combined posterior probability basis.

6.2. *– The 2016-17 Rain Season*

Figure 16 depicts the U.S. NCDC Climate Division standardized July-June precipitation anomalies for the 2016-17 season, one that transitioned from a La Nina to a Neutral after the start of 2017.

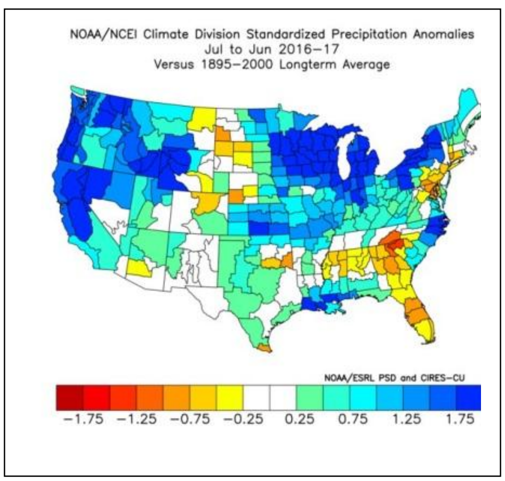

Figure 16. U. S. Climate Divisions’ July-June Standardized Precipitation Anomalies for 2016-17.

Again surveying the twelve divisions, the portrayals reflect wet seasons for each and all, the majority at moderate to dark blue color shadings. In fact, ten of the twelve divisions had standardized anomalies of +1.50z or greater. The calculated standardized anomalies here are from the 1895-96 thru 2016-17 period record, the assumption being that a map similar the Figure 16 utilizing the additional 17 years’ data (or ~16 % more) would appear very similar. The 2016-17 least positive anomaly statistic for the twelve divisions (+0.57z) set a 122-year mark for the highest of record, shading the previous mark of +0.56z for the 2010-2011 season (a La Nina). Ranking third (+0.53z) is that for 1982-83 (one of the historically strong El Nino’s). Five other exclusively positive cases exist, but their minimum statistics are all just above zero: +0.02z to +0.10z. So, focusing on 2016-17, 2010-2011, and 1982-83, whose statistics are appreciable in magnitude and differ only slightly, one might make the generalization that such a uniformly, decidedly wet regime, south to north, occurs about once every 40 years.

Comparing 2016-17’s pattern to the seven clusters’ configurations, the closest match is that for Figure 15, which except for “South Coast” California displays positive anomalies for all divisions, ten of the twelve with standardized magnitudes of +1.00z or higher, six at +2.00z or greater; two of 2016-17’s divisional anomalies, in contrast, were above +2.00z. Referring to the Table 1 posteriors, that for an “Ordinary La Nina” relative to this pattern was just 7.1%, for a “Neutral” 2.5%, neither much different than the prior (4.2%). Again, as earlier discussed, such a regime is most characteristic of a “Strong La Nina” (posterior: 16.7%).

7. SUMMARY

Utilizing a Bayesian probability scheme created in 2016 that related twelve NCDC California, Oregon, and Washington climate divisions’ July-June seasonal precipitation patterns to ENSO phase, based on a K-Mean clustering analysis covering the 1895-96 thru 2013-14 periods of record, the ensuing two years’ (2015-16 and 2016-17) precipitation character were evaluated by applying the scheme, consisting of seven idealized patterns or modes, and six ENSO phases. Results confirmed anecdotal impressions of the atypical character of the two seasons’ total rainfall patterns, especially 2015-16, in which a historically strong El Nino behaved more like a strong La Nina – an occurrence not previously experienced in the historical record.

8. REFERENCES

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