11. DISCUSSION OF PMP PARAMETERS

In the process of deriving SSPMP values, various assumptions and subjective judgments were made which affect the PMP values. In addition, specific procedures were used which could be derived from a range of possible alternatives and result in different values. Therefore, it is important to understand how the assumptions and choice of procedures used could potentially affect certain aspects of the SSPMP calculations.

11.1 Assumptions

11.1.1 Saturated Storm Atmospheres

The atmospheric air masses that provide moisture to both the historic storms and the PMP storm are assumed to be saturated through the entire depth of the atmosphere and to contain the maximum moisture possible based on the surface dew point. This assumes moist pseudo-adiabatic temperature profiles for both the historic storms and the PMP storm. Limited evaluation of this assumption in the EPRI Michigan/Wisconsin PMP study (Tomlinson 1993) and the Blenheim Gilboa (Tomlinson et al. 2008) study indicated that historic storm atmospheric profiles are generally not entirely saturated and contain somewhat less precipitable water than is assumed in the PMP procedure. It follows that the PMP storm (if it were to occur) would also have somewhat less precipitable water available than the assumed saturated PMP atmosphere would contain. What is used in the PMP procedure is the *ratio* of precipitable water associated with each storm. If the precipitable water values for each storm are both slightly overestimated, the ratio of these values will be essentially unchanged. For example, consider the case where instead of a historic storm with a storm representative dew point of 70^{o}F degrees having 2.25 inches of precipitable water assuming a saturated atmosphere, it actually had 90% of that value or about 2.02 inches. The PMP procedure assumes the same type of storm with similar atmospheric characteristics for the maximized storm but with a higher dew point, say 76 ^{o} F degrees. The maximized storm, having similar atmospheric conditions, would have about 2.69 inches of precipitable water instead of the 2.99 inches associated with a saturated atmosphere with a dew point of 76^{o}F degrees. The maximization factor computed using the assumed saturated atmospheric values would be 2.99/2.25 = 1.33. If both storms were about 90% saturated instead, the maximization factor would be 2.69/2.02 = 1.33. Therefore potential inaccuracy of assuming saturated atmospheres (whereas the atmospheres may be somewhat less than saturated) should have a minimal impact on storm maximization and subsequent PMP calculations.

11.1.2 Maximum Storm Efficiency

The assumption is made that if a sufficient period of record is available for rainfall observations, at least a few storms would have been observed that attained the maximum efficiency possible for converting atmospheric moisture to rainfall for regions with similar meteorology and topography. The further assumption is made that if additional atmospheric moisture had been available, the storm would have maintained the same efficiency for converting atmospheric moisture to rainfall. The ratio of the maximized rainfall amounts to the actual rainfall amounts would be the same as the ratio of the precipitable water in the atmospheres associated with each storm.

There are two issues to be considered. First is the assumption that a storm has occurred that has a rainfall efficiency close to the maximum possible. Unfortunately, state-of-the-science in meteorology does not support a theoretical evaluation of storm efficiency. However, if the period of record is considered (generally over 100 years), along with the extended geographic region with transpositionable storms, it is accepted that there should have been at least one storm with dynamics that approach the maximum efficiency for rainfall production.

The other issue is the assumption that storm efficiency does not change if additional atmospheric moisture is available. Storm dynamics could potentially become more efficient or possibly less efficient depending on the interaction of cloud microphysical processes with the storm dynamics. Offsetting effects could indeed lead to the storm efficiency remaining essentially unchanged. For the present, the assumption of no change in storm efficiency is accepted.

11.2 Parameters

This discussion applies to both dew points and SSTs although only SSTs will be addressed in this sections as SSTs are used as substitutes for land based dew points for all storms in this study for inflow vectors that originate over ocean regions and have the same sensitivity considerations.

The maximization factor depends on the determination of storm representative SSTs, along with maximum historical SST values. The magnitude of the maximization factor varies depending on the values used for the storm representative SST and the maximum SST. Holding all other variables constant, the maximization factor is smaller for higher storm representative SSTs as well as for lower maximum SST values. Likewise, larger maximization factors result from the use of lower storm representative SSTs and/or higher maximum SSTs. The magnitude of the change in the maximization factor varies dependent on the SST values. For the range of SST values used in most PMP studies, the maximization factor for a particular storm will change about 5% for every 1^{o}F difference between the storm representative and maximum SST values. The same sensitivity applies to the transposition factor, with about a 5% change for every 1^{o}F change in either the in-place maximum SST or the transposition maximum SST.

For example, consider the following case:

Storm representative SST:	75^{o}F	Precipitable water:	2.85”
Maximum SST:	79^{o}F	Precipitable water:	3.44”

Maximization factor = 3.44”/2.85” = 1.21

If the storm representative SST were 74°F with precipitable water of 2.73”,
Maximization factor = 3.44”/2.73” = 1.26 (an increase of approximately 4%)

If the maximum SST were 78°F with precipitable water of 3.29”,
Maximization factor = 3.29”/2.85” = 1.15 (a decrease of approximately 5%)

12. RECOMMENDATIONS FOR APPLICATION

12.1 Site-Specific PMP Applications

Site-specific PMP values have been computed that provide rainfall amounts for use in computing the PMF. The study addressed several issues that could potentially affect the magnitude of the PMP storm over the Susitna-Watana basin.

The HMRs use a procedure for locating the largest amounts of rainfall associated with the PMP storm, such that the largest volume of rain falls within the watershed boundaries, either using the 100-year 24-hour isopercental analysis or using a significant storm over the basin and the judgment of the user (HMR 57 Section 15.2, Step 9). As the authors of HMR 57 explicitly state in that section of the report, "It is left to a future study to resolve the issue of how to distribute general storm PMP…" This study has directly addressed this issue by using the gridded approach and developing spatial and temporal patterns based on the largest historic storm events that have occurred over the basin. Further, the temperature time series developed for this study explicitly addresses the antecedent and within-storm temperature profile that would be expected during a PMP storm over the basin, thereby eliminating much of the subjectivity employed in previous HMRs (e.g. HMR 57 Section 15.2 Step 10). These updated applications, based on actual data specific to the storms which affect this basin, allows the PMP rainfall to be distributed in a pattern that is physically possible based on the unique topography and climate of the basin. It is recommended that the use of the gridded approach to spatially distribute the PMP rainfall at each duration at each grid point be used to derive the PMF as presented in this report for the Susitna-Watana basin.

The storm search and selection of storms for the short list emphasized storms with the largest rainfall values that occurred over areas that are both meteorologically and topographically similar to the Susitna-Watana drainage basin. Results of this study should not be used for watersheds where meteorological and/or topographical parameters are different from the Susitna-Watana drainage basin without further evaluation.

12.2 Calibration Storm Events

AWA utilized the SPAS to analyze rainfall over the Susitna-Watana basin. Six storm events were selected for calibration of the PMF hydrologic model (Table 12.1). AWA analyzed a sufficiently large storm domain that included sufficient hourly rain gauge observations to calibrate the NEXRAD data if available over larger domain that included the Susitna-Watana region. Quality controlled NEXRAD data was acquired from Weather Decisions Technologies, Inc. Non-radar events utilized climatological basemaps to aid in the spatial distribution of precipitation.

Table 12.1. Six storm events were selected for hydrologic model calibration.

Hydrologic Calibration Events Selected		
SPAS #	Date	Radar
1256	Sep-12	Yes
1269	Aug-71	No
1270	Aug-67	No
6008	Jun-64	No
6009	Jun-71	No
6010	Jun-72	No

The rainfall analysis results were provided on a 1/3mi^2 grid with a temporal frequency of 60-minutes. In addition to the rainfall grids, clipped to the Susitna-Watana drainage, sub-basin average rainfall statistics were provided for all 34 sub-basins. Note, the calibration analysis included six extra sub-basins for calibration purposes to include the region immediately downstream of the dam site to the Gold Creek USGS gage.

12.2.1 September 14-30, 2012 Precipitation

The hourly precipitation grids derived from the SPAS 1256 analysis were used in conjunction with SPAS-Lite 6007 as the basis for the Susitna-Watana calibration. SPAS-Lite 6007 was utilized to fill in a longer duration than what was analyzed for SPAS 1256, the calibration period is referenced as SPAS 1256. The SPAS 1256 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS 1256 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 9/14-30/2012. In general, between 0.80 and 10.30 inches of rain fell across the Susitna-Watana drainage (Figure 12.1 - 12.3).

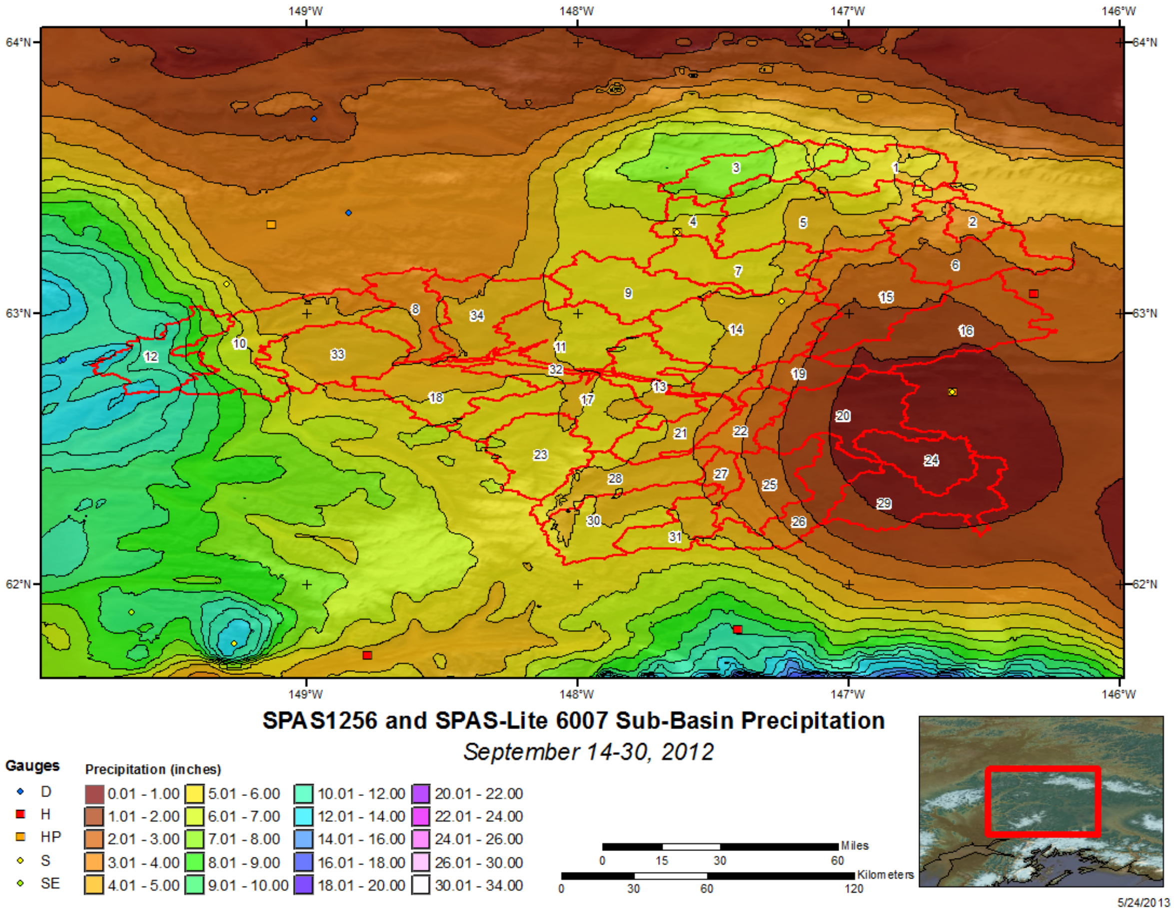


Figure 12.1. Total storm rainfall for SPAS 1256 across Susitna-Watana drainage.

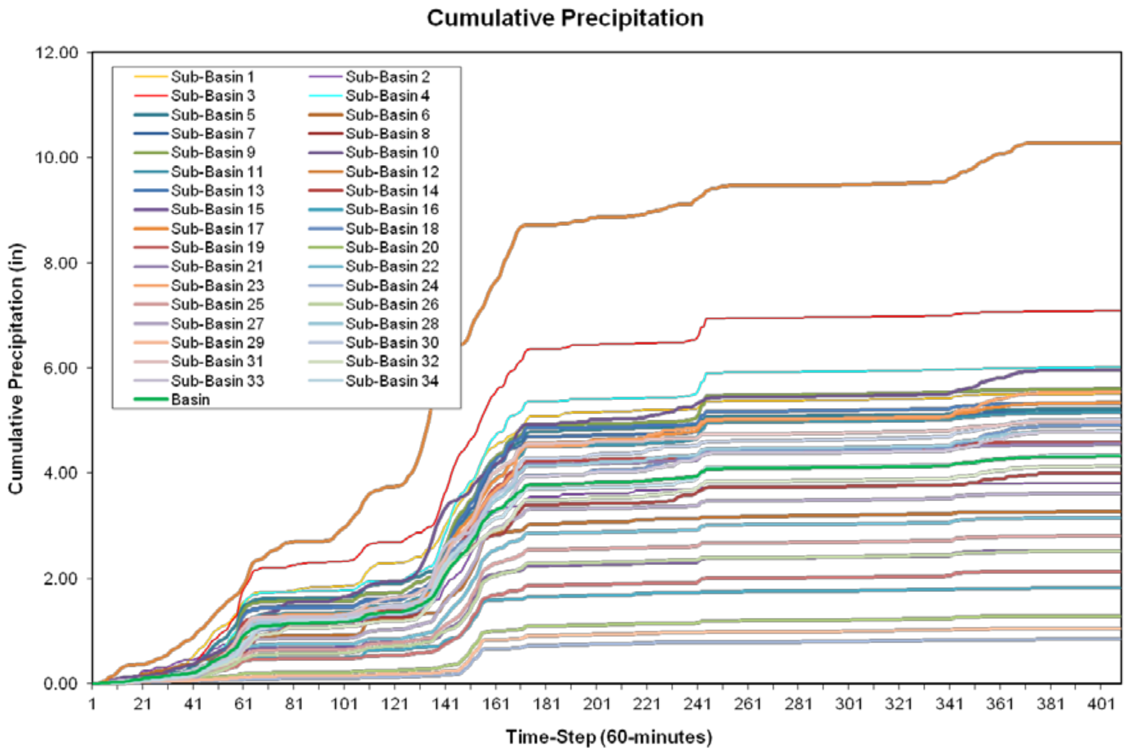


Figure 12.2. Susitna-Watana sub-basin average accumulated rainfall SPAS 1256.

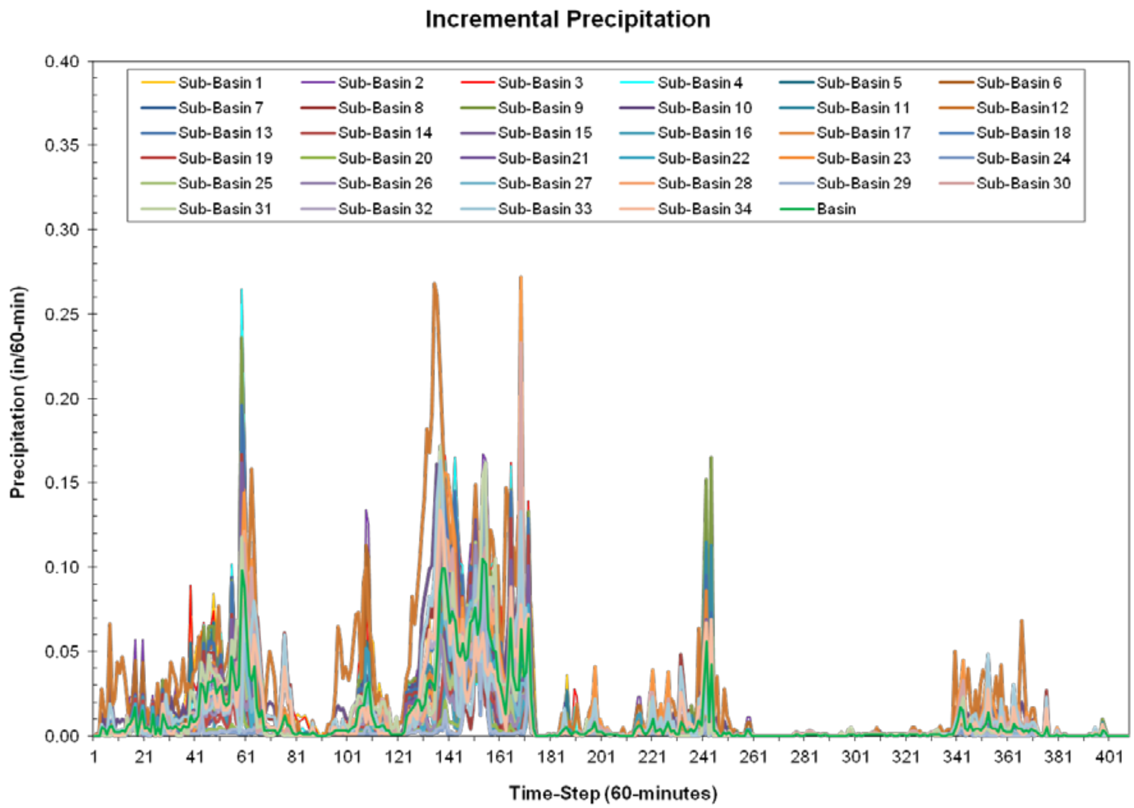


Figure 12.3. Susitna-Watana sub-basin average incremental rainfall SPAS 1256.

12.2.2 August 14-17, 1971 Precipitation

The hourly precipitation grids derived from the SPAS 1269 analysis were used in conjunction with SPAS-Lite 6001 as the basis for the Susitna-Watana calibration. SPAS-Lite 6001 was utilized to fill in a longer duration than what was analyzed for SPAS 1269, the calibration period is referenced as SPAS 1269. The SPAS 1269 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS 1269 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 8/4-17/1971. In general, between 1.50 and 5.80 inches of rain fell across the Susitna-Watana drainage (Figure 12.4 - 12.6).

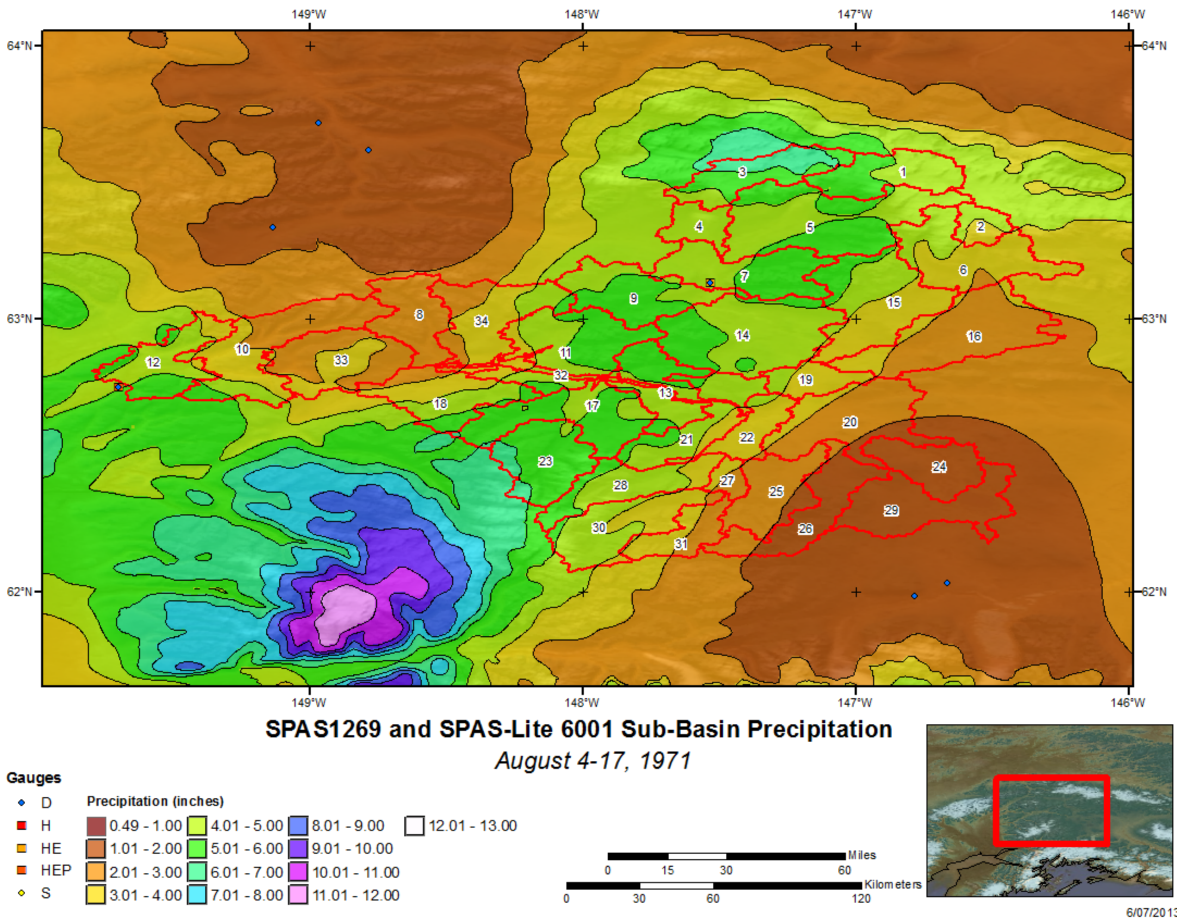


Figure 12.4. Total storm rainfall for SPAS 1269 across Susitna-Watana drainage.

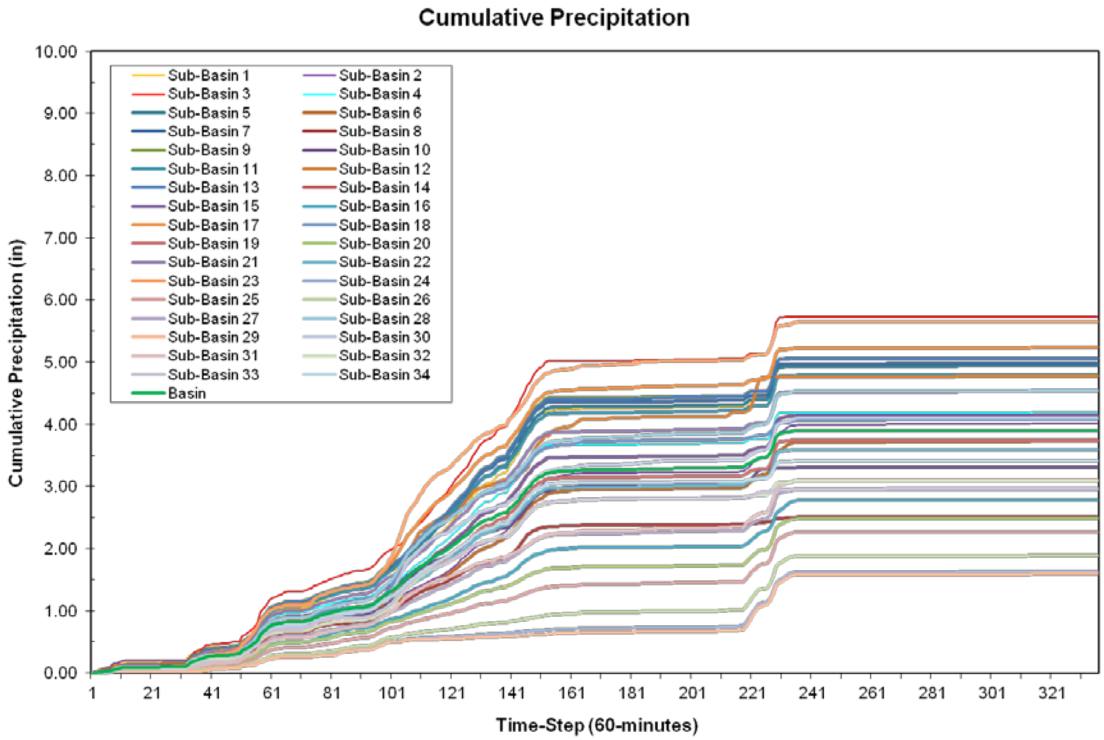


Figure 12.5. Susitna-Watana sub-basin average accumulated rainfall SPAS 1269.

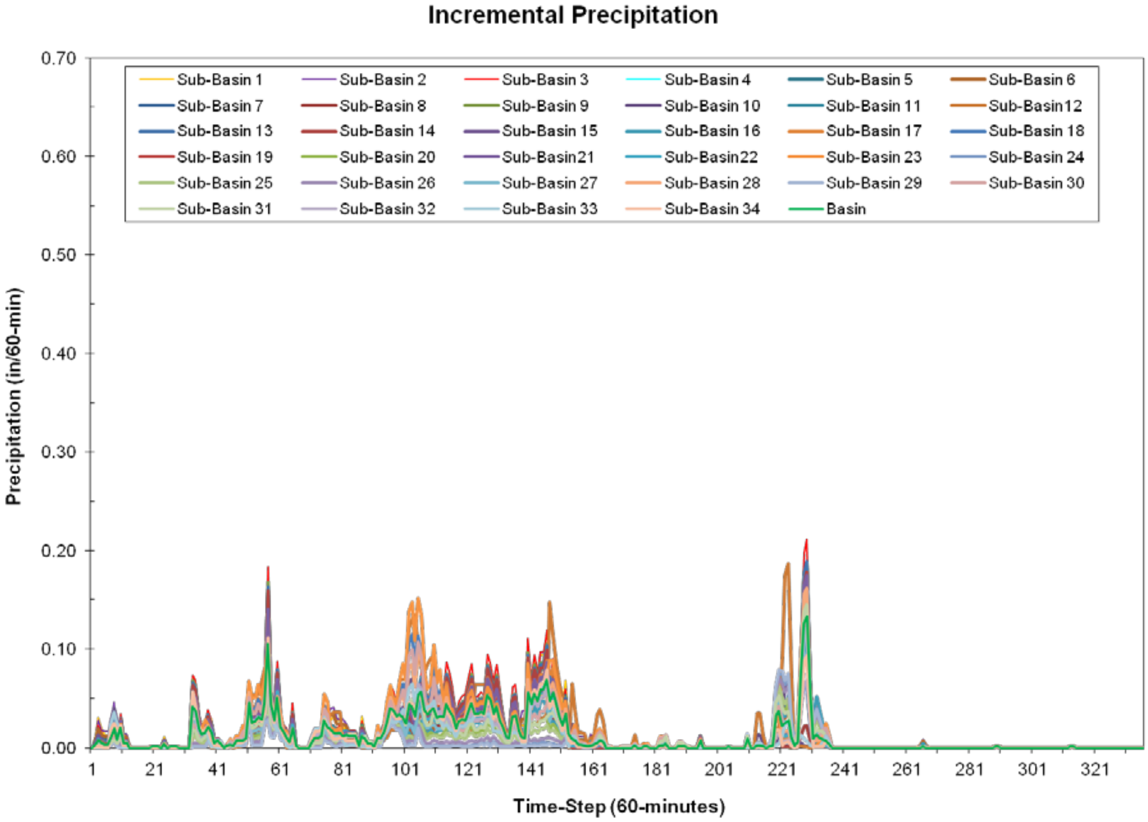


Figure 12.6. Susitna-Watana sub-basin average incremental rainfall SPAS 1269.

12.2.3 August 8-21, 1967 Precipitation

The hourly precipitation grids derived from the SPAS 1270 analysis were used in conjunction with SPAS-Lite 6002 as the basis for the Susitna-Watana calibration. SPAS-Lite 6002 was utilized to fill in a longer duration than what was analyzed for SPAS 1270, the calibration period is referenced as SPAS 1270. The SPAS 1270 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS 1270 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 8/8-21/1967. In general, between 0.50 and 7.20 inches of rain fell across the Susitna-Watana drainage (Figure 12.7 - 12.9).

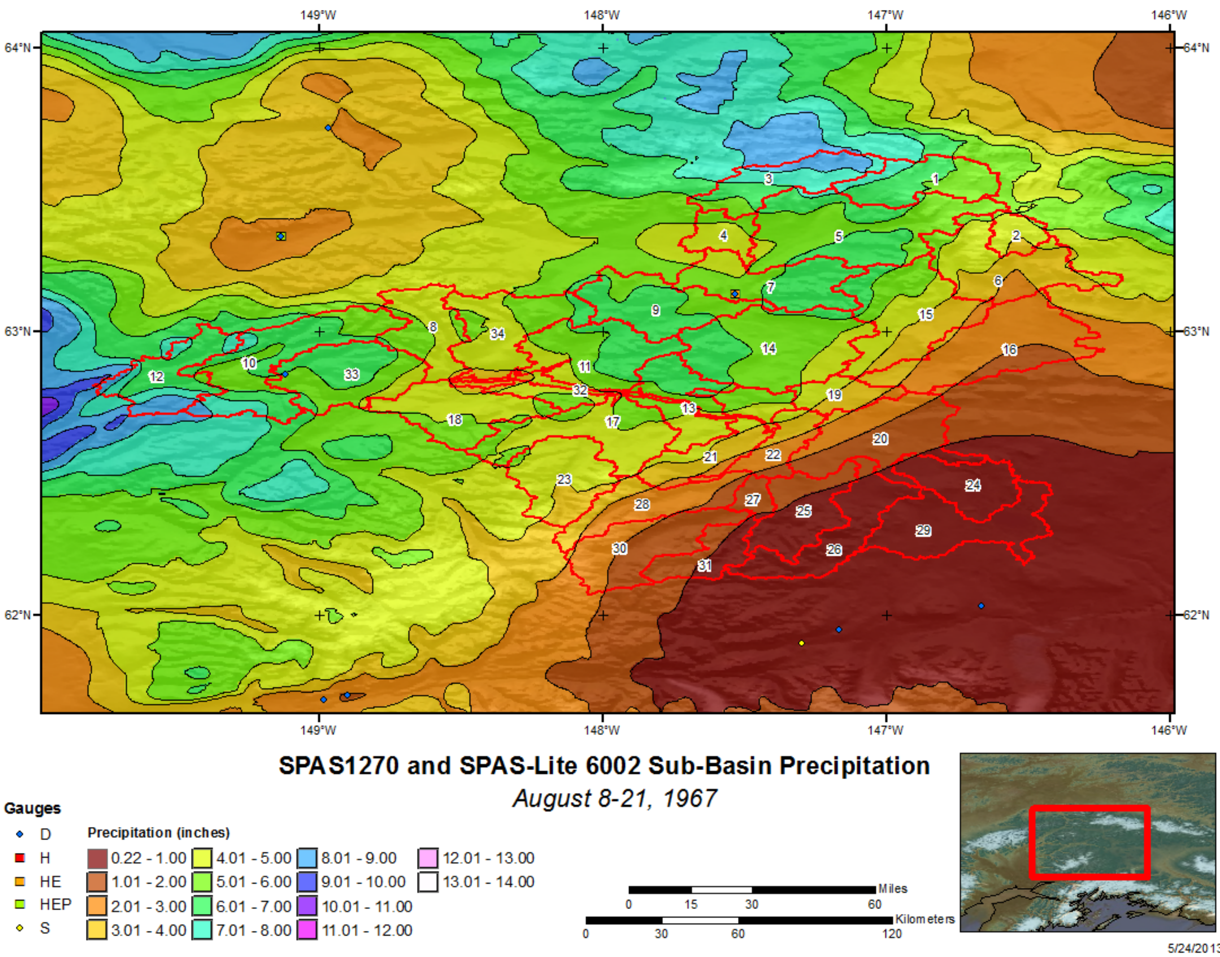


Figure 12.7. Total storm rainfall for SPAS 1270 across Susitna-Watana drainage.

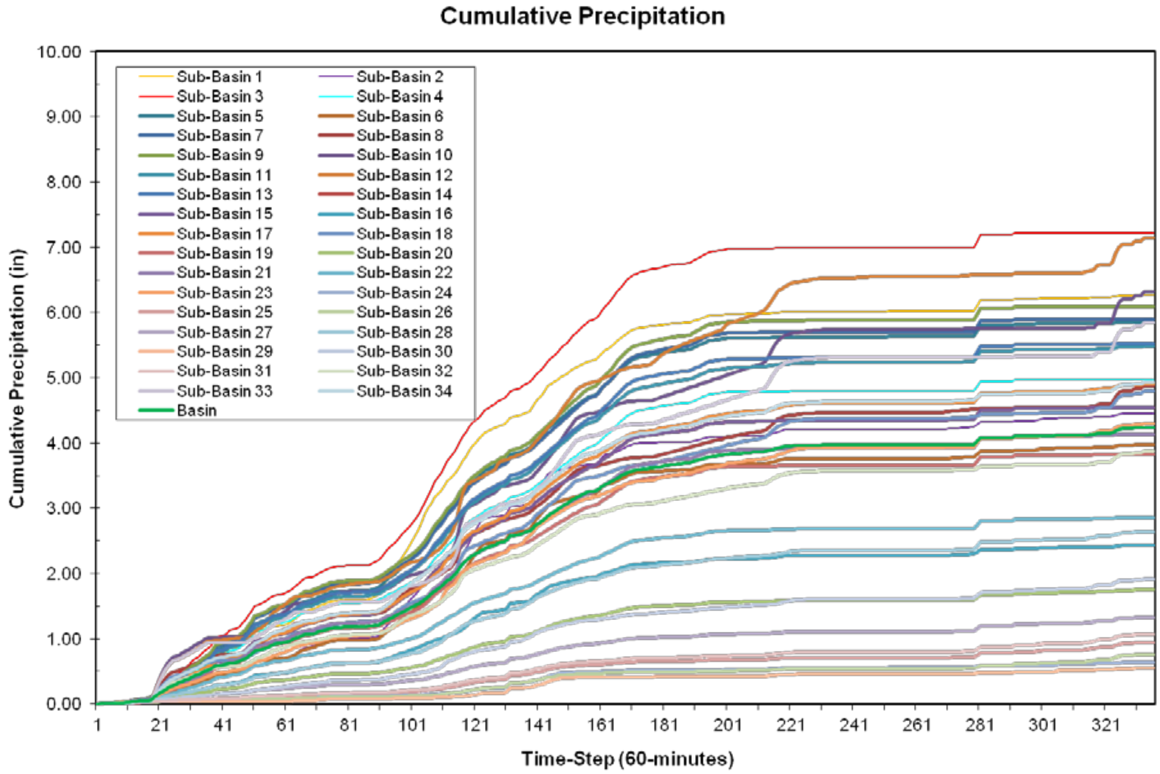


Figure 12.8. Susitna-Watana sub-basin average accumulated rainfall SPAS 1270.

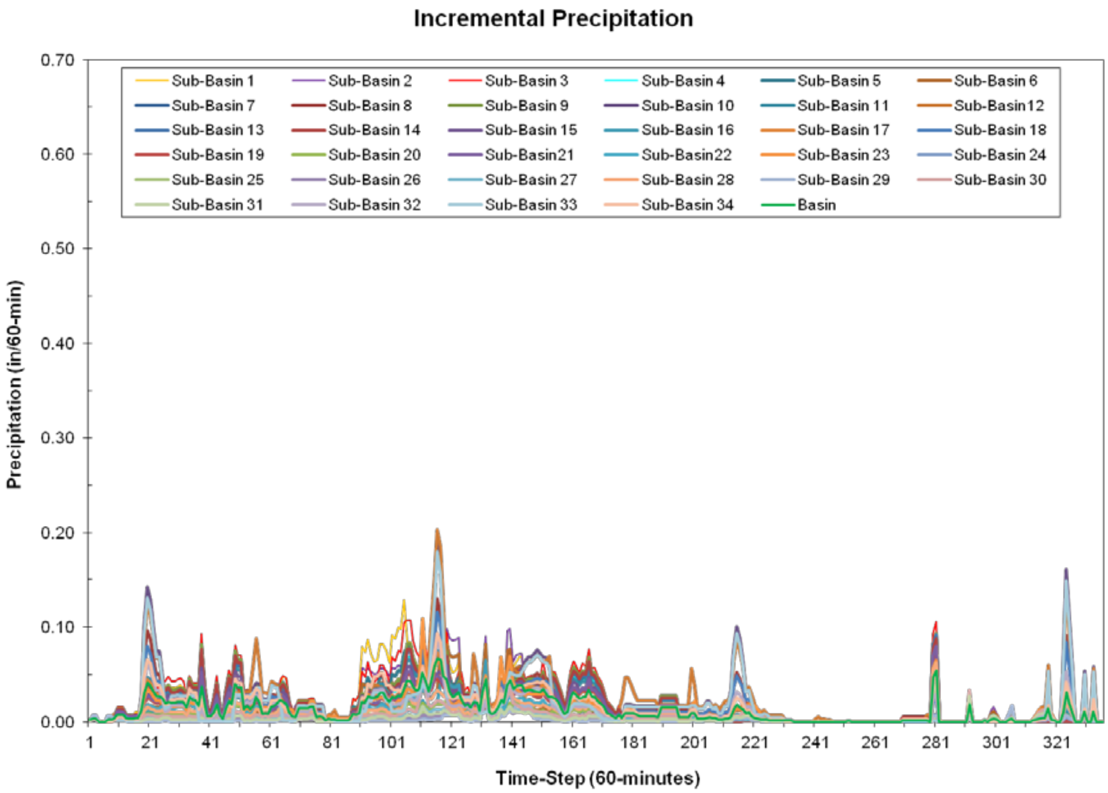


Figure 12.9. Susitna-Watana sub-basin average incremental rainfall SPAS 1270.

12.2.4 May 27, 1964 - June 13, 1964 Precipitation

The hourly precipitation grids derived from the SPAS-Lite 6008 analysis were used as the basis for the Susitna-Watana basin calibration. The SPAS-Lite 6008 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS-Lite 6008 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 5/27/1964 - 6/13/1964. In general, between 0.20 and 1.50 inches of rain fell across the Susitna-Watana drainage (Figure 12.10 - 12.12).

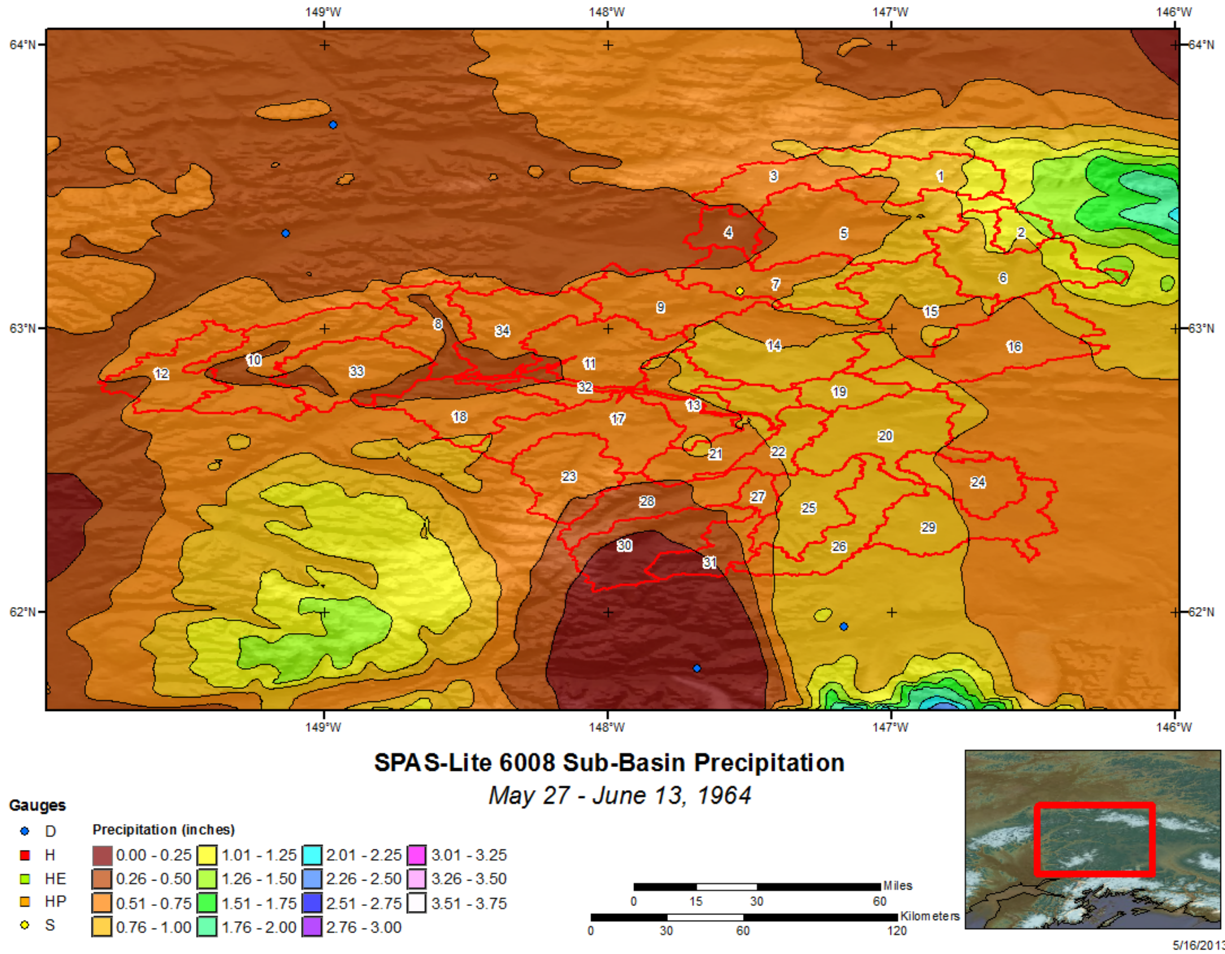


Figure 12.10. Total storm rainfall for SPAS 6008 across Susitna-Watana drainage.

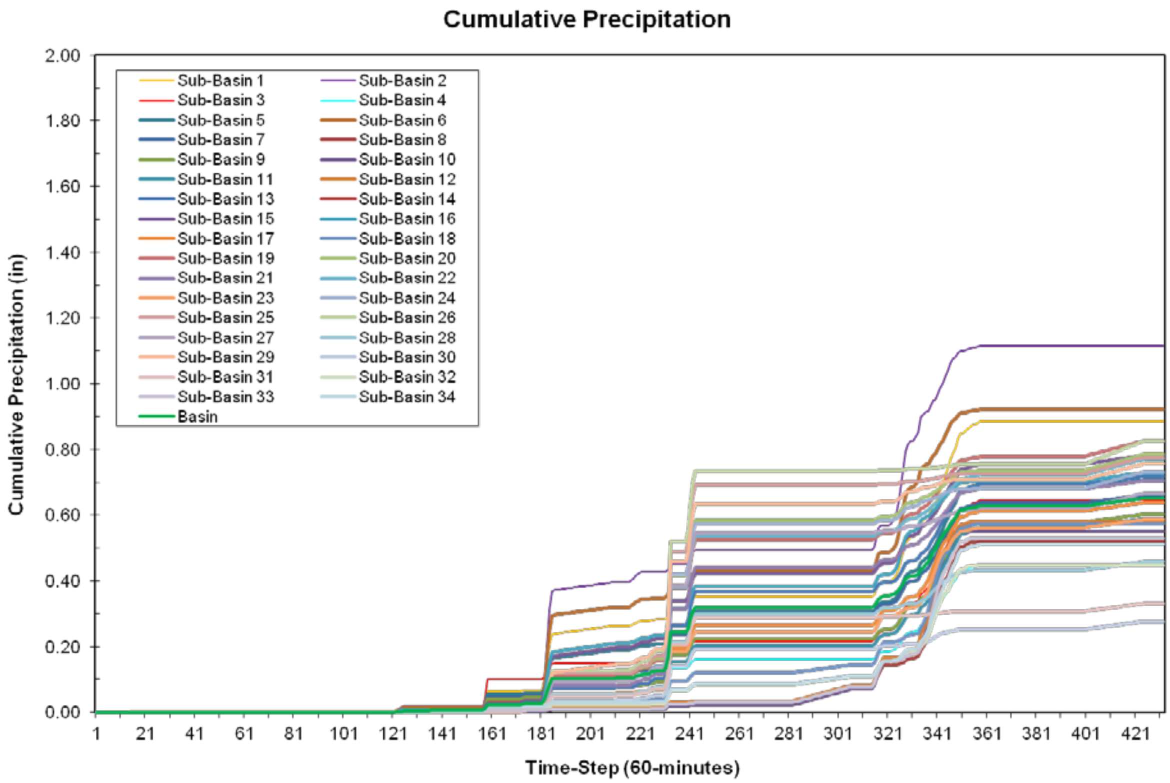


Figure 12.11. Susitna-Watana sub-basin average accumulated rainfall SPAS 6008.

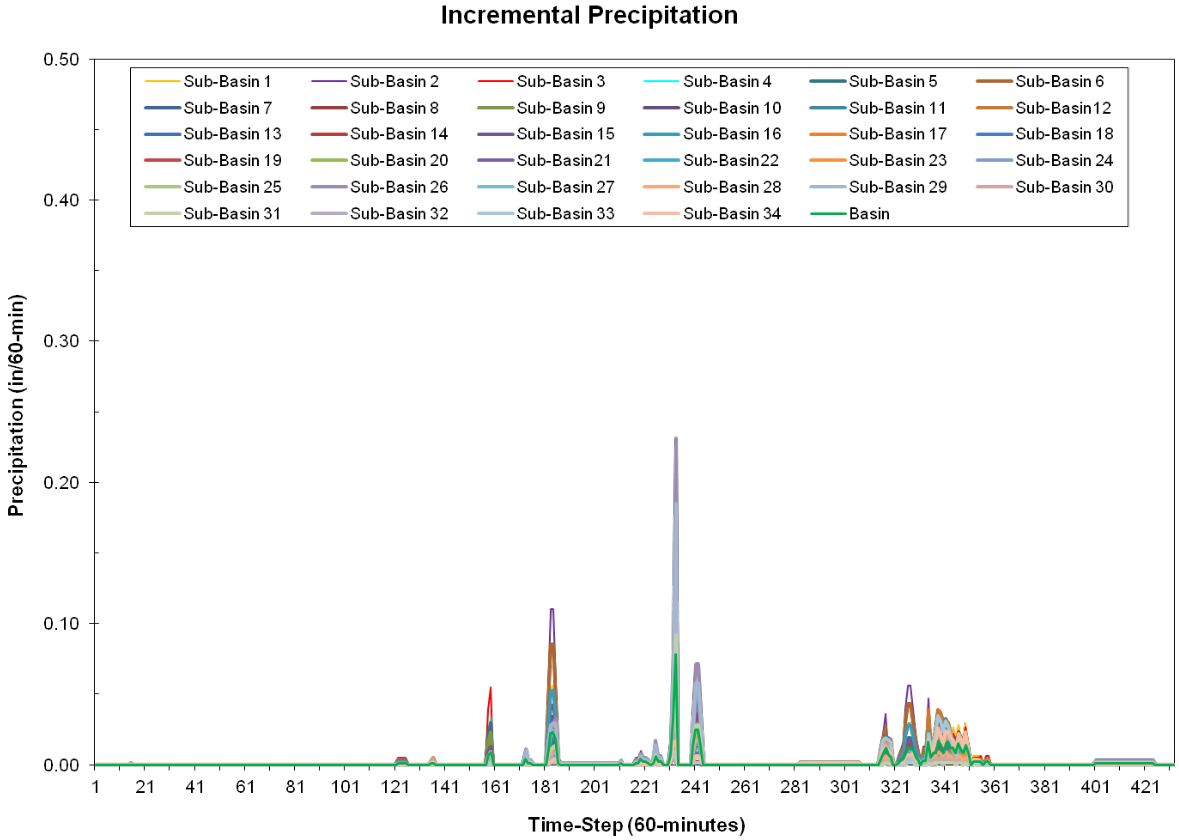


Figure 12.12. Susitna-Watana sub-basin average incremental rainfall SPAS 6008.

12.2.5 June 3-17, 1971 Precipitation

The hourly precipitation grids derived from the SPAS-Lite 6009 analysis were used as the basis for the Susitna-Watana basin calibration. The SPAS-Lite 6009 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS-Lite 6009 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 6/3-17/1971. In general, between 0.20 and 1.30 inches of rain fell across the Susitna-Watana drainage (Figure 12.13 - 12.15).

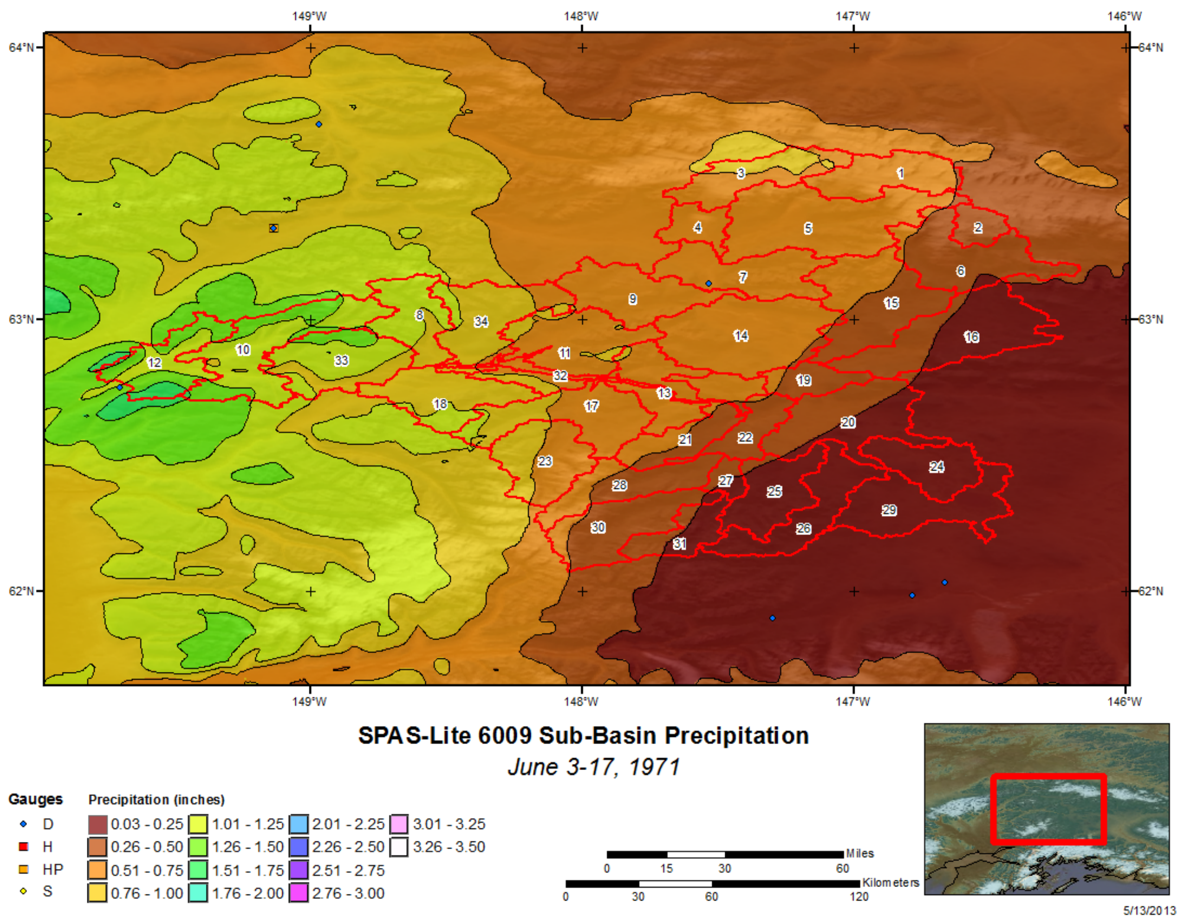


Figure 12.13. Total storm rainfall for SPAS 6009 across Susitna-Watana drainage.

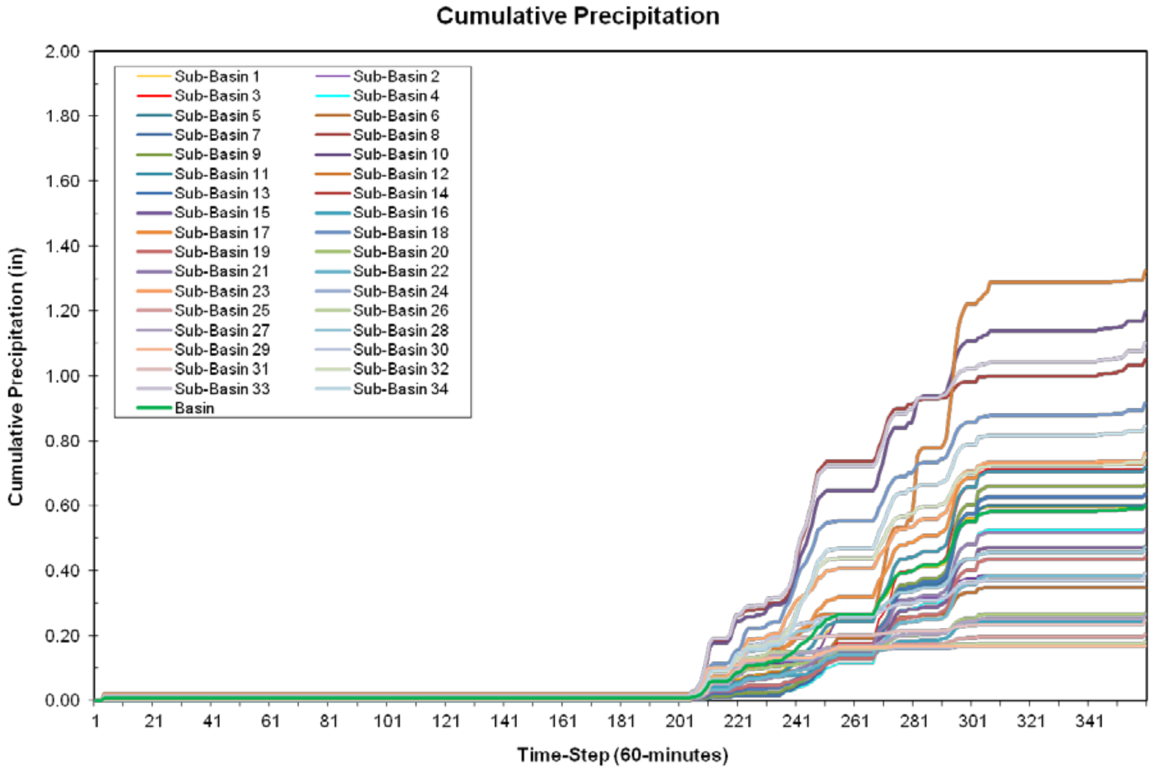


Figure 12.14. Susitna-Watana sub-basin average accumulated rainfall SPAS 6009.

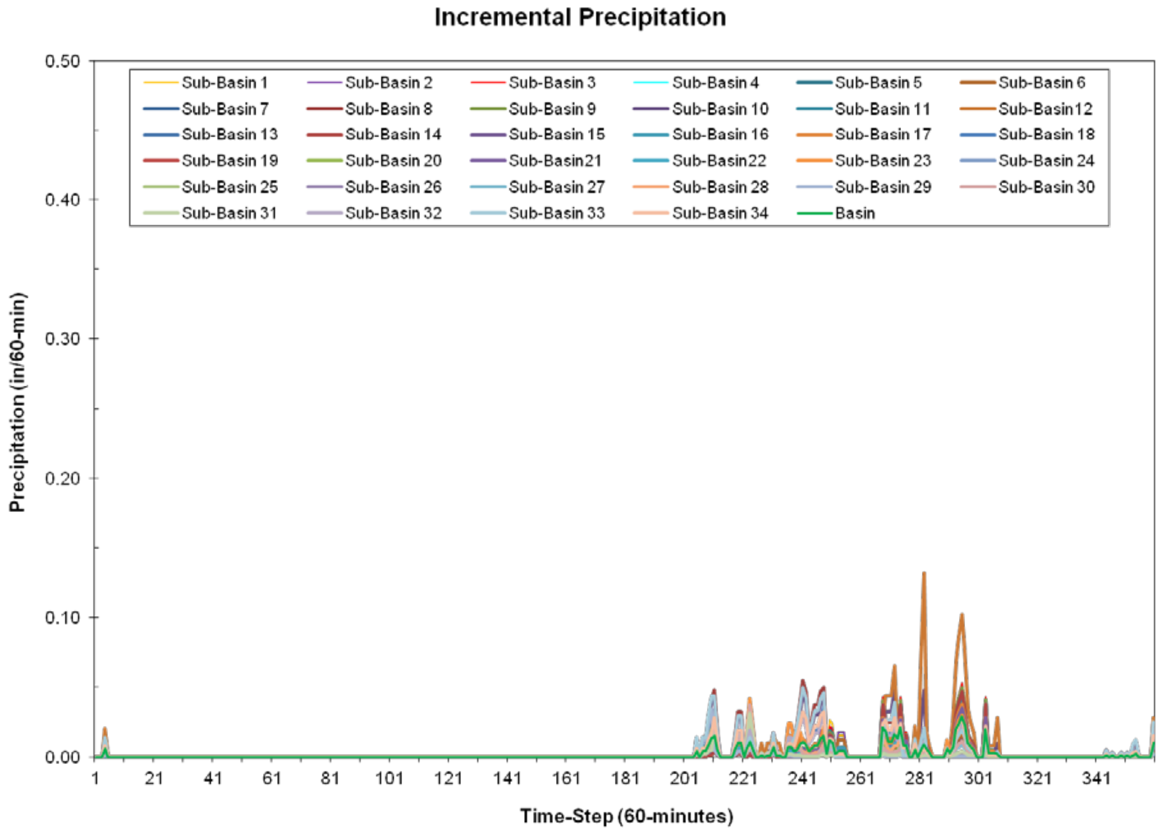


Figure 12.15. Susitna-Watana sub-basin average incremental rainfall SPAS 6009.

12.2.6 June 7-22, 1972 Precipitation

The hourly precipitation grids derived from the SPAS-Lite 6010 analysis were used as the basis for the Susitna-Watana basin calibration. The SPAS-Lite 6010 analysis encompassed the 34 sub-basins of Susitna-Watana. The SPAS-Lite 6010 hourly grids were clipped to each of the Susitna-Watana sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 6/7-22/1972. In general, between 0.50 and 1.50 inches of rain fell across the Susitna-Watana drainage (Figure 12.16 - 12.18).

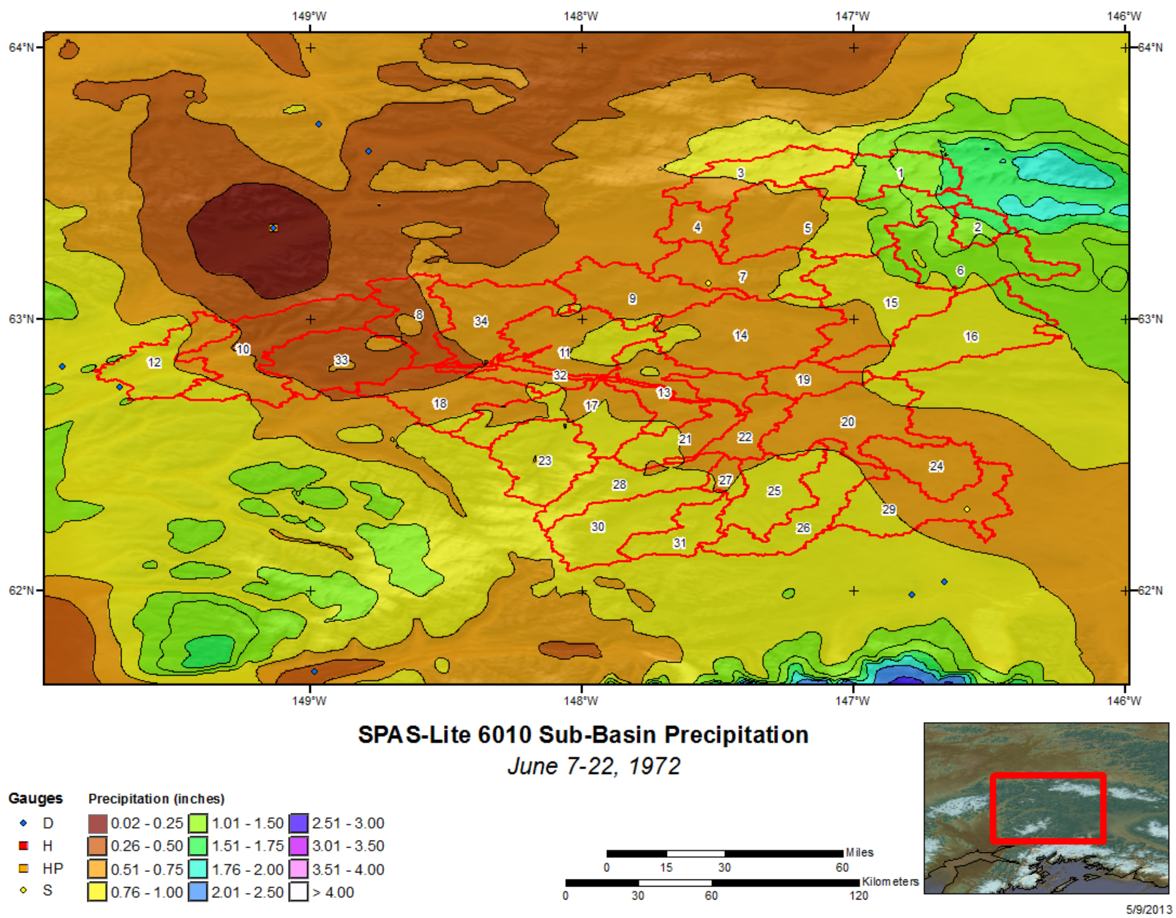


Figure 12.16. Total storm rainfall for SPAS 6010 across Susitna-Watana drainage.

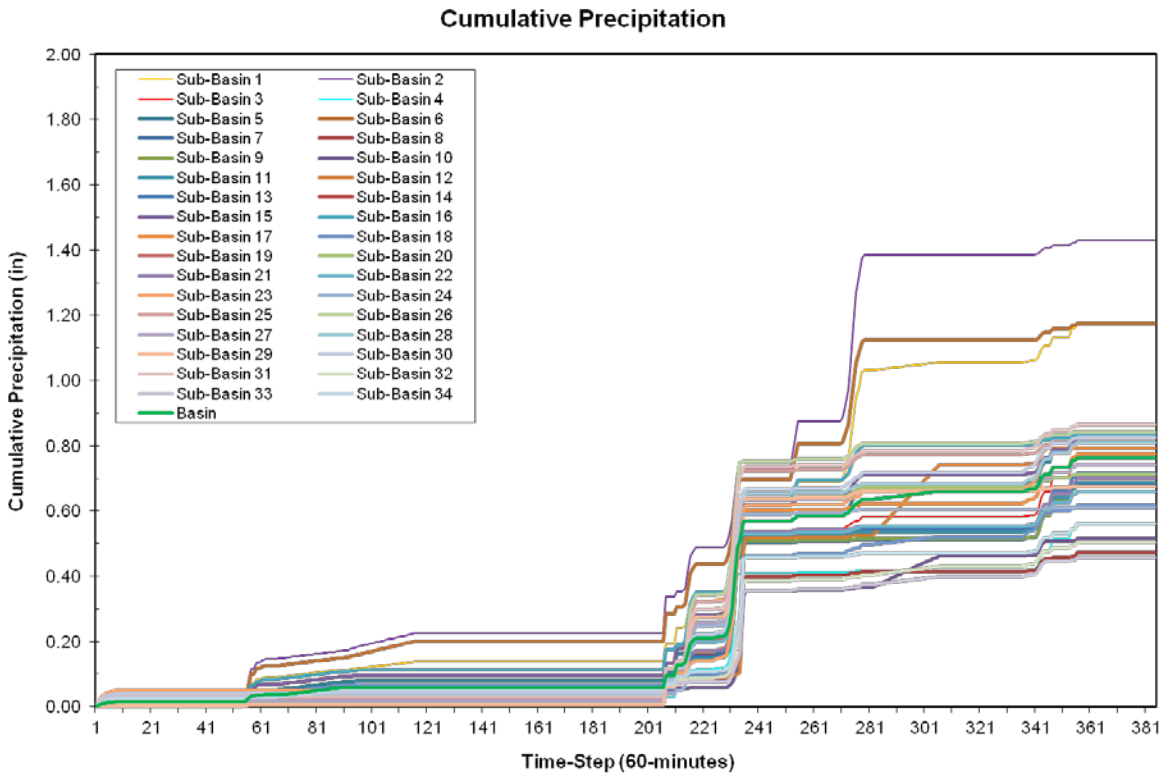


Figure 12.17. Susitna-Watana sub-basin average accumulated rainfall SPAS 6010.

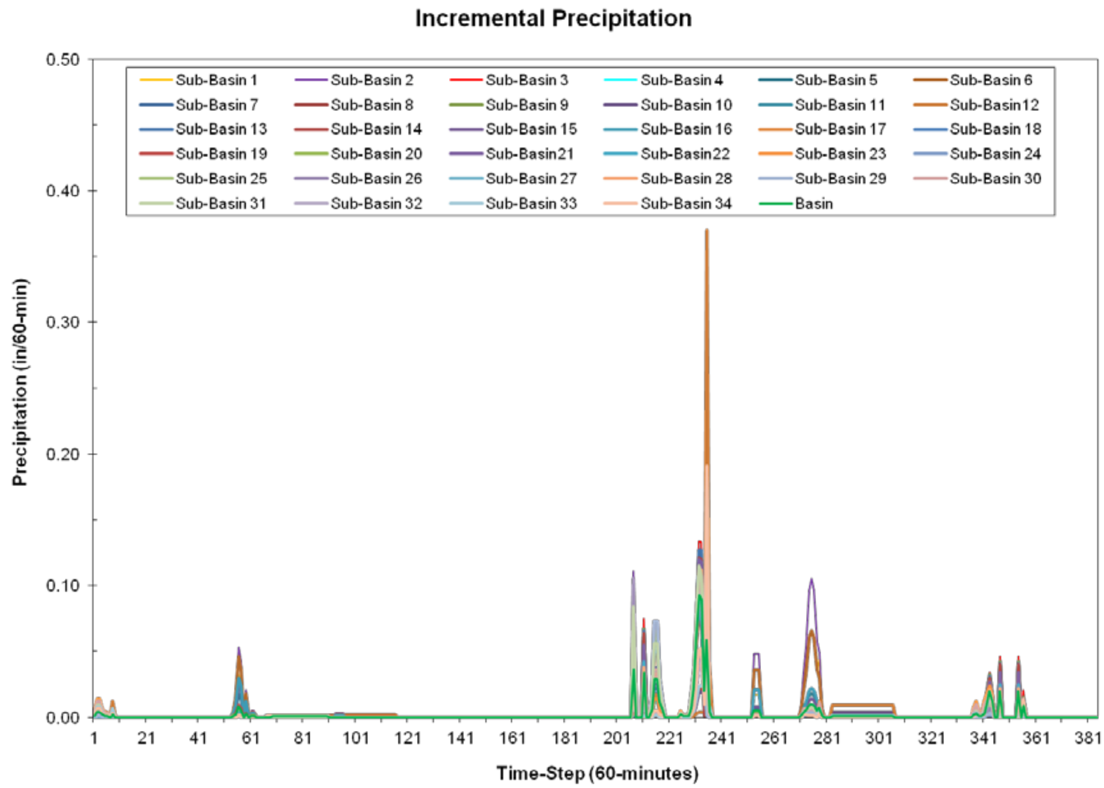


Figure 12.18. Susitna-Watana sub-basin average incremental rainfall SPAS 6010.

12.3 Meteorological Time Series for Calibration Events

Hourly meteorological time series were developed for the six calibration events (see Table 12.1). The meteorological time series parameters derived were temperature, dew point temperature and wind speed over the Susitna-Watana basin. The hydrologic model requirements were a single temperature and dew point temperature time series at a given base elevation and wind speed at 1,000-ft increments from 0 - 15,000-ft. Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna River basin and the Fairbanks and Anchorage radiosonde data.

Vertical wind speed profiles at 1,000-ft increments were derived based on wind speed data from the Fairbanks radiosonde data and observed surface wind speed data for stations in and around the Susitna-Watana basin. The radiosonde wind speed represents free atmospheric wind (unobstructed flow). The free-air data were adjusted to surface wind speeds based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. The wind speed derivation methodology was based on methods described in HMR 42 (Weather Bureau 1966). HMR 42 measured winds at Gulkana glacier (4,800 ft) and compared them to free-air winds at Fairbanks; the study found that average wind on the glacier was 0.60 that of the free-air. In this updated analysis, comparisons were made using both Anchorage and Fairbanks radiosonde data. This analysis showed the Anchorage radiosonde data were not as representative of the surface wind speeds over the basin based on comparisons made to the September 2012 storm event. Instead, the Fairbanks data better represented the timing and magnitude of the observed surface wind speeds.

12.3.1 September 14-30, 2012 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Independence Mine and Talkeetna, ii) PAZK and Talkeetna, iii) PAZK and Renee, and iv) Monahan Flats and McKinley. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.2).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were PAZK, PANC, Blair Lakes, Dunkle Hills, Eielson VC, Paxson, Renee, Toklat, Independence Mine, Monahan Flat, Susitna VH, Tokositna Valley, Fairbanks, Ft Greeley, Gulkana, McKinley NP, Palmer, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.2).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.2). The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds. The average free-air adjustment for the six stations was 0.620 with a maximum of 0.968 and a minimum of 0.385 (Table 12.3). In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-foot elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.666 = 30-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.2. Station based and radiosonde based lapse rates for September 14-30, 2012.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Indep. Mine vs. Talkeetna	-2.50	-1.98	-
PAZK vs. Talkeetna	-2.17	-1.69	-
PAZK vs. Renee	-3.10	-3.64	-
Monahan Flat vs. McKinley	-1.73	-2.53	-
All Stations	-2.40	-2.38	-
Average	-2.38	-2.44	-2.43

Table 12.3. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for September 14-30, 2012.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.968
McKinley	1500	0.471
Talkeetna	500	0.769
PAZK	3500	0.385
Renee	2500	0.623
Eielson	3500	0.505
	Average	*0.620*
	Maximum	0.968
	Minimum	0.385

The final temperature and dew point temperature series were based on surface data at Monahan Flats, Alaska with a base elevation of 2,700-ft (Figure 12.19). The Monahan Flats station data were selected because it was within the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -2.40°F. The -2.40°F lapse rate was based on the average of all station comparisons. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.620 applied to represent anemometer level wind speeds (Figure 12.20).

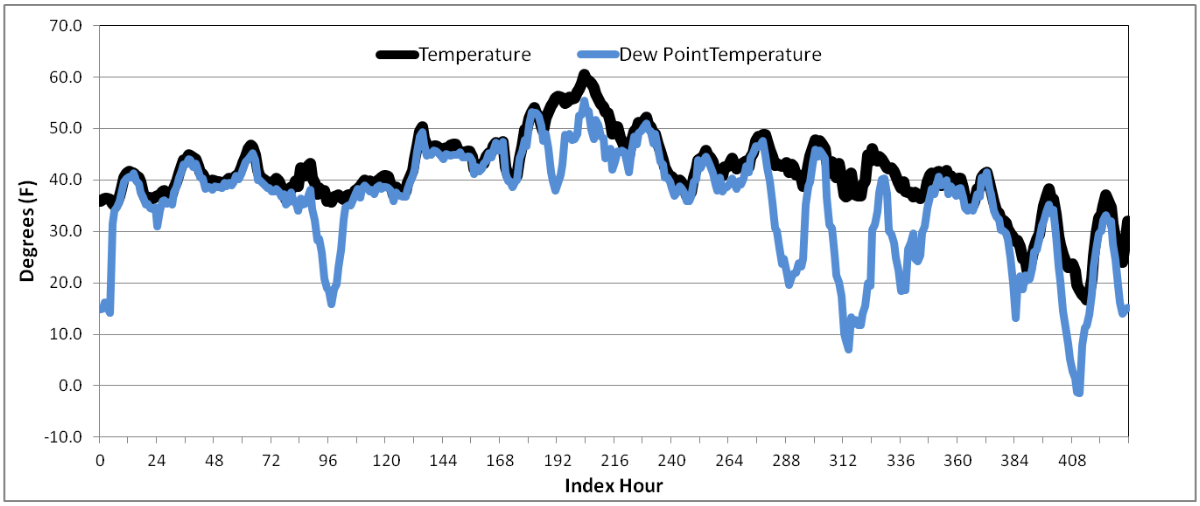


Figure 12.19. Temperature and dew point time series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -2.40°F for September 14-30, 2012.

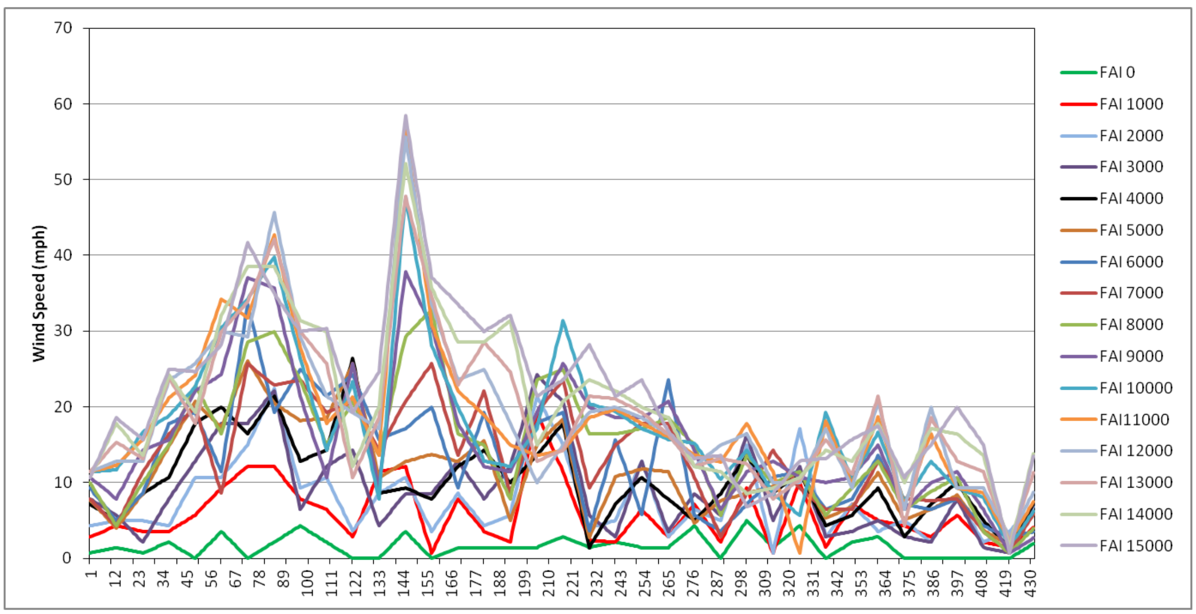


Figure 12.20. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.62 applied to represent anemometer level wind speeds for September 14-30, 2012.

12.3.2 August 4-17, 1971 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Talkeetna and Summit, ii) Anchorage and Gulkana, iii) Ft Greeley and Summit, and iv) Ft Greeley and Fairbanks. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.4).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were PANC, Anchorage, Fairbanks, Ft Greeley, Gulkana, Summit, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.4).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.4).

Table 12.4. Station based and radiosonde based lapse rates for August 4-17, 1971.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Talkeetna vs. Summit	-3.31	-2.62	-
Anchorage vs. Gulkana	-0.86	0.17	-
Ft Greely vs. Summit	-3.34	-5.15	-
Ft Greely vs. Fairbanks	-2.47	-2.18	-
All Stations	-2.27	-2.11	-
Average*	-2.85	-3.01	-3.40

* Comparison excludes Anchorage vs. Gulkana lapse rate

The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds elevations based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds (Table 12.5). The average free-air adjustment for the six stations was 0.666 with a maximum of 0.895 and a minimum of 0.390. In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-foot elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.666 = 30-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.5. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for August 4-17, 1971.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.768
Summit	2500	0.608
Talkeetna	500	0.390
Anchorage	0	0.869
Ft Greely	1500	0.468
Fairbanks	500	0.895
	Average	*0.666*
	Maximum	0.895
	Minimum	0.390

The final temperature and dew point temperature series were based on surface data at Summit, Alaska with a base elevation of 2,400-ft (Figure 12.21). The Summit station data were selected because it was in close proximity to the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -2.85°F. The -2.85°F lapse rate was based on the average of all station comparison except the Anchorage and Gulkana comparison. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.666 applied to represent anemometer level wind speeds (Figure 12.22).

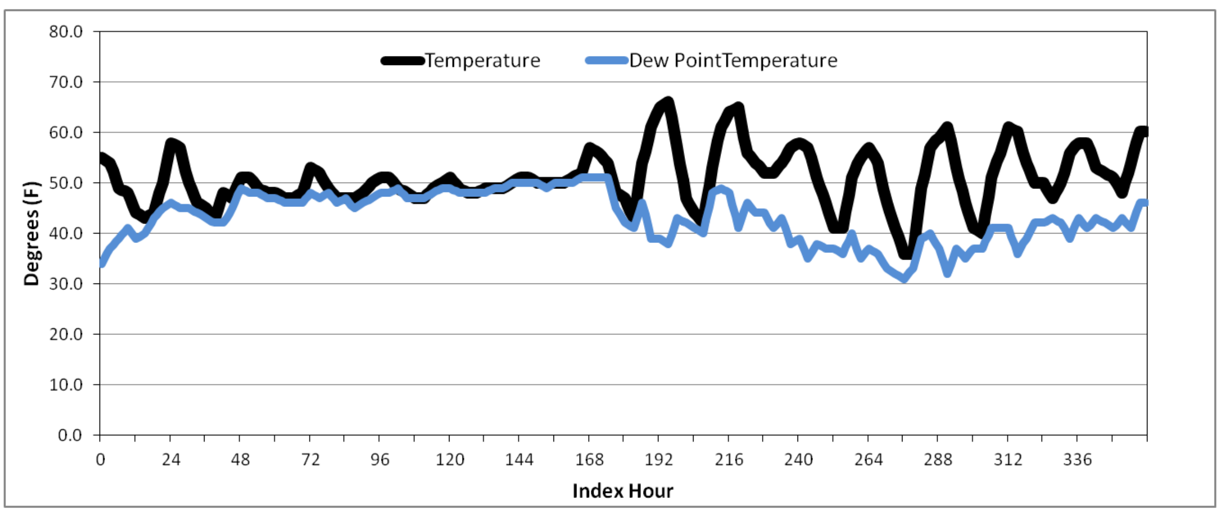


Figure 12.21. Temperature and dew point temperature series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -2.85°F for August 4-17, 1971.

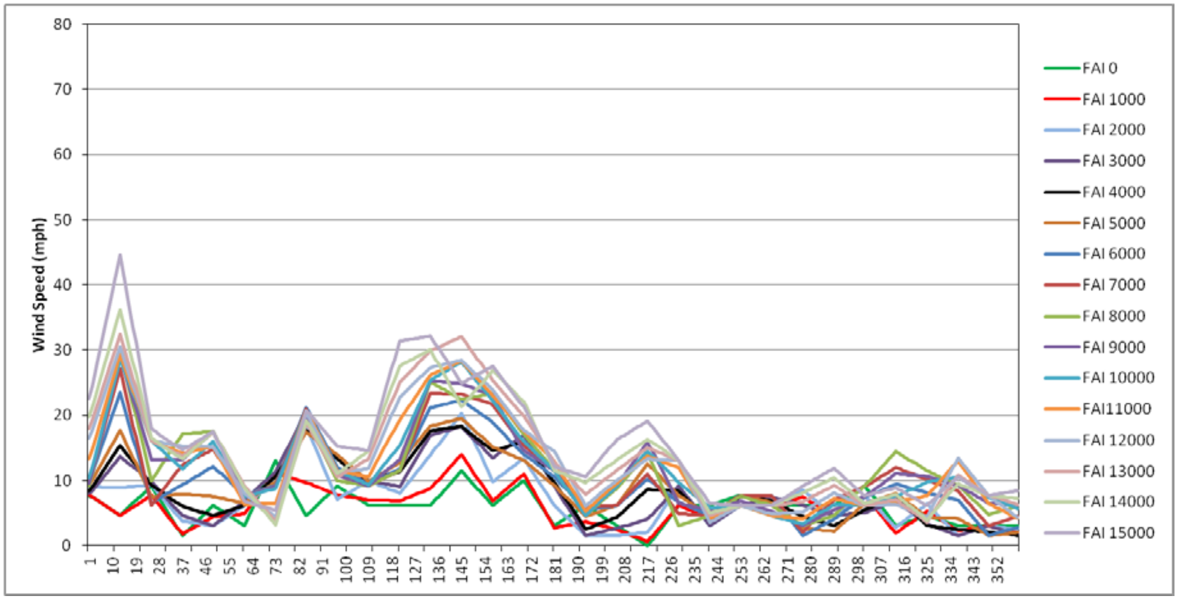


Figure 12.22. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.666 applied to represent anemometer level wind speeds for August 4-17, 1971.

12.3.3 August 8-21, 1967 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Talkeetna and Summit, ii) Anchorage and Gulkana, iii) Ft Greeley and Summit, and iv) Ft Greeley and Fairbanks. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.6).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were KINR, Anchorage, Cordova, Fairbanks, Ft Greeley, Gulkana, Nenana, Summit, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.6).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.6).

Table 12.6. Station based and radiosonde based lapse rates for August 8-21, 1967.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Talkeetna vs. Summit	-3.51	-3.83	-
Anchorage vs. Gulkana	-1.72	-2.13	-
Ft Greely vs. Summit	-7.33	-7.22	-
Ft Greely vs. Fairbanks	0.46	0.17	-
All Stations	-1.39	-1.35	-
Average*	-2.70	-2.87	-3.25

* -2.87 was used based on testing lapse rate at Summit to Anchorage and Nenana

The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds elevations based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds (Table 12.7). The average free-air adjustment for the six stations was 0.610 with a maximum of 0.813 and a minimum of 0.337. In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-ft elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.620 = 27.5-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.7. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for August 8-21, 1967.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.813
Summit	2500	0.643
Talkeetna	500	0.662
Cordova	0	0.337
Ft Greely	1500	0.411
Fairbanks	500	0.519
	Average*	*0.610*
	Maximum	0.813
	Minimum	0.337

* Average excludes Cordova

The final temperature and dew point temperature series were based on surface data at Summit, Alaska with a base elevation of 2,400-ft (Figure 12.23). The Summit station data were selected because it was in close proximity to the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -2.87°F. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.610 applied to represent anemometer level wind speeds (Figure 12.24).

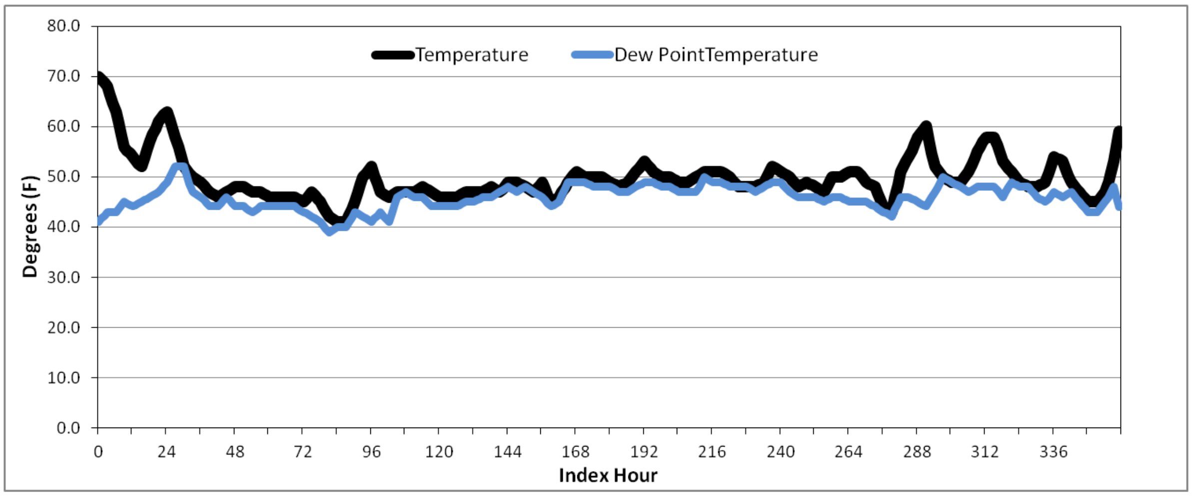


Figure 12.23. Temperature and dew point temperature series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -2.87°F for August 8-21, 1967.

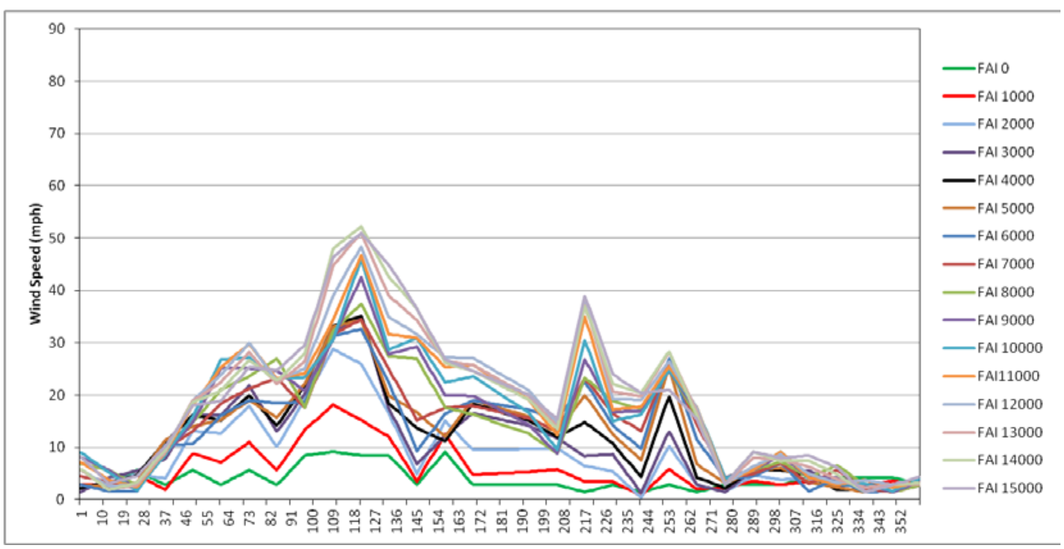


Figure 12.24. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.610 applied to represent anemometer level wind speeds for August 8-21, 1967.

12.3.4 May 27, 1964 - June 13, 1964 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Talkeetna and Summit, ii) Anchorage and Gulkana, iii) Ft Greeley and Summit, and iv) Ft Greeley and Fairbanks. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.8).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were PANC, Anchorage, Fairbanks, Ft Greeley, Gulkana, Summit, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.8).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.8).

Table 12.8 Station based and radiosonde based lapse rates for May 27 - June 13, 1964.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Talkeetna vs. Summit	-4.17	-4.09	-
Anchorage vs. Gulkana	0.02	1.35	-
Ft Greely vs. Summit	-5.93	-7.36	-
Ft Greely vs. Fairbanks	-1.18	-0.27	-
All Stations	-3.01	-2.08	-
Average*	-3.57	-3.45	-3.54

* Comparison excludes Anchorage vs. Gulkana lapse rate

The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds elevations based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds (Table 12.9). The average free-air adjustment for the six stations was 0.614 with a maximum of 0.839 and a minimum of 0.448. In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-ft elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.614 =

27.6-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.9. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for May 27 – June 13, 1964.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.571
Summit	2500	0.615
Talkeetna	500	0.448
Anchorage	0	0.839
Ft Greely	1500	0.525
Fairbanks	500	0.685
	Average	*0.614*
	Maximum	0.839
	Minimum	0.448

The final temperature and dew point temperature series were based on surface data at Summit, Alaska with a base elevation of 2,400-ft (Figure 12.25). The Summit station data were selected because it was in close proximity to the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -3.57°F. The -3.57°F lapse rate was based on the average of all station comparison except the Anchorage and Gulkana comparison. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.614 applied to represent anemometer level wind speeds (Figure 12.26).

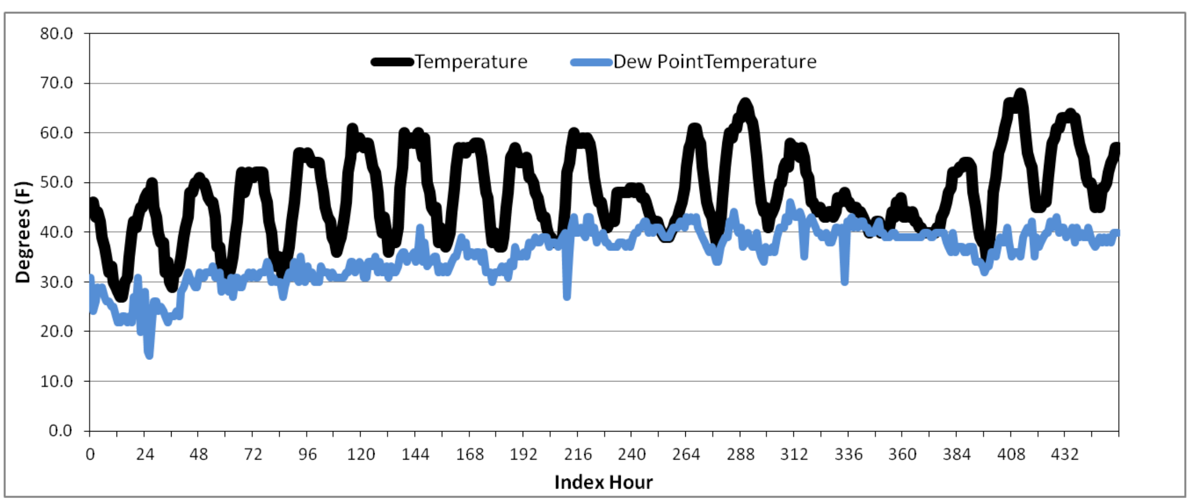


Figure 12.25. Temperature and dew point temperature series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -3.57°F for May 27 - June 13, 1964.

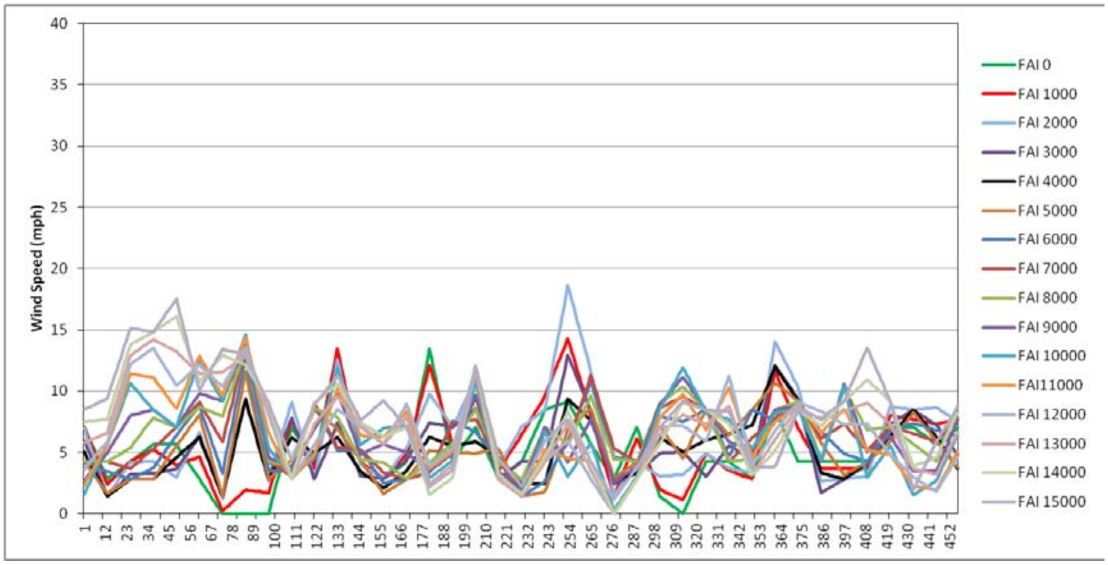


Figure 12.26. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.614 applied to represent anemometer level wind speeds for May 27 - June 13, 1964.

12.3.5 June 3-17, 1971 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Talkeetna and Summit, ii) Anchorage and Gulkana, iii) Ft Greeley and Summit, and iv) Ft Greeley and Fairbanks. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.10).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were PANC, Anchorage, Fairbanks, Ft Greeley, Gulkana, Summit, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.10).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.10).

Table 12.10. Station based and radiosonde based lapse rates for June 3-17, 1971.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Talkeetna vs. Summit	-3.89	-3.44	-
Anchorage vs. Gulkana	1.99	0.92	-
Ft Greely vs. Summit	-12.35	-11.15	-
Ft Greely vs. Fairbanks	-3.39	-2.83	-
All Stations	-2.05	-2.49	-
Average*	-3.11	-2.92	-3.76

* Comparison excludes Anchorage vs. Gulkana lapse rate

* Comparison excludes Ft Greeley vs. Summit lapse rate

The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds elevations based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds (Table 12.11). The average free-air adjustment for the six stations was 0.785 with a maximum of 0.946 and a minimum of 0.493. In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-ft elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.785 = 35.3-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.11. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for June 3-17, 1971.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.895
Summit	2500	0.719
Talkeetna	500	0.493
Anchorage	0	0.909
Ft Greely	1500	0.910
Fairbanks	500	0.946
	Average*	*0.785*
	Maximum	0.946
	Minimum	0.493

* Average excludes Anchorage

The final temperature and dew point temperature series were based on surface data at Summit, Alaska with a base elevation of 2,400-ft (Figure 12.28). The Summit station data were selected because it was in close proximity to the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -2.90°F. The -2.90°F lapse rate was based on the average of all station comparison except the Anchorage and Gulkana comparison and Ft Greeley and Summit comparison. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.785 applied to represent anemometer level wind speeds (Figure 12.28).

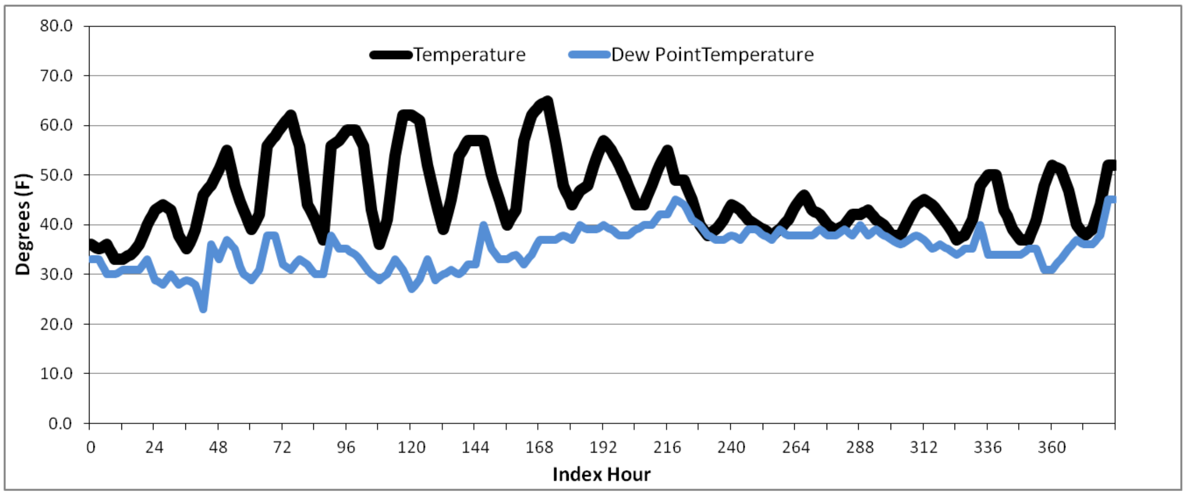


Figure 12.27. Temperature and dew point temperature series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -2.90°F for June 3-17, 1971.

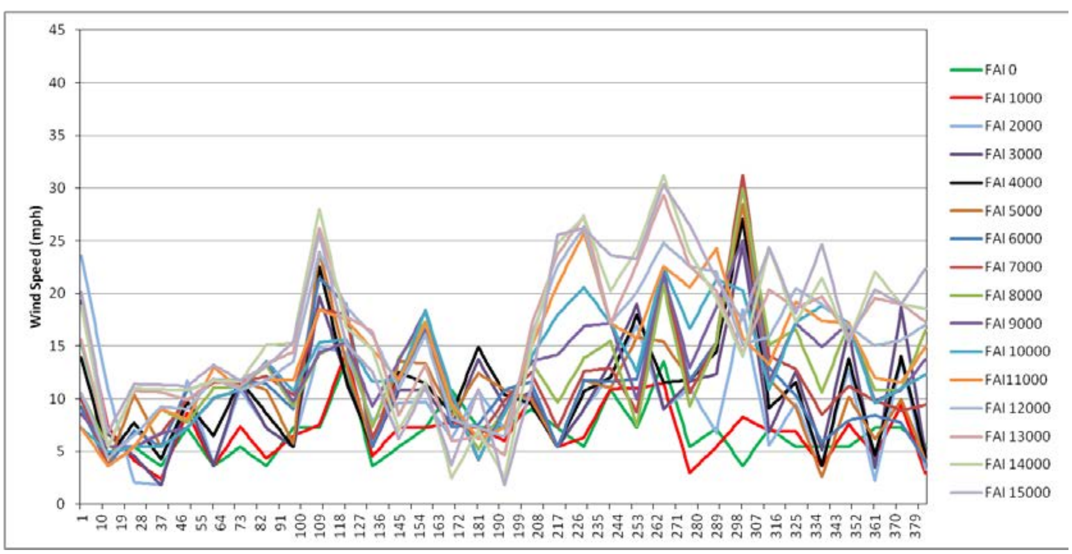


Figure 12.28. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.785 applied to represent anemometer level wind speeds for June 3-17, 1971.

12.3.6 June 7-22, 1972 Meteorological Time Series

Temperature lapse rates were estimated using observed surface temperature data for stations in and around the Susitna-Watana basin. Lapse rates were derived each hour using observed surface data at two locations. Station based lapse rates were calculated between: i) Talkeetna and Summit, ii) Anchorage and Gulkana, iii) Ft Greeley and Summit, and iv) Ft Greeley and Fairbanks. The hourly lapse rates were used to calculate an average lapse rate for the entire calibration period and an average lapse rate based on when rain was occurring during the calibration event (Table 12.12).

Station data were also used to derive an average station based lapse rate for each hour of the storm event. The stations used for this analysis were PANC, Anchorage, Fairbanks, Ft Greeley, Gulkana, Summit, and Talkeetna. The station average lapse rate was derived using linear regression between temperature and elevation. Based on the hourly station data linear relationship, a lapse rate (regression slope) was calculated for each hour of the analysis period. The average of the station based lapse rates (based on linear regression) was compared to individual station (station 1 @ X elevation compared to station 2 @ X elevation) based lapse rates discussed above (Table 12.12).

Vertical temperature at 1,000-foot increments from 0 - 6,000-ft were derived base on temperature data from the Fairbanks radiosonde. The Fairbanks radiosonde lapse rate data were used to calculate an average lapse rate for the entire calibration period (Table 12.12).

Table 12.12. Station based and radiosonde based lapse rates for June 7-22, 1972.

Station Comparisons	Hourly Average	Hourly Rainfall Average	FAI Radiosonde
Talkeetna vs. Summit	-3.20	-2.16	-
Anchorage vs. Gulkana	1.06	0.84	-
Ft Greely vs. Summit	-5.19	-6.53	-
Ft Greely vs. Fairbanks	-1.36	-2.13	-
All Stations	-1.65	-1.30	-
Average*	-2.85	-3.03	-3.52

* Comparison excludes Anchorage vs. Gulkana lapse rate

The radiosonde wind speed represents free atmospheric winds, unobstructed flow, the free-air data were adjusted to surface wind speeds elevations based on comparisons of anemometer level wind speeds with concurrent free-air wind speeds. Surface wind speeds were compared at six locations with varying elevations across the Susitna River basin to the Fairbanks free-air wind speeds (Table 12.13). The average free-air adjustment for the six stations was 0.887 with a maximum of 0.979 and a minimum of 0.748. In order to convert free-air wind speed data to anemometer level wind speeds the adjustment/ratio is applied to the free-air data. For example, at 1,000-ft elevation free-air wind speed is 45-mph would be 30-mph at the anemometer level (45-mph * 0.887 = 39.9-mph). The radiosonde data are measured every 12-hours (0-UTC and 12-UTC), the 12-hour data were interpolated to hourly data using the bounding hourly data and a linear relationship.

Table 12.13. Fairbanks radiosonde free-air wind speed conversion ratio to anemometer height wind speed for June 7-22, 1972.

Station	Elevation (ft)	FAI Radiosonde Ratio
Gulkana	1500	0.979
Summit	2500	0.914
Talkeetna	500	0.886
Anchorage	0	0.929
Ft Greely	1500	0.748
Fairbanks	500	0.868
	Average	*0.887*
	Maximum	0.979
	Minimum	0.748

The final temperature and dew point temperature series were based on surface data at Summit, Alaska with a base elevation of 2,400-ft (Figure 12.29). The Summit station data were selected because it was in close proximity to the Susitna River basin and provided a complete and representative profile of temperature and dew point temperature. The lapse rate used to adjust temperature and dew point temperature to other elevations was -2.85°F. The -2.85°F lapse rate was based on the average of all station comparison except the Anchorage and Gulkana comparison. The final vertical wind speed data were based on Fairbanks free-air wind speeds with an adjustment ratio of 0.887 applied to represent anemometer level wind speeds (Figure 12.30).

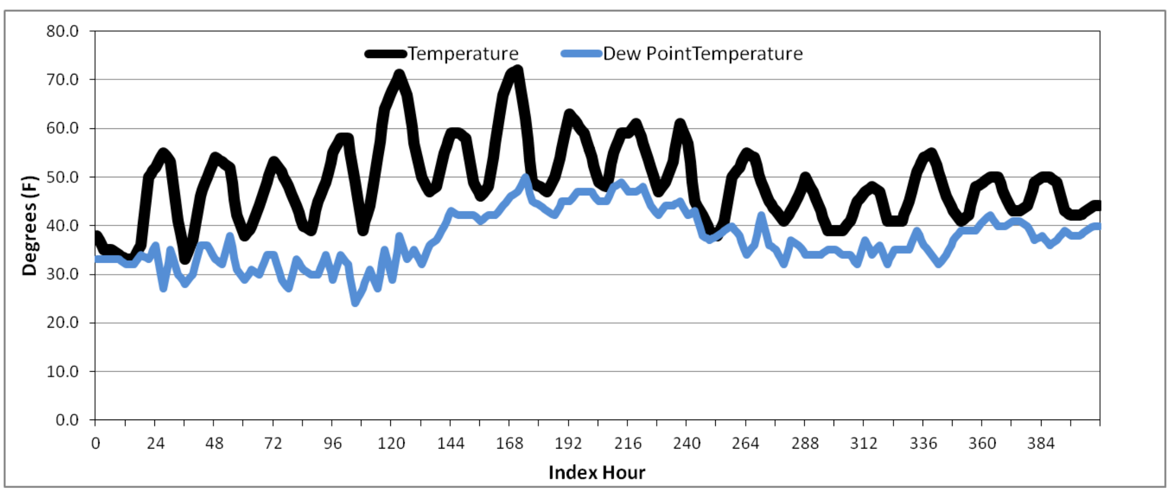


Figure 12.29. Temperature and dew point temperature series based on surface data at Summit, Alaska with a base elevation of 2,400-ft and lapse rate of -2.85°F for June 7-22, 1972.

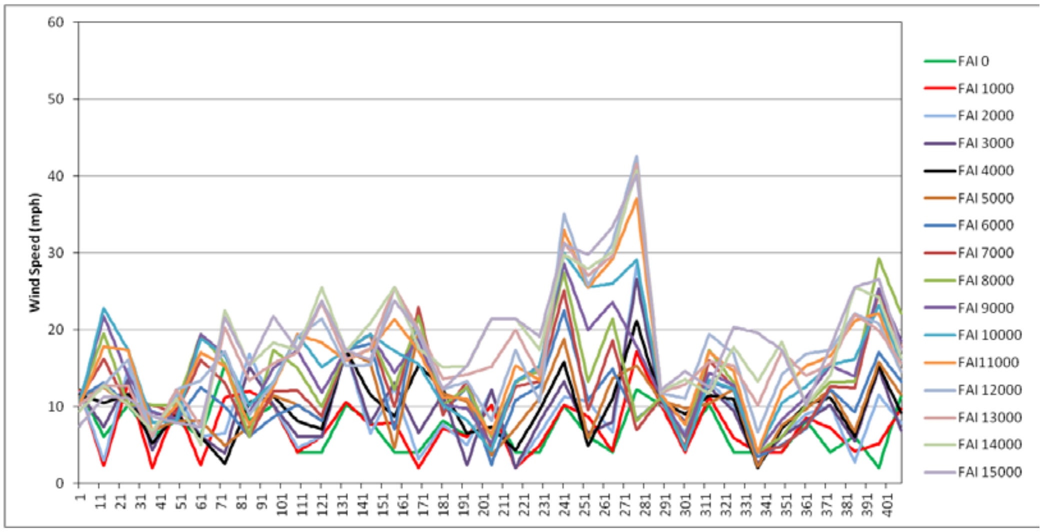


Figure 12.30. Wind speed data based on Fairbanks free-air wind speeds with an adjustment ratio of 0.887 applied to represent anemometer level wind speeds for June 7-22, 1972.

GLOSSARY

Adiabat: Curve of thermodynamic change taking place without addition or subtraction of heat. On an adiabatic chart or pseudo-adiabatic diagram, a line showing pressure and temperature changes undergone by air rising or condensation of its water vapor; a line, thus, of constant potential temperature.

Adiabatic: Referring to the process described by adiabat.

Advection: The process of transfer (of an air mass property) by virtue of motion. In particular cases, advection may be confined to either the horizontal or vertical components of the motion. However, the term is often used to signify horizontal transfer only.

Air mass: Extensive body of air approximating horizontal homogeneity, identified as to source region and subsequent modifications.

Barrier: A mountain range that partially blocks the flow of warm humid air from a source of moisture to the basin under study.

Basin centroid: The point at the exact center of the drainage basin as determined through geographical information systems calculations using the basin outline.

Cold front: Front where relatively colder air displaces warmer air.

Convergence: Horizontal shrinking and vertical stretching of a volume of air, accompanied by net inflow horizontally and internal upward motion.

Cyclone: A distribution of atmospheric pressure in which there is a low central pressure relative to the surroundings. On large-scale weather charts, cyclones are characterized by a system of closed constant pressure lines (isobars), generally approximately circular or oval in form, enclosing a central low-pressure area. Cyclonic circulation is counterclockwise in the northern hemisphere and clockwise in the southern. (That is, the sense of rotation about the local vertical is the same as that of the earth's rotation.)

dBZ: It is a meteorological measure of equivalent reflectivity (Z) of a radar signal reflected off a remote object. The reference level for Z is 1 $mm^6\ m^{-3}$, which is equal to 1 μm^3. It is related to the number of drops per unit volume and the sixth power of drop diameter.

Depth-Area curve: Curve showing, for a given duration, the relation of maximum average depth to size of area within a storm or storms.

Depth-Area-Duration: The precipitation values derived from Depth-Area and Depth-Duration curves at each time and area size increment analyzed for a PMP evaluation.

Depth-Area-Duration values: The combination of depth-area and duration-depth relations. Also called depth-duration-area.

Decimal Degrees: Latitude and longitude geographic coordinates as decimal fractions and are used in many Geographic Information Systems (GIS). Decimal degrees are an alternative to using degrees, minutes, and seconds. As with latitude and longitude, the values are bounded by ±90° and ±180° each. Positive latitudes are north of the equator, negative latitudes are south of the equator. Positive longitudes are east of Prime Meridian, negative longitudes are west of the Prime Meridian. Latitude and longitude are usually expressed in that sequence, latitude before longitude.

Depth-Duration curve: Curve showing, for a given area size, the relation of maximum average depth of precipitation to duration periods within a storm or storms.

Dew point: The temperature to which a given parcel of air must be cooled at constant pressure and constant water vapor content for saturation to occur.

Envelopment: A process for selecting the largest value from any set of data. In estimating PMP, the maximum and transposed rainfall data are plotted on graph paper, and a smooth curve is drawn through the largest values.

Front: The interface or transition zone between two air masses of different parameters. The parameters describing the air masses are temperature and dew point.

General storm: A storm event, that produces precipitation over areas in excess of 500-square miles, has a duration longer than 6 hours, and is associated with a major synoptic weather feature.

HYSPLIT: HYbrid Single-Particle Lagrangian Integrated Trajectory. A complete system for computing parcel trajectories to complex dispersion and deposition simulations using either puff or particle approaches. Gridded meteorological data, on one of three conformal (Polar, Lambert, or Mercator latitude-longitude grid) map projections, are required at regular time intervals. Calculations may be performed sequentially or concurrently on multiple meteorological grids, usually specified from fine to coarse resolution.

In-Place Maximization Factor: The adjustment factor representing the maximum amount of atmospheric moisture that could have been present to the storm for rainfall production

Isohyets: Lines of equal value of precipitation for a given time interval.

Isohyetal Pattern: The pattern formed by the isohyets of an individual storm.

Jet Stream: A strong, narrow current concentrated along a quasi-horizontal axis (with respect to the earth's surface) in the upper troposphere or in the lower stratosphere, characterized by strong vertical and lateral wind shears. Along this axis it features at least one velocity maximum (jet streak). Typical jet streams are thousands of kilometers long, hundreds of kilometers wide, and several kilometers deep. Vertical wind shears are on the order of 10 to 20 mph per kilometer of altitude and lateral winds shears are on the order of 10 mph per 100 kilometer of horizontal distance.

Mass curve: Curve of cumulative values of precipitation through time.

Mid-latitude frontal system: An assemblage of fronts as they appear on a synoptic chart north of the tropics and south of the polar latitudes. This term is used for a continuous front and its characteristics along its entire extent, its variations of intensity, and any frontal cyclones along it.

Moisture Transposition Factor: The adjustment factor which accounts for the difference in available moisture between the location where the storm occurred and the Susitna River basin

Observational day: The 24-hour time period between daily observation times for two consecutive days at cooperative stations, e.g., 6:00PM to 6:00PM.

One-hundred year rainfall event: The point rainfall amount that has a one-percent probability of occurrence in any year. Also referred to as the rainfall amount that on the average occurs once in a hundred years or has a 1 percent chance of occurring in any single year.

Orographic Rainfall: Rainfall enhancement resulting mainly from the forced lifting of moisture-laden air masses by elevated terrain, when combined with unstable atmospheric conditions often results in heavy (high intensity, long duration) rainfall at rates higher than what would be experienced if the elevated terrain were not present.

Orographic Transposition Factor: A factor obtained from the results of the proportionality constant calculation which compares the 24-hour precipitation frequency characteristics between the storm target and source locations

Polar front: A semi-permanent, semi-continuous front that separates tropical air masses from polar air masses.

Precipitable water: The total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between any two specified levels in the atmosphere; commonly expressed in terms of the height to which the liquid water would stand if the vapor were completely condensed and collected in a vessel of the same unit cross-section. The total precipitable water in the atmosphere at a location is that contained in a column or unit cross-section extending from the earth's surface all the way to the "top" of the atmosphere. The 30,000 foot level (approximately 300mb) is considered the top of the atmosphere in this study.

Persisting dew point: The dew point value at a station that has been equaled or exceeded throughout a specific period of time. Commonly durations of 12 or 24 hours are used, though other durations may be used at times.

Probable Maximum Precipitation (PMP): Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographic location at a certain time of the year.

Pseudo-adiabat: Line on thermodynamic diagram showing the pressure and temperature changes undergone by saturated air rising in the atmosphere, without ice-crystal formation and without exchange of heat with its environment, other than that involved in removal of any liquid water formed by condensation.

Pseudo-adiabatic: Referring to the process described by the pseudo-adiabat.

Rainshadow: The region, on the lee side of a mountain or mountain range, where the precipitation is noticeably less than on the windward side.

PMP storm pattern: The isohyetal pattern that encloses the PMP area, plus the isohyets of residual precipitation outside the PMP portion of the pattern.

Saturation: Upper limit of water-vapor content in a given space; solely a function of temperature.

Short list of storms: The short list of storms is the final list of storms used to derive the site-specific PMP values for the basin. The list represents the most extreme historic storms of record that are considered to be PMP-type storm events.

Spatial distribution: The geographic distribution of precipitation over a drainage according to an idealized storm pattern of the PMP for the storm area.

Storm maximization: The process of adjusting observed precipitation amounts upward based upon the hypothesis of increased moisture inflow to the storm. (Also referred to as "moisture maximization" in HMR 57.)

Storm transposition: The hypothetical transfer, or relocation of storms, from the location where they occurred to other areas where they could occur. The transfer and the mathematical adjustment of storm rainfall amounts from the storm site to another location is termed "explicit transposition." The areal, durational, and regional smoothing done to obtain comprehensive individual drainage estimates and generalized PMP studies is termed "implicit transposition" (WMO, 1986).

Synoptic: Showing the distribution of meteorological elements over an area at a given time, e.g., a synoptic chart. Use in this report also means a weather system that is large enough to be a major feature on large-scale maps (e.g., of the continental U.S.).

Temporal distribution: The time order in which incremental PMP amounts are arranged within a PMP storm.

Tropical Storm: A cyclone of tropical origin that derives its energy from the ocean surface.

Transposition limits: The outer boundaries of the region surrounding an actual storm location that has similar, but not identical, climatic and topographic characteristics throughout. The storm can be transpositioned within the transposition limits with only relatively minor modifications to the observed storm rainfall amounts.

ACRONYMS AND ABBREVIATIONS USED IN THIS REPORT

ALERT: Automated Local Evaluation in Real Time

AWA: Applied Weather Associates, LLC

DA: Depth-Area

DAD: Depth-Area-Duration

.dbf: Database file extension

DD: Depth-Duration

dd: decimal degrees

DEM: Digital elevation model

DND: drop number distribution

DSD: drop size distribution

EPRI: Electric Power Research Institute

F: Fahrenheit

FERC: Federal Energy Regulatory Commission

ft: feet

GIS: Geographical Information System

GRASS: Geographic Resource Analysis Support System

HMR: Hydrometeorological Report

HYSPLIT: Hybrid Single Particle Lagrangian Integrated Trajectory Model

IPMF: In-Place Maximization Factor

mb: millibar

mph: Mile per hour

MTF: Moisture Transposition Factor

NCAR: National Center for Atmospheric Research

NCDC: National Climatic Data Center

NCEP: National Centers for Environmental Prediction

NESDIS: National Environmental Satellite, Data, and Information Service

NEXRAD: National Weather Service 88-D Next Generation Radar

NOAA: National Oceanic and Atmospheric Administration

NWS: National Weather Service

PMF: Probable Maximum Flood

OTF: Orographic Transposition Factor

PMP: Probable Maximum Precipitation

PW: Precipitable water

QC: Quality control

R: Rainfall rate

RAWS: Remote Automated Weather Station

SNOTEL: Snow Telemetry station

SPAS: Storm Precipitation and Analysis System

SPP: Storm Precipitation Period

SSPMP: Site-specific Probable Maximum Precipitation

SST: Sea Surface Temperature

USACE: US Army Corps of Engineers

USGS: United States Geological Survey

WMO: World Meteorological Organization

Z: Radar reflectivity, measured in units of dBZ

REFERENCES

American Meteorological Society, 1996: *Glossary of Weather and Climate*, Boston, Ma., 272 pp.

Bao, J.W., S.A. Michelson, P.J. Neiman, F.M. Ralph, and J.M. Wilczak, 2006: Interpretation of Enhanced Integrated Water Vapor Bands Associated with Extratropical Cyclones: Their Formation and Connection to Tropical Moisture. *Mon. Wea. Rev.*, **134**, 1063–1080.

Bolsenga, S.J., 1965: The Relationship between Total Atmospheric Water Vapor and Surface Dewpoint on a Mean Daily and Hourly Basis, *J. Appl. Meteor.*, **4**, 430–432.

Bonnin, G.M., Todd, D., Lin, B., Parzybok, T., Yekta, M., and D. Riley, 2011: Precipitation-Frequency Atlas of the United States, NOAA Atlas 14, Volumes 1 through 6, NOAA, National Weather Service, Silver Spring, Maryland. http://hdsc.nws.noaa.gov/hdsc/pfds/.

Corps of Engineers, U.S. Army, 1945-1973: Storm Rainfall in the United States, Depth-Area-Duration Data. Office of Chief of Engineers, Washington, D.C.

Corrigan, P., D.D. Fenn, D.R. Kluck, and J.L. Vogel, 1999: Probable Maximum Precipitation for California, *Hydrometeorological Report Number 59*, National Weather Service, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, Silver Spring, Md, 392 pp.

Daly, C., R.P. Neilson, and D.L. Phillips, 1994: A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountainous Terrain. *J. Appl. Meteor.*, **33**, 140–158.

Daly, C., G. Taylor, and W. Gibson, 1997: The PRISM Approach to Mapping Precipitation and Temperature, 10th Conf. on Applied Climatology, Reno, NV, Amer. Meteor. Soc., 10-12.

Draxler, R.R. and Rolph, G.D., 2003: HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website (http://www.arl.noaa.gov/ready/hysplit4.html). NOAA Air Resources Laboratory, Silver Spring, MD.

Draxler, R.R. and Rolph, G.D., 2010. HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website (http://ready.arl.noaa.gov/HYSPLIT.php). NOAA Air Resources Laboratory, Silver Spring, MD.

Duchon, C.E., and G.R. Essenberg, 2001: Comparative Rainfall Observations from Pit and Above Ground Rain Gauges with and without Wind Shields, *Water Resources Research*, Vol. 37, N. 12, 3253-3263.

Environmental Data Service, 1968: Maximum 12-hour 1000-mb persisting Dew Points Monthly and of Record. *Climatic Atlas of the United States*, Environmental Science Services Administration, U.S. Department of Commerce, Washington D.C., pp. 59-60.

GRASS (Geographic Resources Analysis Support System) GIS is an open source, free software GIS with raster, topological vector, image processing, and graphics production functionality that operates on various platforms. http://grass.itc.it/.

Gou, J. C. Y., Urbonas, Ben, and Stewart, Kevin, 2001. *Rain Catch under Wind and Vegetal Effects*. ASCE, Journal of Hydrologic Engineering, Vol. 6, No. 1.

Hansen, E.M., L.C. Schreiner and J.F. Miller, 1982: Application of Probable Maximum Precipitation Estimates – United States East of the 105th Meridian. *Hydrometeorological Report No. 52*, U.S. Department of Commerce, Washington, D.C., 168 pp.

———, F.K. Schwarz, and J.T Reidel, 1977: Probable Maximum Precipitation Estimates. Colorado River and Great Basin Drainages. *Hydrometeorological Report No. 49*, NWS, NOAA, U.S. Department of Commerce, Silver Spring, MD, 161 pp.

———, D.D. Fenn, L.C. Schreiner, R.W. Stodt, and J.F. Miller, 1988: Probable Maximum Precipitation Estimates – United States Between the Continental Divide and the 103rd Meridian. *Hydrometeorological Report No. 55A*, U.S. Department of Commerce, Silver Spring, MD, 242 pp.

———, D.D. Fenn, P. Corrigan, J.L. Vogel, L.C. Schreiner, and R.W. Stodt, 1994: Probable Maximum Precipitation-Pacific Northwest States, *Hydrometeorological Report Number 57*, National Weather Service, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, Silver Spring, MD, 338 pp.

Hershfield, D.M., 1961: Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years, *Technical Paper No. 40*, U. S. Weather Bureau, Washington, D.C., 61p.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, A. Leetmaa, R. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. Mo, C. Ropelewski, J. Wang, R. Jenne, and D. Joseph, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.*, **77**, 437–471.

Kent E.C, Scott D. Woodruff, and David I. Berry, 2007: Metadata from WMO Publication No. 47 and an Assessment of Voluntary Observing Ship Observation Heights in ICOADS. *J. Atmos and Ocean Tech.*, **24(2)**, 214-234.

Martner, B.E, and V. Dubovskiy, 2005: Z-R Relations from Raindrop Disdrometers: Sensitivity to Regression Methods and DSD Data Refinements. 32nd Radar Meteorology Conference, Albuquerque, NM, October, 2005.

Mesinger, F., G. DiMego, E. Kalnay, K. Mitchell, P.C. Shafran, W. Ebisuzaki, D. Jović, J. Woollen, E. Rogers, E.H. Berbery, M.B. Ek, Y. Fan, R. Grumbine, W. Higgins, H. Li, Y. Lin, G. Manikin, D. Parrish, and W. Shi, 2006: North American Regional Reanalysis. *Bull. Amer. Meteor. Soc.*, **87**, 343–360.

Miller, J.F., R.H. Fredrick, and R.J. Tracey, 1973: *NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States.* U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, MD.

National Climatic Data Center (NCDC). NCDC TD-3200 and TD-3206 datasets - Cooperative Summary of the Day.

National Climatic Data Center (NCDC) Heavy Precipitation Page http://www.ncdc.noaa.gov/oa/climate/severeweather/rainfall.html#maps.

National Oceanic and Atmospheric Administration, Forecast Systems Laboratory FSL Hourly/Daily Rain Data, http://precip.fsl.noaa.gov/hourly_precip.html.

National Oceanic and Atmospheric Administration Central Library Data Imaging Project *Daily weather maps*, http://docs.lib.noaa.gov/rescue/dwm/data_rescue_daily_weather_maps.html.

Neiman, P.J., F.M. Ralph, R.L. Weber, T. Uttal, L.B. Nance, and D.H. Levinson, 2001: Observations of Nonclassical Frontal Propagation and Frontally Forced Gravity Waves Adjacent to Steep Topography. *Mon. Wea. Rev.*, **129**, 2633–2659.

———, P.J., F.M. Ralph, G.A. Wick, Y.H. Kuo, T.K. Wee, Z. Ma, G.H. Taylor, and M.D. Dettinger, 2008: Diagnosis of an Intense Atmospheric River Impacting the Pacific Northwest: Storm Summary and Offshore Vertical Structure Observed with COSMIC Satellite Retrievals. *Mon. Wea. Rev.*, **136**, 4398–4420.

———, P.J., F.M. Ralph, G.A. Wick, J.D. Lundquist, and M.D. Dettinger, 2008: Meteorological Characteristics and Overland Precipitation Impacts of Atmospheric Rivers Affecting the West Coast of North America Based on Eight Years of SSM/I Satellite Observations. *J. Hydrometeor.*, **9**, 22–47.

———, P.J., L.J. Schick, F.M. Ralph, M. Hughes, and G.A. Wick, *2011: Flooding in Western Washington: The Connection to Atmospheric River*. Presented at the 25th Conference of Hydrology at the American Meteorological Society annual meeting, Seattle, WA.

Parzybok, T.W., and E.M. Tomlinson, 2006: A New System for Analyzing Precipitation from Storms, *Hydro Review*, Vol. XXV, No. 3, 58-65.

Ralph, F.M., P.J. Neiman, D.E. Kingsmill, P.O.G. Persson, A.B. White, E.T. Strem, E.D. Andrews, and R.C. Antweiler, 2003: The Impact of a Prominent Rain Shadow on Flooding in California's Santa Cruz Mountains: A CALJET Case Study and Sensitivity to the ENSO Cycle. *J. Hydrometeor.*, **4**, 1243–1264.

———, F.M., P.J. Neiman, and G.A. Wick, 2004: Satellite and CALJET Aircraft Observations of Atmospheric Rivers over the Eastern North Pacific Ocean during the Winter of 1997/98. *Mon. Wea. Rev.*, **132**, 1721–1745.

———, F.M., P.J. Neiman, and R. Rotunno, 2005: Dropsonde Observations in Low-Level Jets over the Northeastern Pacific Ocean from CALJET-1998 and PACJET-2001: Mean Vertical-Profile and Atmospheric-River Characteristics. *Mon. Wea. Rev.*, **133**, 889–910.

———, F.M., P.J. Neiman, and R. Rotunno, 2005: Dropsonde Observations in Low-Level Jets over the Northeastern Pacific Ocean from CALJET-1998 and PACJET-2001: Mean Vertical-Profile and Atmospheric-River Characteristics. *Mon. Wea. Rev.*, **133**, 889–910.

———, F.M., P.J. Neiman, G.A. Wick, S.I. Gutman, M.D. Dettinger, D.R. Cayan, and A.B. White, 2006: Flooding on California's Russian River: The role of atmospheric rivers. *Geophys. Res. Lett.*, **33**, L13801.

———, F. M., P. J. Neiman, G. N. Kiladis, K. Weickmann, and D. W. Reynolds, 2011: A Multiscale Observational Case Study of a Pacific Atmospheric River Exhibiting Tropical–Extratropical Connections and a Mesoscale Frontal Wave. *Mon. Wea. Rev.*, **139**, 1169–1189.

Remote Automated Weather Stations RAWS, http://www.raws.dri.edu/index.html.

Reynolds, R.W., T.M. Smith, C. Liu, D.B. Chelton, K.S. Casey, and M.G. Schlax, 2007: Daily High-resolution Blended Analysis for Sea Surface Temperature. *J. Climate.*, **20**, 5473-5496.

Riedel, J.T., and L.C. Schreiner, 1980: Comparison of Generalized Estimates of Probable Maximum Precipitation with Greatest Observed Rainfalls, *NOAA Technical Report NWS 25*, U.S. Department of Commerce, NOAA, Silver Spring, Md, 46 pp.

Rolph, G.D., 2003: Real-time Environmental Applications and Display sYstem (READY) Website http://www.arl.noaa.gov/ready/hysplit4.html. NOAA Air Resources Laboratory, Silver Spring, MD.

Rolph, G.D., 2010. Real-time Environmental Applications and Display sYstem (READY) Website http://ready.arl.noaa.gov. NOAA Air Resources Laboratory, Silver Spring, MD.

Schreiner, L.C., and J.T. Riedel, 1978: Probable Maximum Precipitation Estimates, United States East of the 105th Meridian. *Hydrometeorological Report No. 51*, U.S. Department of Commerce, Silver Spring, MD, 242pp.

Smith, C.D., 1950: The Intense Pacific Coast Storms of October 26-28, 1950, *Monthly Weather Review*, 191-195.

Spatial Climate Analysis Service, Oregon Climate Service, Oregon State University. http://www.ocs.orst.edu/prism/.

Tomlinson, E.M., 1993: Probable Maximum Precipitation Study for Michigan and Wisconsin, Electric Power Research Institute, Palo Alto, Ca, TR-101554, V1.

———, Williams, R.A., and T.W. Parzybok, September 2002: Site-Specific Probable Maximum Precipitation (PMP) Study for the Upper and Middle Dams Drainage Basin, Prepared for FPLE, Lewiston, ME.

———, Williams, R.A., and T.W. Parzybok, September 2003: Site-Specific Probable Maximum Precipitation (PMP) Study for the Great Sacandaga Lake / Stewarts Bridge Drainage Basin, Prepared for Reliant Energy Corporation, Liverpool, New York.

———, Williams, R.A., and T.W. Parzybok, September 2003: Site-Specific Probable Maximum Precipitation (PMP) Study for the Cherry Creek Drainage Basin, Prepared for the Colorado Water Conservation Board, Denver, CO.

———, Kappel W.D., Parzybok, T.W., Hultstrand, D., Muhlestein, G., and B. Rappolt, May 2008: Site-Specific Probable Maximum Precipitation (PMP) Study for the Wanahoo Drainage Basin, Prepared for Olsson Associates, Omaha, Nebraska.

———, Kappel W.D., Parzybok, T.W., Hultstrand, D., Muhlestein, G., and B. Rappolt, June 2008: Site-Specific Probable Maximum Precipitation (PMP) Study for the Blenheim Gilboa Drainage Basin, Prepared for New York Power Authority, White Plains, NY.

———, Kappel W.D., and T.W. Parzybok, February 2008: Site-Specific Probable Maximum Precipitation (PMP) Study for the Magma FRS Drainage Basin, Prepared for AMEC, Tucson, Arizona.

———, Kappel, W.D., and T.W. Parzybok, December 2008: Statewide Probable Maximum Precipitation (PMP) Study for the State of Nebraska.

———, Kappel, W.D., and T.W. Parzybok, February 2009: Site-Specific Probable Maximum Precipitation (PMP) Study for the Tuxedo Lake Drainage Basin, New York.

———, Kappel, W.D., and T.W. Parzybok, July 2009: Site-Specific Probable Maximum Precipitation (PMP) Study for the Scoggins Dam Drainage Basin, Oregon.

———, Kappel, W.D., and T.W. Parzybok, February 2010: Site-Specific Probable Maximum Precipitation (PMP) Study for the Magma FRS Drainage Basin, Arizona.

———, and W. D. Kappel, October 2009: Revisiting PMPs, *Hydro Review*, Vol. 28, No. 7, 10-17.

U.S. Weather Bureau, 1951: Tables of Precipitable Water and Other Factors for a Saturated Pseudo-Adiabatic Atmosphere. *Technical Paper No. 14*, U.S. Department of Commerce, Weather Bureau, Washington, D.C., 27 pp.

U.S. Weather Bureau, 1963, Rainfall Frequency Atlas of the United States, for Duration of 30 Minutes to 24 Hours and Return Periods of 1 to 100 Years, *Technical Paper Number 40*, U.S. Department of Commerce, Washington, DC, 65 pp.

Woodruff, S.D., H.F. Diaz, S.J. Worley, R.W. Reynolds, and S.J. Lubker, 2005: Early ship observational data and ICOADS. *Climatic Change*, 73, 169-194.

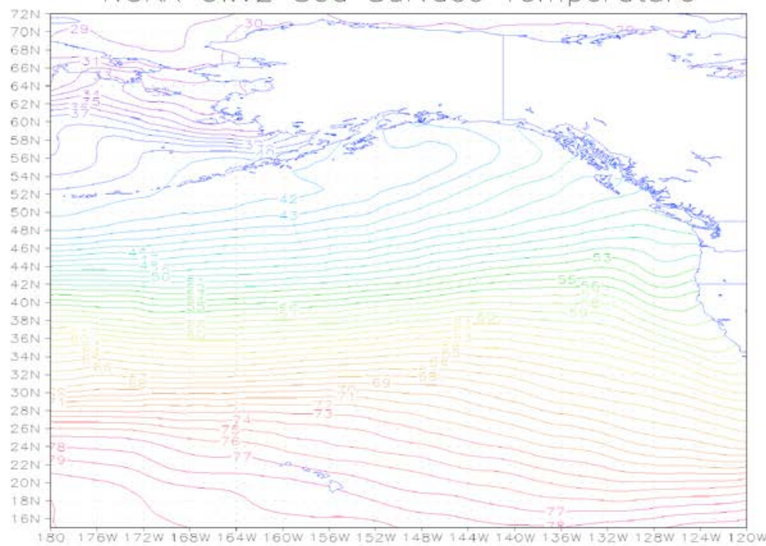
World Meteorological Organization, 2009: Manual for Estimation of Probable Maximum Precipitation, *Operational Hydrology Report No 1045*, WMO, Geneva, 259 pp.

Worley, S.J., S.D. Woodruff, R.W. Reynolds, S.J. Lubker, and N. Lott, 2005: ICOADS Release 2.1 data and products. *Int. J. Climatol. (CLIMAR-II Special Issue)*, 25, 823-842.

Appendix A

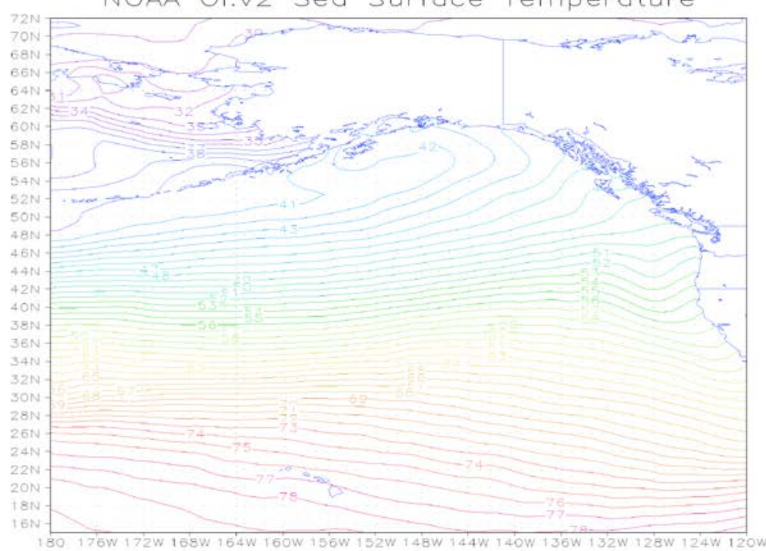
Sea Surface Temperatures Climatology Maps

+2 sigma (1982−2012) Jan SST (DegF)
NOAA OI.v2 Sea Surface Temperature



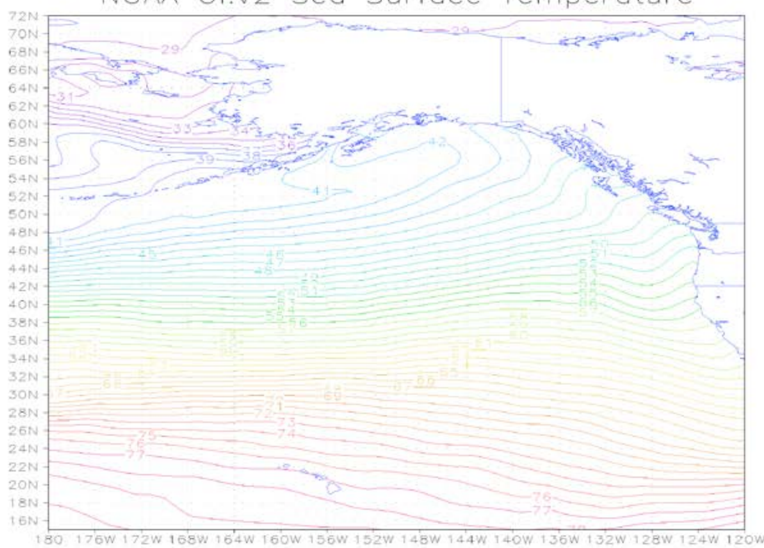
GrADS: COLA/IGES 2013−03−14−16:51

+2 sigma (1982−2012) Feb SST (DegF)
NOAA OI.v2 Sea Surface Temperature



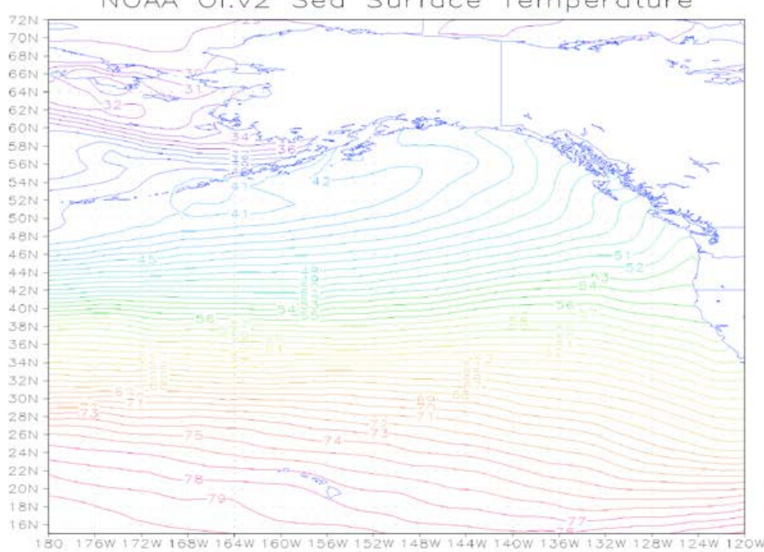
GrADS: COLA/IGES 2013−03−14−16:51

+2 sigma (1982−2012) Mar SST (DegF)
NOAA OI.v2 Sea Surface Temperature

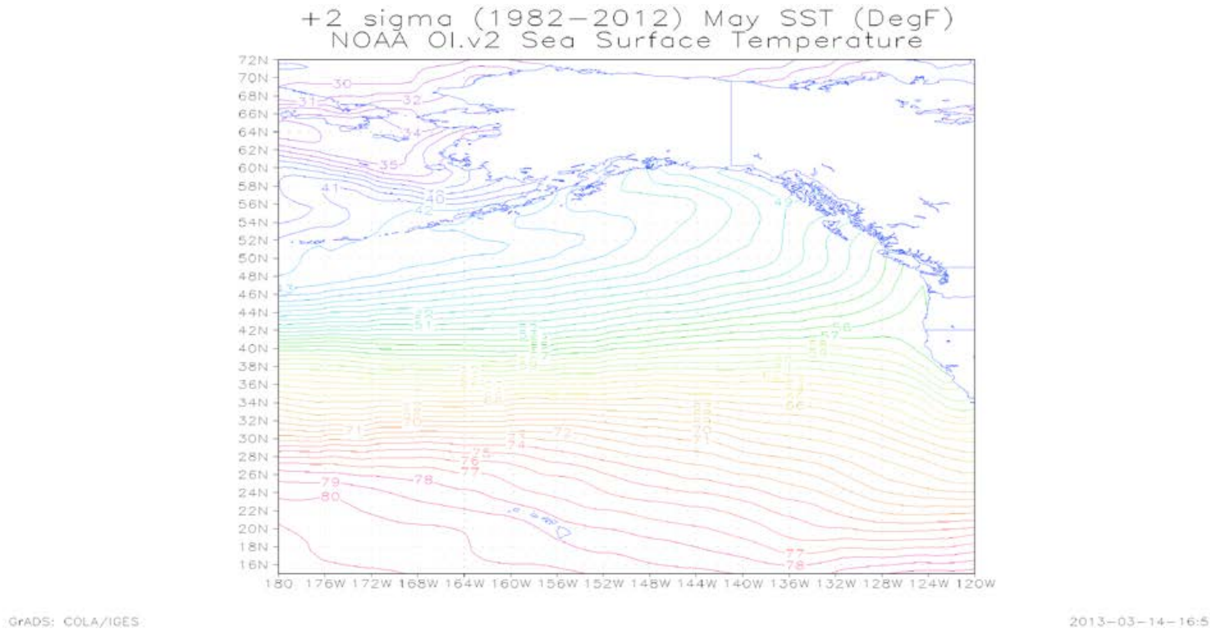


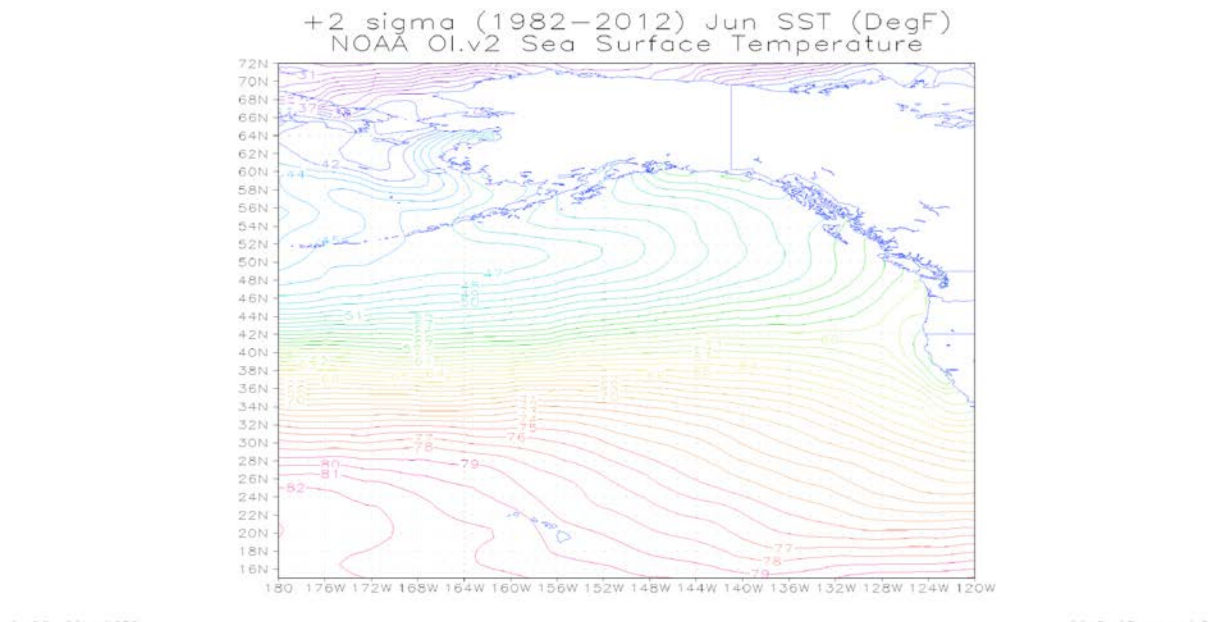
GrADS: COLA/IGES 2013−03−14−16:51

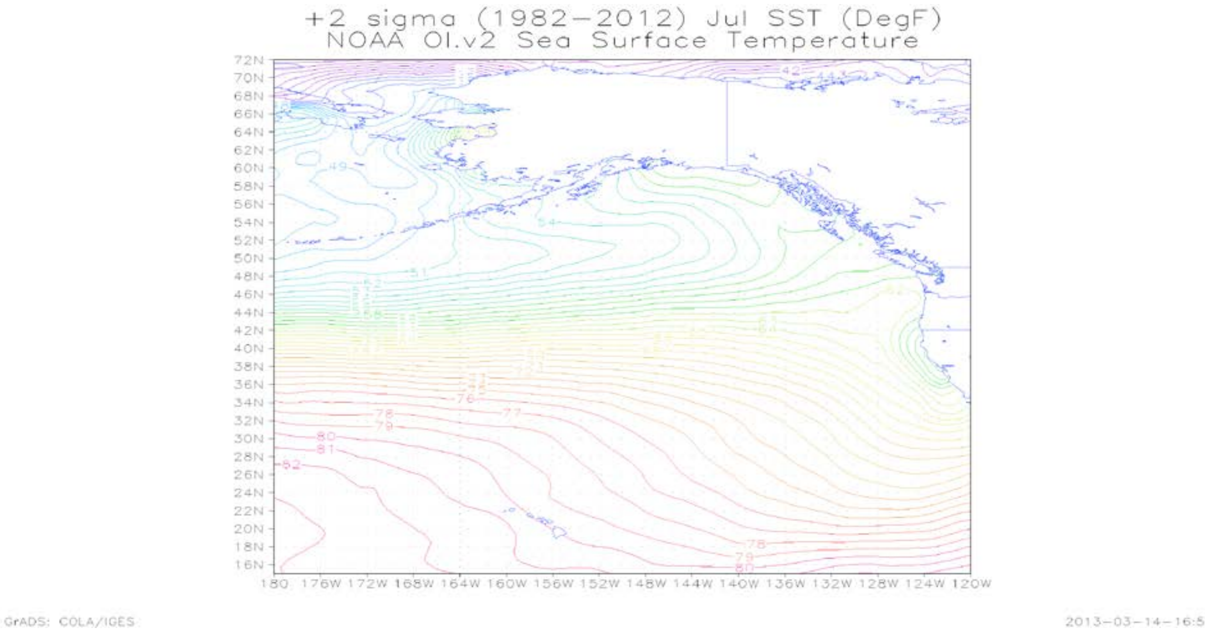
+2 sigma (1982−2012) Apr SST (DegF)
NOAA OI.v2 Sea Surface Temperature

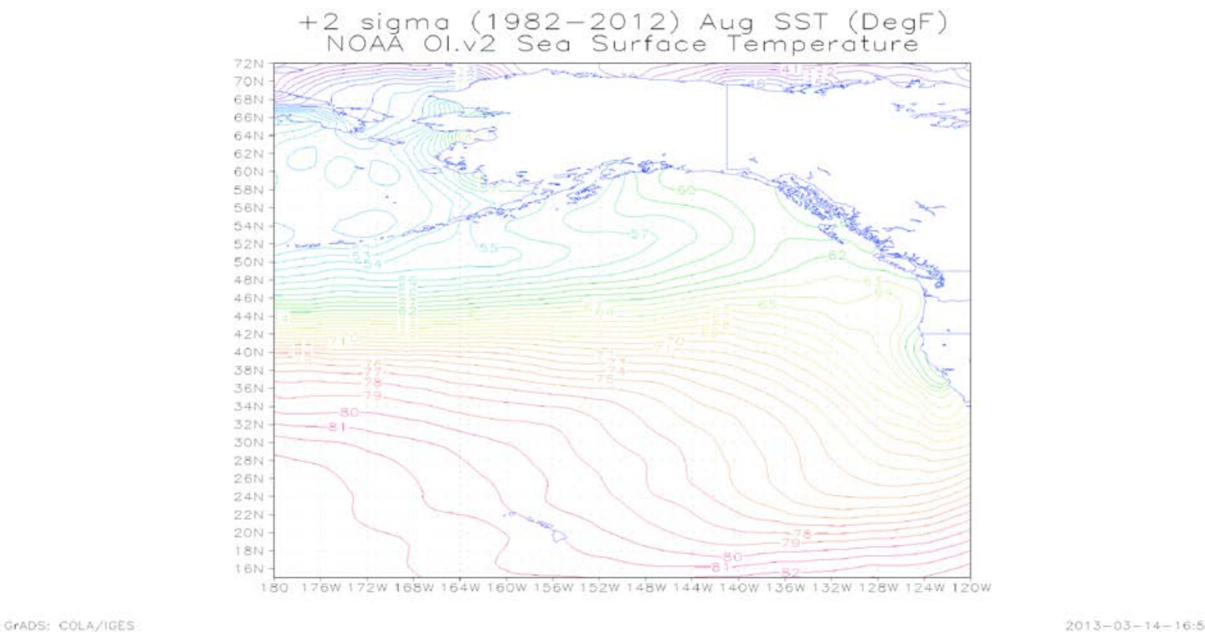


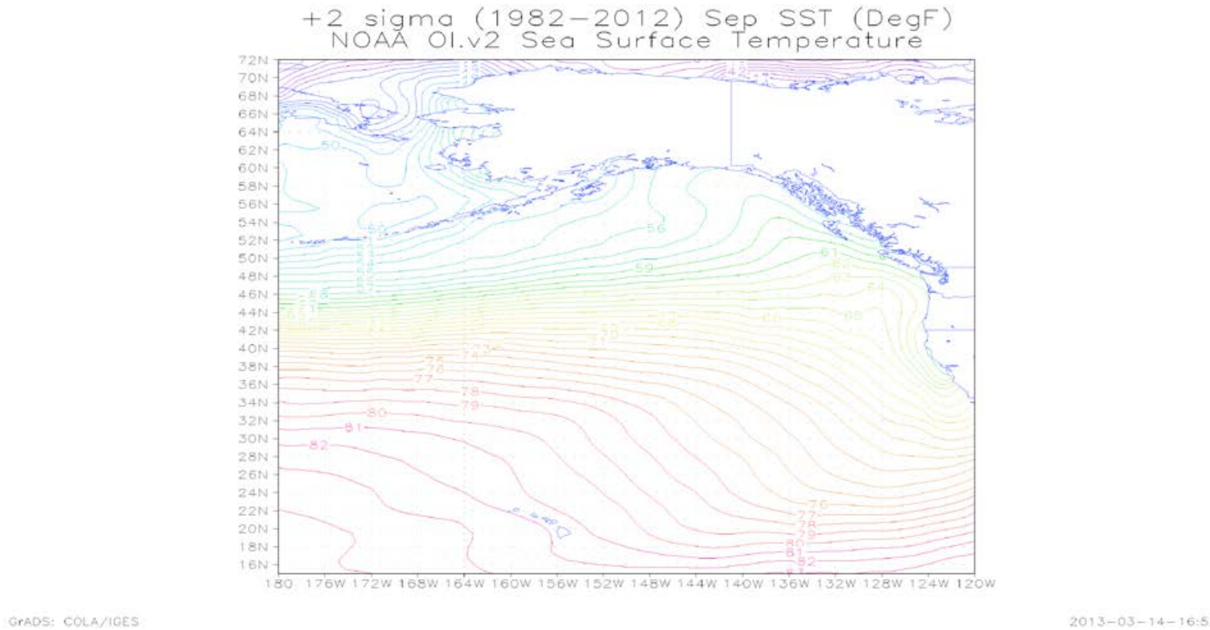
GrADS: COLA/IGES 2013−03−14−16:51

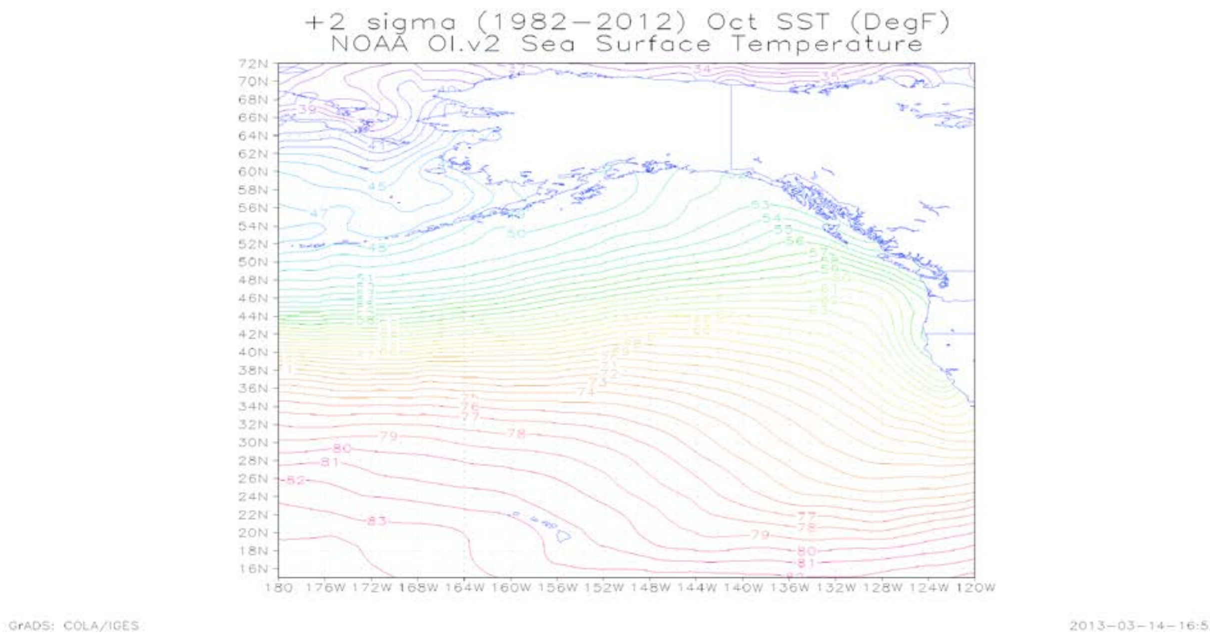

+2 sigma (1982–2012) May SST (DegF)
NOAA OI.v2 Sea Surface Temperature
72N 70N 68N 66N 64N 62N 60N 58N 56N 54N 52N 50N 48N 46N 44N 42N 40N 38N 36N 34N 32N 30N 28N 26N 24N 22N 20N 18N 16N
180 176W 172W 168W 164W 160W 156W 152W 148W 144W 140W 136W 132W 128W 124W 120W
GrADS: COLA/IGES
2013–03–14–16:51

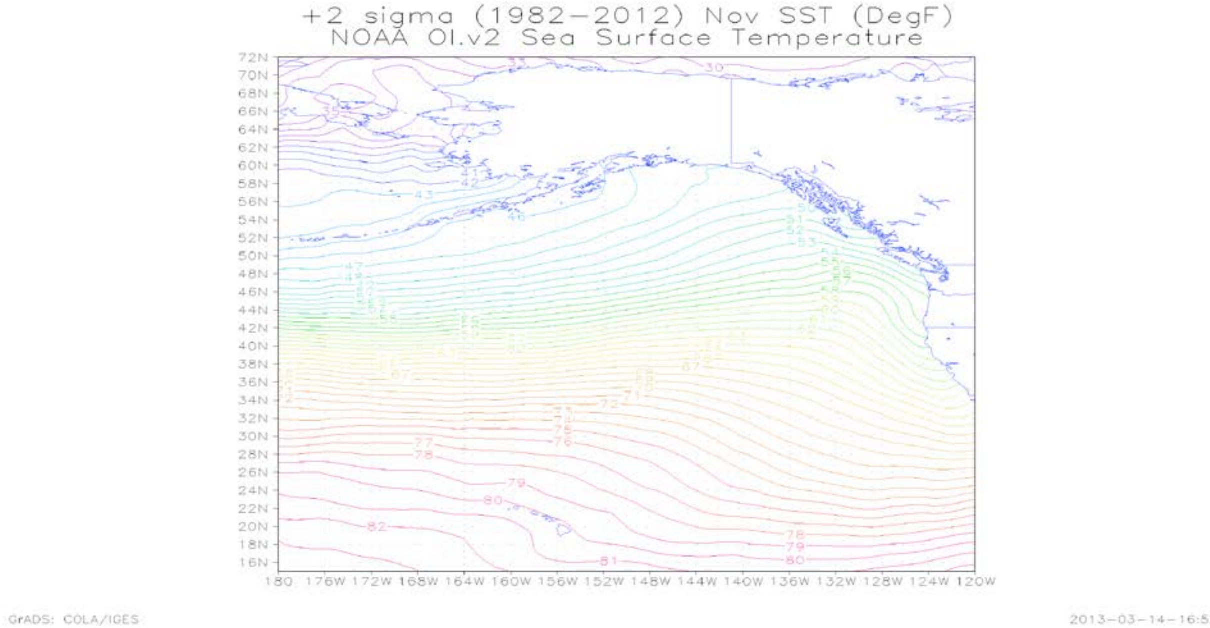

+2 sigma (1982–2012) Jun SST (DegF)
NOAA OI.v2 Sea Surface Temperature
72N 70N 68N 66N 64N 62N 60N 58N 56N 54N 52N 50N 48N 46N 44N 42N 40N 38N 36N 34N 32N 30N 28N 26N 24N 22N 20N 18N 16N
180 176W 172W 168W 164W 160W 156W 152W 148W 144W 140W 136W 132W 128W 124W 120W
GrADS: COLA/IGES
2013–03–14–16:52

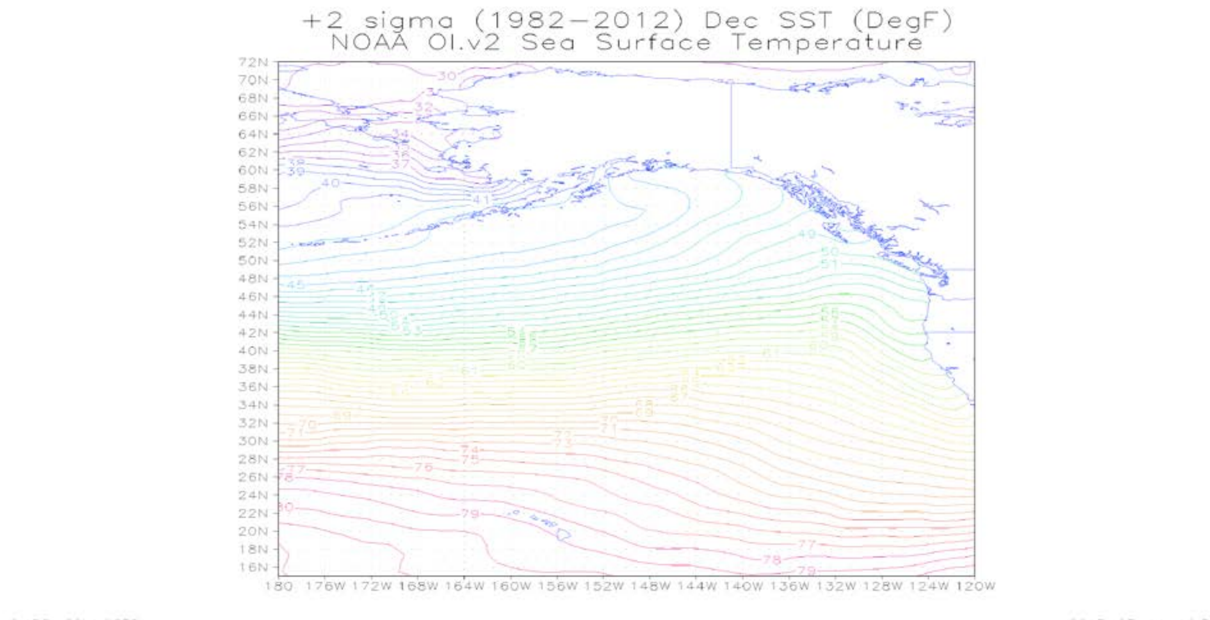

+2 sigma (1982-2012) Jul SST (DegF)
NOAA OI.v2 Sea Surface Temperature
72N 70N 68N 66N 64N 62N 60N 58N 56N 54N 52N 50N 48N 46N 44N 42N 40N 38N 36N 34N 32N 30N 28N 26N 24N 22N 20N 18N 16N
180 176W 172W 168W 164W 160W 156W 152W 148W 144W 140W 136W 132W 128W 124W 120W
GrADS: COLA/IGES
2013-03-14-16:52


+2 sigma (1982-2012) Aug SST (DegF)
NOAA OI.v2 Sea Surface Temperature
72N 70N 68N 66N 64N 62N 60N 58N 56N 54N 52N 50N 48N 46N 44N 42N 40N 38N 36N 34N 32N 30N 28N 26N 24N 22N 20N 18N 16N
180 176W 172W 168W 164W 160W 156W 152W 148W 144W 140W 136W 132W 128W 124W 120W
GrADS: COLA/IGES
2013-03-14-16:52


+2 sigma (1982−2012) Sep SST (DegF)
NOAA OI.v2 Sea Surface Temperature
72N 70N 68N 66N 64N 62N 60N 58N 56N 54N 52N 50N 48N 46N 44N 42N 40N 38N 36N 34N 32N 30N 28N 26N 24N 22N 20N 18N 16N
180 176W 172W 168W 164W 160W 156W 152W 148W 144W 140W 136W 132W 128W 124W 120W
GrADS: COLA/IGES
2013−03−14−16:52


+2 sigma (1982−2012) Oct SST (DegF)
NOAA OI.v2 Sea Surface Temperature
72N 70N 68N 66N 64N 62N 60N 58N 56N 54N 52N 50N 48N 46N 44N 42N 40N 38N 36N 34N 32N 30N 28N 26N 24N 22N 20N 18N 16N
180 176W 172W 168W 164W 160W 156W 152W 148W 144W 140W 136W 132W 128W 124W 120W
GrADS: COLA/IGES
2013−03−14−16:52


+2 sigma (1982–2012) Nov SST (DegF)
NOAA OI.v2 Sea Surface Temperature
GrADS: COLA/IGES
2013–03–14–16:52


+2 sigma (1982–2012) Dec SST (DegF)
NOAA OI.v2 Sea Surface Temperature
GrADS: COLA/IGES
2013–03–14–16:53

Appendix B

PYTHON Code for ArcGIS PMP Calculation Tool

```
‘‘‘ ---------------------------------------------------------------------------
Name: PMP_Calc.py
Version: 1.00
ArcGIS Version: ArcGIS Desktop 10.2 SP1 (2013)
Author: Applied Weather Associates
Usage:  The tool is designed to be executed within the ArcMap or ArcCatalog desktop environment.
Required Arguments:
- A basin outline polygon shapefile or feature class
- Directory location path of the “PMP_Evaluation_Tool” folder
- String of durations to analyze.
Description:
   This tool calculates PMP depths for a given drainage basin for the
specified durations.  PMP values are
calculated (in inches) for each grid point (spaced at 90 arc-second intervals)
within (or adjacent to) the drainage basin. A GRID raster layer is created over
the basin from the grid point PMP values.
---------------------------------------------------------------------------’’’
###############################################################################
## import Python modules
import sys
import arcpy
from arcpy import env
import arcpy.management as dm
import arcpy.conversion as con
arcpy.env.overwriteOutput = True                                      # Set overwrite option
###############################################################################
## get input parameters
basin = arcpy.GetParameter(0)                                        # get AOI Basin Shapefile
home = arcpy.GetParameterAsText(1)                                        # get location of ‘PMP’ Project Folder
durInput = arcpy.GetParameter(2)                                     # get durations (string)
dadGDB = home + “\\Input\\DAD_Tables.gdb”                                  # location of DAD tables
adjFactGDB = home + “\\Input\\Storm_Adj_Factors.gdb”                         # location of feature datasets containing total adjustment
factors
def pmpAnalysis(aoiBasin, stormType):
   ###############################################################################
   ## Create PMP Point Feature Class from points within AOI basin and add fields
   def createPMPfc():
      global outPath
      env.workspace = outPath + “PMP.gdb”                                                # set environment workspace
      arcpy.AddMessage(“\nCreating feature class: PMP_Points...”)
      dm.MakeFeatureLayer(home + “\\Input\Non_Storm_Data.gdb\\Vector_Grid\\Vector_Grid_AZ”, “vgLayer”)    # make a feature
layer of vector grid cells
      dm.SelectLayerByLocation(“vgLayer”, “INTERSECT”, aoiBasin)                              # select the vector grid cells that
intersect the aoiBasin polygon
      dm.MakeFeatureLayer(home + “\\Input\Non_Storm_Data.gdb\\Vector_Grid\\Grid_Points_AZ”, “gpLayer”)    # make a feature
layer of grid points
      dm.SelectLayerByLocation(“gpLayer”, “HAVE_THEIR_CENTER_IN”, “vgLayer”)                     # select the grid points
within the vector grid selection
      con.FeatureClassToFeatureClass(“gpLayer”, env.workspace, “PMP_Points”)                      # save feature layer as
“PMP_Points” feature class
      arcpy.AddMessage(“(“ + str(dm.GetCount(“gpLayer”)) + “ grid points will be analyzed)”)
      # Add PMP Fields
      for dur in durList:
```

```
      arcpy.AddMessage("\n\t...adding field: PMP_" + str(dur))
      dm.AddField("PMP_Points", "PMP_" + dur, "DOUBLE")
    # Add STORM Fields (this string values identifies the driving storm by SPAS ID number)
    for dur in durList:
      arcpy.AddMessage("\n\t...adding field: STORM_" + str(dur))
      dm.AddField("PMP_Points", "STORM_" + dur, "TEXT", "", "", 16)
  def getAOIarea():
    sr = arcpy.Describe(aoiBasin).SpatialReference          # Determine aoiBasin spatial reference system
    srname = sr.name
    srtype = sr.type
    srunitname = sr.linearUnitName                    # Units
    arcpy.AddMessage("\nAOI Basin Spatial Reference:  " + srname + "\nUnit Name: " + srunitname + "\nSpatial Ref. type: " +
srtype)

    aoiArea = 0.0
    rows = arcpy.SearchCursor(aoiBasin)
    for row in rows:
      feat = row.getValue("Shape")
      aoiArea += feat.area
    if srtype == 'Geographic':                    # Must have a surface projection
      arcpy.AddMessage("\nThe basin shapefile's spatial reference '" + srtype + "' is not supported.  Please use a 'Projected'
shapefile or feature class.\n")
      raise SystemExit
    elif srtype == 'Projected':
      if srunitname == "Meter":
        aoiArea = aoiArea * 0.000000386102            # Converts square meters to square miles
      elif srunitname == "Foot" or "Foot_US":
        aoiArea = aoiArea * 0.00000003587            # Converts square feet to square miles
      else:
        arcpy.AddMessage("\nThe basin shapefile's unit type '" + srunitname + "' is not supported.")
        sys.exit("Invalid linear units")              # Units must be meters or feet

    aoiArea = round(aoiArea, 3)
    arcpy.AddMessage("\nArea of interest: " + str(aoiArea) + " square miles.")

    # aoiArea = 100     ## Enable a constant area size
    arcpy.AddMessage("\n***Area used for PMP analysis: " + str(aoiArea) + " sqmi***")
    return aoiArea
  ###########################################################################
  ##  Define dadLookup() function:
  ##  The dadLookup() function determines the DAD value for the current storm
  ##  and duration according to the basin area size.  The DAD depth is interpolated
  ##  linearly between the two nearest areal values within the DAD table.
  def dadLookup(stormLayer, duration, area):            # dadLookup() accepts the current storm layer name (string), the current
duration (string), and AOI area size (float)
    #arcpy.AddMessage("\t\tfunction dadLookup() called.")
    durField = "H_" + duration                    # defines the name of the duration field (eg., "H_06" for 6-hour)
    dadTable = dadGDB + "\\" + stormLayer
    rows = arcpy.SearchCursor(dadTable)

    try:
      row = rows.next()                        # Sets DAD area x1 for basins that are smaller than the smallest DAD area.
      x1 = row.AREASQMI
      y1 = row.getValue(durField)
```

```
      xFlag = “FALSE”                          # Sets DAD area x2 for basins that are larger than the largest DAD area.
    except RuntimeError:                        # return if duration does not exist in DAD table
      return

    #arcpy.AddMessage(“\nInitial x1 = “ + str(x1) + “\ny1 = “ + str(y1))

    row = rows.next()
    i = 0
    while row:                              # iterates through the DAD table - assiging the bounding values directly above and
below the basin area size
      i += 1
      if row.AREASQMI < area:
        x1 = row.AREASQMI
        y1 = row.getValue(durField)
      else:
        xFlag = “TRUE”
        x2 = row.AREASQMI
        y2 = row.getValue(durField)
        #arcpy.AddMessage(“\nLoop “ + str(i)+ “\nx1 = “ + str(x1) + “\ny1 = “ + str(y1) + “\nx2 = “ + str(x2))
        break

      row = rows.next()
    del row, rows, i
    if xFlag == “FALSE”:
      x2 = area                             # If x2 is equal to the basin area, this means that the largest DAD area is smaller than
the basin and the resulting DAD value must be extrapolated.
      #arcpy.AddMessage(“x2 = “ + str(x2))
      arcpy.AddMessage(“\n\tThe basin area size: “ + str(area) + “ sqmi is greater than the largest DAD area: “ + str(x1) + “ sqmi.
DAD value is estimated by extrapolation.”)    # In this case, y (the DAD depth) is estimated by extrapolating the DAD area to the
basin area size.
      y = x1 / x2 * y1
      return y                              # The extrapolated DAD depth (in inches) is returned.
    # arcpy.AddMessage(“\nArea = “ + str(area) + “\nx1 = “ + str(x1) + “\nx2 = “ + str(x2) + “\ny1 = “ + str(y1) + “\ny2 = “ + str(y2))

    x = area                                # If the basin area size is within the DAD table area range, the DAD depth is interpolated
    deltax = x2 - x1                          # to determine the DAD value (y) at area (x) based on next lower (x1) and next higher
(x2) areas.
    deltay = y2 - y1
    diffx = x - x1
    y = y1 + diffx * deltay / deltax
    return y                                # The interpolated DAD depth (in inches) is returned.
  ###############################################################################
  ##  Define updatePMP() function:
  ##  This function updates the ‘PMP_XX_’ and ‘STORM_XX’ fields of the PMP_Points
  ##  feature class with the largest value from all analyzed storms stored in the
  ##  pmpValues list.
  def updatePMP(pmpValues, stormID, duration):                          # Accepts four arguments: pmpValues - largest
adjusted rainfall for current duration (float list); stormID - driver storm ID for each PMP value (text list); and duration (string)
    pmpfield = “PMP_” + duration
    stormfield = “STORM_” + duration
    gridRows = arcpy.UpdateCursor(outPath + “PMP.gdb\\PMP_Points”)                # iterates through PMP_Points rows
    i = 0
    for row in gridRows:
```

```
        row.setValue(pmpfield, pmpValues[i])                    # Sets the PMP field value equal to the Max Adj.
Rainfall value (if larger than existing value).
        row.setValue(stormfield, stormID[i])                    # Sets the storm ID field to indicate the driving storm
event
        gridRows.updateRow(row)
        i += 1
      del row, gridRows, pmpfield, stormfield
      arcpy.AddMessage("\n\t" + duration + "-hour PMP values update complete. \n")
      return
   def outputPMP():
      global outPath
      pmpPoints = outPath + "PMP.gdb\\PMP_Points"               # Location of 'PMP_Points' feature class which will provide
data for output

      arcpy.AddMessage("\nBeginning PMP Raster Creation...")
      for dur in durList:                                       # This code creates a raster GRID from the current PMP point
layer
        durField = "PMP_" + dur
        outLoc = outPath + "GRIDs.gdb\\pmp_" + dur
        arcpy.AddMessage("\n\tInput Path: " + pmpPoints)
        arcpy.AddMessage("\tOutput raster path: " + outPath)
        arcpy.AddMessage("\tField name: " + durField)
        con.FeatureToRaster(pmpPoints, durField, outLoc, "0.025")
        arcpy.AddMessage("\tOutput raster created...")
      del durField
      outFile = open(outPath + "Text_Output\\PMP_Distribution.txt", 'w')
      arcpy.AddMessage("\nPMP Raster Creation complete.")

      ######  This section applies the metadata templates to the output GIS files ######
      pointMetaLoc = home + "\\Input\\Metadata_Templates\\PMP_Points_Metadata_FGDC.xml"         # Location of
'PMP_Points' feature class metadata template
      rasMetaLoc = home + "\\Input\\Metadata_Templates\\PMP_Raster_Metadata_FGDC.xml"            # Location
of 'PMP_XX' raster file metadata template
      arcpy.AddMessage("\nAdding metadata to output files...")
      arcpy.AddMessage("\n\tPMP_Points feature class")
      con.MetadataImporter(pointMetaLoc, pmpPoints)                          # Applies metadata to
'PMP_Points' feature class
      for dur in durList:                                       # Applies metadata to 'PMP_XX' GRIDs
        targetPath = outPath + "GRIDs.gdb\\pmp_" + dur
        arcpy.AddMessage("\tPMP_" + str(dur) + " feature class")
        con.MetadataImporter(rasMetaLoc, targetPath)
      arcpy.AddMessage("\nOutput metadata import complete.")
   ###########################################################################
   ##  This portion of the code iterates through each storm feature class in the
   ##  'Storm_Adj_Factors' geodatabase (evaluating the feature class only within
   ##  the Local, Tropical, or general feature dataset).  For each duration,
   ##  at each grid point within the aoi basin, the transpositionality is
   ##  confirmed.  Then the DAD precip depth is retrieved and applied to the
   ##  total adjustement factor to yield the total adjusted rainfall.  This
   ##  value is then sent to the updatePMP() function to update the 'PMP_Points'
   ##  feature class.
##~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
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   desc = arcpy.Describe(basin)                                 # Check to ensure AOI input shape is a Polygon. If not - exit.
```

```
   basinShape = desc.shapeType
   if desc.shapeType == “Polygon”:
      arcpy.AddMessage(“\nBasin shape type: “ + desc.shapeType)
   else:
      arcpy.AddMessage(“\nBasin shape type: “ + desc.shapeType)
      arcpy.AddMessage(“\nError: Input shapefile must be a polygon!\n”)
      sys.exit()

   createPMPfc()                                               # Call the createPMPfc() function to create the PMP_Points feature
class.
   env.workspace = adjFactGDB                                  # the workspace environment is set to the ‘Storm_Adj_Factors’
file geodatabase
   aoiSQMI = round(getAOIarea(),2)                             # Calls the getAOIarea() function to assign area of AOI
shapefile to ‘aoiSQMI’

   for dur in durList:
      stormList = arcpy.ListFeatureClasses(““, “Point”, stormType)          # List all the total adjustment factor feature classes
within the storm type feature dataset.
      arcpy.AddMessage(“\n*******************************************************************\nEvaluating “ + dur + “-hour duration...”)
      pmpList = []
      driverList = []
      gridRows = arcpy.SearchCursor(outPath + “PMP.gdb\\PMP_Points”)
      try:
         for row in gridRows:
            pmpList.append(0.0)                                # creates pmpList of empty float values for each grid point to
store final PMP values
            driverList.append(“STORM”)                         # creates driverList of empty text values for each grid point to
store final Driver Storm IDs
         del row, gridRows
      except UnboundLocalError:
         arcpy.AddMessage(“\n***Error: No data present within basin/AOI area.***\n”)
         sys.exit()
      for storm in stormList:
         arcpy.AddMessage(“\n\tEvaluating storm: “ + storm + “...”)
         dm.MakeFeatureLayer(storm, “stormLayer”)                         # creates a feature layer for the current storm
         dm.SelectLayerByLocation(“stormLayer”, “HAVE_THEIR_CENTER_IN”, “vgLayer”)   # examines only the grid points that lie
within the AOI
         gridRows = arcpy.SearchCursor(“stormLayer”)
         pmpField = “PMP_” + dur
         i = 0
         try:
            dadPrecip = round(dadLookup(storm, dur, aoiSQMI),3)
            arcpy.AddMessage(“\t\t” + dur + “-hour DAD value:  “ + str(dadPrecip) + chr(34))
         except TypeError:                                     # In no duration exists in the DAD table - move to the next storm
            arcpy.AddMessage(“\t***Duration ‘“ + str(dur) + “-hour’ is not present for “ + str(storm) + “.***\n”)
            continue
         arcpy.AddMessage(“\t\tComparing “ + storm + “ adjusted rainfall values against current driver values...\n”)
         for row in gridRows:
            if row.TRANS == 1:                                 # Only continue if grid point is transpositionable (‘1’ is transpostionable, ‘0’
is not).
               try:                                            # get total adj. factor if duration exists
                  maxAdjRain = round(dadPrecip * row.TAF,2)
                  if maxAdjRain > pmpList[i]:
                     pmpList[i] = maxAdjRain
```

```
                driverList[i] = storm
            except RuntimeError:
                arcpy.AddMessage("\t\t   *Warning* PMP value failed to set for row " + str(row.CNT))
                break
            i += 1
        del row
    del storm, stormList, gridRows, dadPrecip
    updatePMP(pmpList, driverList, dur)          # calls function to update "PMP Points" feature class
  del dur, pmpList

  arcpy.AddMessage("\n'PMP_Points' Feature Class 'PMP_XX' fields update complete for all '" + stormType + "' storms.")

  outputPMP()                    # calls outputPMP() function

##~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
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type = "General"
durList = durInput
outPath = home + "\\Output\\General\\"
arcpy.AddMessage("\nRunning PMP analysis for storm type: " + type)
pmpAnalysis(basin, type)        # Calls the pmpAnalysis() function to calculate the General storm PMP
arcpy.AddMessage("\nGeneral storm analysis
complete...\n***********************************************************************************************************")
```