PRECIPITATION AND FLOODING IN SOUTHERN ARIZONA: THE LEGACY OF TROPICAL STORM HEATHER, OCTOBER, 1977

by

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1. INTRODUCTION

One of the worst floods in Arizona's history took place in October of 1977 in southern Arizona (Perfrement and Wood, 1978). The Santa Cruz and San Pedro Rivers (see Figure 1), draining to the north from the southern border region of Arizona, produced extensive flooding of many small towns and thousands of acres of valuable agricultural land. The massive flooding followed record-setting rainfall intensities in southern Arizona during October 3rd through 9th, when tropical storm Heather, situated near Baja California, spread moisture over much of the southwestern U.S. The hardest hit community was Nogales, Arizona, with a staggering total of 8.30 inches of rain from the storm (unofficial reports indicate that 12.0 inches fell in some areas of the city). The very intense rainfall was confined to a small zone near the southeastern Arizona/Mexico region.

The largest city affected by the flood waters was Tucson, Arizona, which suffered $3 million damage - mostly to roads and utilities. Mr. Brian M. Reich, city of Tucson Floodplain Engineer, was quoted as saying, "It does not take much imagination to envision how much worse it would have been in Tucson if the storm which produced the flood had been concentrated nearer the city

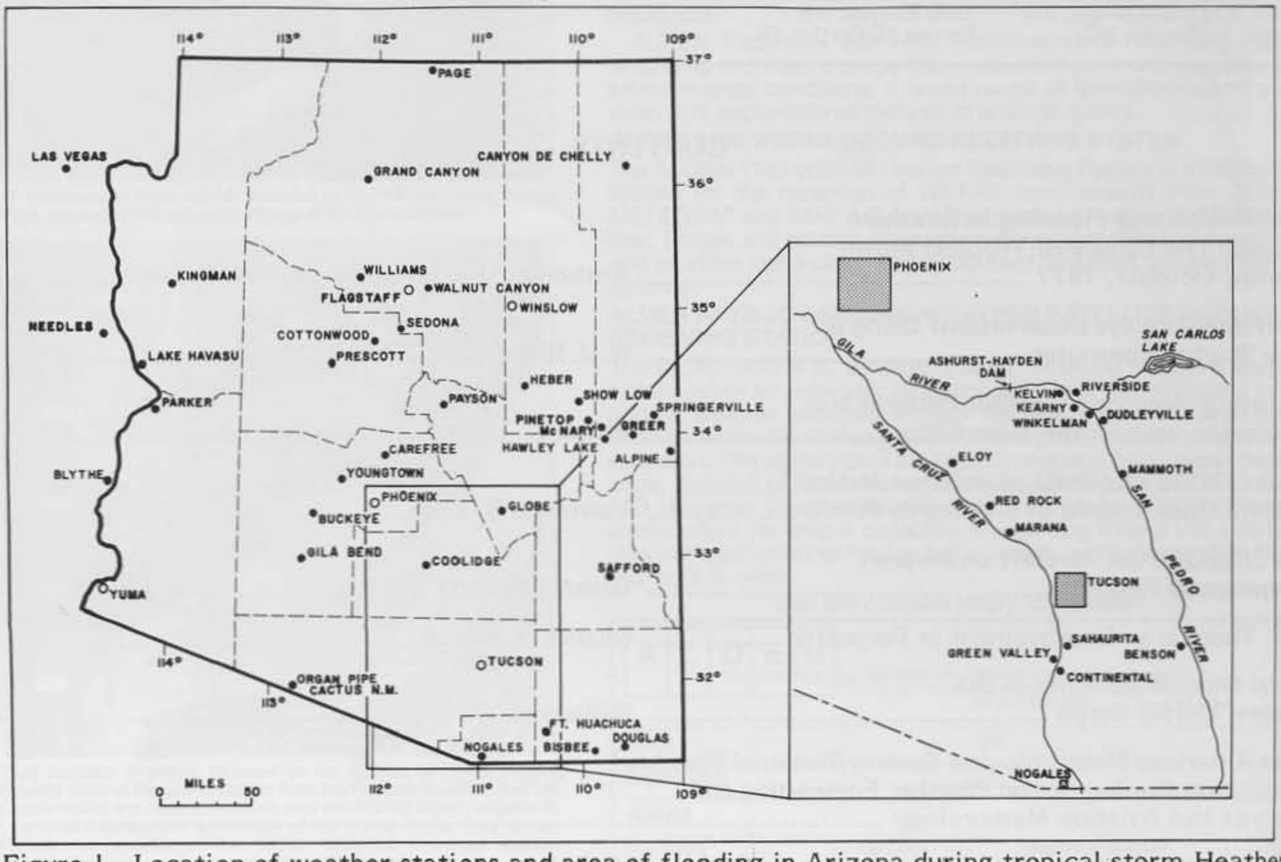

Figure 1. Location of weather stations and area of flooding in Arizona during tropical storm Heather.

rather than in the area of the border with Mexico" *(Arizona Water Resources News Bulletin,* 1977).

The Santa Cruz River passing by Tucson peaked at 22,000 cubic feet per second (cfs) which was equivalent to a 50-year flood. However, to the south of Tucson, small communities probably would find little solace in Mr. Reich's statements. The flooding was extremely severe along the Santa Cruz and San Pedro Rivers. At Nogales, the Santa Cruz rose 3 feet in 15 minutes during the height of the storm and crested at 4:45 p.m. on the 9th of October. Near Nogales, peak flow was 33,500 cfs - larger than a 100-year flood value for this location. The Santa Cruz stayed in its banks past Tucson, but widened out and flooded Marana at 12:00 a.m. on October 12th. In the meantime, the San Pedro River also flooded; it crested at 8 feet at Winkelman at 10:30 p.m. on October 10th. Discharge could not be measured, since the gage was washed out. The Gila River crested at 10:30 a.m. on October 11th at Kelvin, measuring 37,000 cfs. The San Pedro River acted as a dam and assisted in cresting the Gila. Its usual flow past this point is only 100 cfs! At Kearney, the Gila River rose 25 inches in 12 hours on the 10th.

TABLE 1

Damages Due to Heather

Type of Damage	Cost
Repairs for damage to state, county, Tucson, and Nogales facilities	$ 1,300,000
150 farms	8,800,000
160 residences	290,000
3 businesses	300,000
Tucson Gas & Electric Co. and Southern Pacific Transportation	700,000
Road damage	2,300,000
Public utility damage	362,000
Golf course	300,000
Water control facility	69,500
Debris clearance cost	69,500
Agricultural land	5,700,000
Agricultural crop (cotton, lettuce, grains)	2,300,000
Livestock, farm structures	No Figure
Total Damages	$13,400,000

Note: Governor Bolin requested $11.3 million flood relief and Bolin set aside $300,000 from state emergency funds for the flood. Tucson damage to roads and utilites was $2.7 million. In Santa Cruz county and Nogales, damage was $4.7 million--75% of this to crops and farmland.

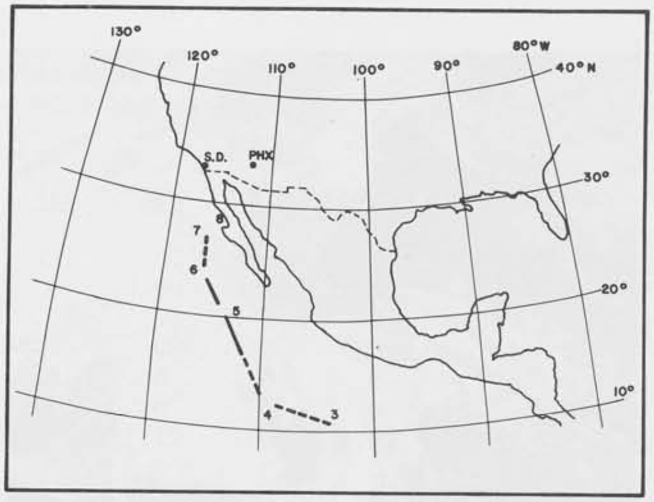

Figure 2. Path of tropical storm Heather, October, 1977. The numbers correspond to the date that Heather was at that position. Solid line represents hurricane stage.

Estimated damage from the storm was $13.4 million, considerably less than the $150 million reported from tropical cyclone Kathleen (10-12 September, 1976) which caused heavy damage to the state of California (Fors, 1977). Table 1 shows a listing of damage as reported by the *Arizona Republic.*

This paper presents an overview of events that produced the localized heavy rainfall that affected southeast Arizona.

2. MOVEMENTS OF THE STORM

Figure 2 depicts the position of tropical storm Heather and its classification from October 3rd to the 9th. The storm was spawned near 10°N latitude and 104°W longitude and moved in a curved path west and north toward Baja California. Heather's rate of movement, from its origin to its final resting place, averaged 13.7 knots - some 3.4 knots higher than the median speed reported by Hansen (1972) for a sample of storms during 1965-1971. Maximum movement occurred during the hurricane stage of the storm on the 4th, 5th, and 6th of October - averaging 21.7 knots. However, this storm was much slower moving than tropical storm Kathleen (September, 1976) whose rate of movement set a record with a speed greater than 30 knots (Fors, 1977).

Tropospheric shearing winds and general westerly flow north of 32°N latitude tended to confine northward movement of the storm and caused it to stagnate near the Pacific island of Cedros, some 350 miles south of San Diego, California. Satellite photos (Figures 3, 4, and 5) show the position of the storm on the 6th and 9th of October.

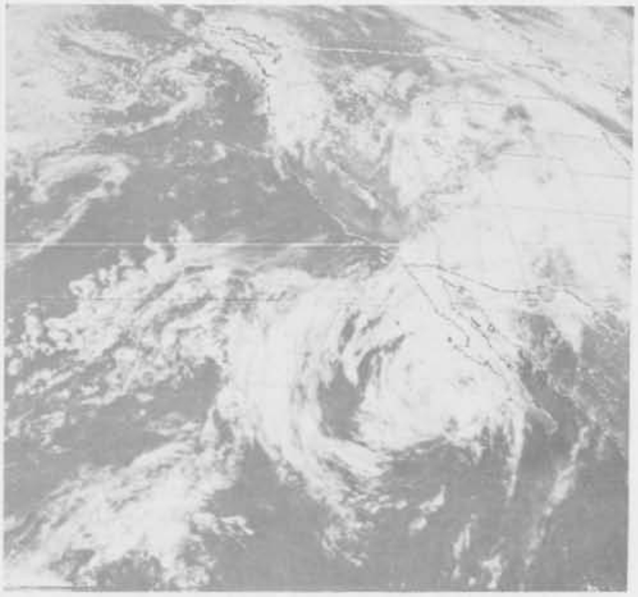

Figure 3. Position of tropical storm Heather at 1815 GMT, Oct. 6, 1977.

As hurricanes go, Heather came relatively late in the eastern Pacific hurricane season (Rosendal, 1963). The probability of a tropical storm reaching within 300 miles of San Diego in October is only once every 25 years (Eidemiller, 1978). Even though this probability is quite low, tropical storms can push as far north as 30°N latitude at this time of year, if there is an extensive low pressure trough over the western United States. This was the case during this period. In addition, a mid-latitude cyclone developed in the western U.S. (see Figure 5). This system played a significant role in the production of unusually heavy precipitation and also in its distribution over the western U.S.

3. TROPICAL STORM HEATHER PRECIPITATION

There is no particularly unusual aspect to the movement of Heather, although it should be footnoted that not many storms are generated at this time of year. Perhaps the most unusual aspect is the unique characteristic of Heather's moisture release. Precipitation from the storm occurred during the period October 3rd to 9th, a 7-day period. October 6th and 9th were selected (Figures 6 and 7) to illustrate an important aspect of the precipitation distribution. Also, Figure 8 shows the storm total precipitation for the western U.S. Many western states received precipitation during this period, but it should be noted that extreme southern Arizona received by far the heaviest amount of precipitation during the storm. Many locations in southern Arizona recorded over 5 inches in a 3-day period (see Table 2).

In order to understand the reasons for this extremely intense rainfall in such a small confined

Figure 4. Dissipation of tropical storm Heather at 1815 GMT, Oct. 9, 1977.

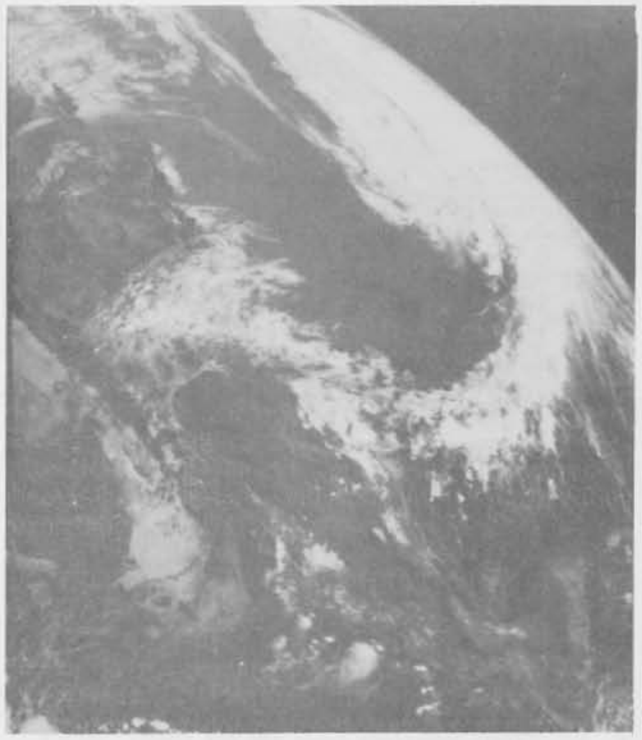

Figure 5. 1515 GMT, Oct. 9, 1977 photo showing the mid-latitude cyclone with accompanying cold front reaching across southern Arizona.

TABLE 2

STORM RAINFALL TOTALS FOR ARIZONA STATIONS
(in inches, taken from the 0500 MST data log)

Station	3rd	4th	5th	6th	7th	8th	9th	Total
Alpine	0	.20	T	.35	.37	M	M	.92
Bisbee	0	0	0	0	2.00	1.52	1.65	5.17
Buckeye	0	0	0	.75	.08	0	0	.83
Canyon de Chelly	.05	0	.15	.35	0	0	0	.55
Coolidge	0	0	0	.31	0	0	0	.31
Cottonwood	0	0	1.45	.14	0	0	0	1.59
Douglas	0	0	0	.61	1.12	1.28	2.02	5.03
Flagstaff	0	0	.49	.49	0	0	0	.98
Flagstaff Airport	0	0	.73	.23	0	0	0	1.01
Ft. Huachuca	T	0	0	2.05	1.18	1.32	.95	5.50
Gila Bend	0	0	0	.13	.23	0	0	.36
Globe	0	0	T	1.20	0	0	0	1.20
Grand Canyon	0	0	.16	0	0	0	0	.16
Greer	.41	.16	.01	.67	.35	.02	0	1.62
Hawley Lake	0	.37	.11	2.28	.12	0	0	2.88
Heber	0	0	.02	1.38	T	T	0	1.40
Kingman	0	0	.07	0	0	0	0	.07
Lake Havasu	0	0	0	0	0	0	0	.00
McNary	0	T	.36	1.64	.03	0	0	2.03
Nogales	T	0	0	2.20	2.26	2.59	.85	8.30
Organ Pipe Cactus	0	T	.02	.42	.72	.02	0	1.18
Page	0	0	.03	.03	0	0	0	.06
Parker	0	0	.47	M	0	0	0	.47
Payson	0	0	0	.58	.05	0	0	.63
Phoenix	0	0	.21	.15	0	0	0	.36
Pinetop	0	T	T	1.40	.31	0	0	1.71
Prescott Airport	0	0	.97	.40	0	0	0	1.37
Prescott City	0	0	1.25	.10	0	0	0	1.35
Safford Exp. Sta.	0	0	.01	.64	T	T	.06	.71
Sedona	0	0	1.79	.44	0	0	0	2.23
Show Low City	0	0	.67	1.10	0	0	0	1.77
Springerville	T	T	T	.51	M	0	M	.51
Tucson	0	0	0	1.83	.39	0	.06	2.28
Walnut Canyon	0	0	.88	.87	0	0	0	1.75
Williams	0	0	.83	1.17	0	0	0	2.00
Winslow	0	0	.07	.56	0	0	0	.63
Youngtown	0	0	0	.36	.06	0	0	.42
Yuma	0	0	T	.24	0	0	0	.24
Blythe, California	0	0	.01	.02	0	0	0	.03
Needles, California	0	0	T	0	0	0	0	T
Las Vegas, Nevada	0	0	0	0	0	0	0	0

T-Trace
M-Missing

zone, it is helpful to analyze the stability, precipitable water, and synoptic maps during this time (Figures 9, 10, and 11). The October 6th and 9th stability and precipitable water maps and the October 7th and 8th 0500 MST synoptic maps are shown.

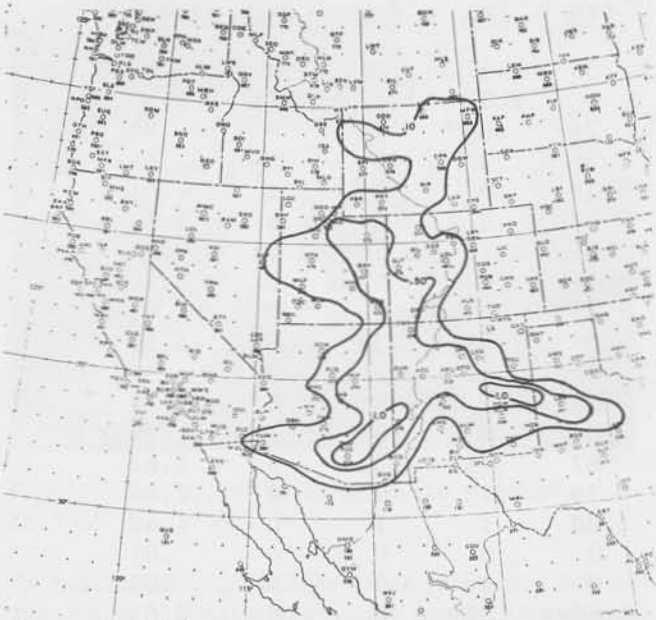

Figure 6. 24-hour precipitation (in inches) ending 0500 MST, Oct. 6, 1977.

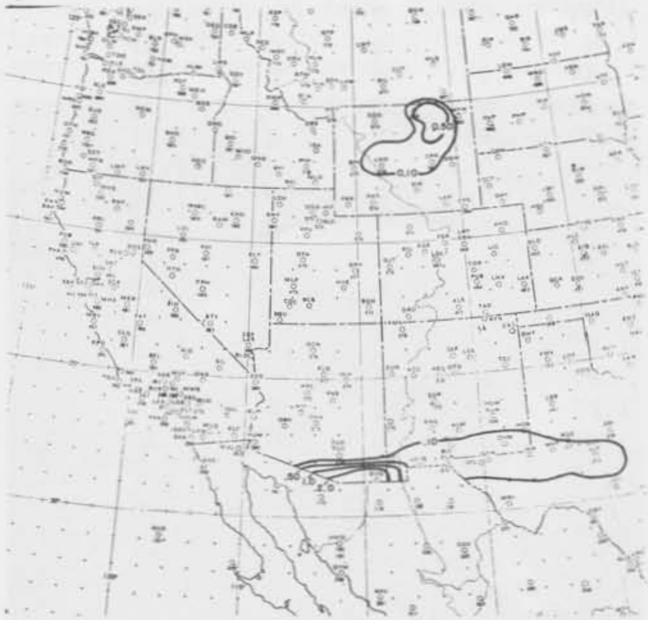

Figure 7. 24-hour precipitation (in inches) ending 0500 MST, Oct. 9, 1977.

As seen on the satellite photo of October 6th, the storm was located slightly to the southwest of central Baja with extensive cloud masses developed to the north and east of the storm center. Most of Arizona, Colorado, New Mexico, and Utah, and parts of southern Idaho, Wyoming, and eastern Nevada experienced overcast skies and

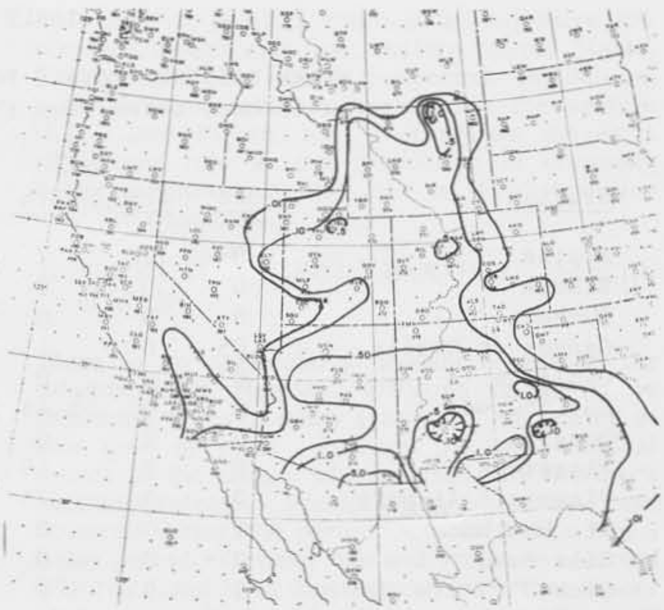

Figure 8. Total precipitation (in inches), Oct. 3 - Oct. 9, 1977.

rainfall (see Figure 6). The stability map (Figure 9) illustrates the wide, extensive distribution of moist, unstable air to the north and east of the center of the storm. Precipitable water vapor on the 6th of October (Figure 10) exceeded 1 inch over an extensive region from central California as far east as Mississippi and parallelled the borders of Arizona, New Mexico, Oklahoma, and Arkansas. Precipitation in Arizona at this time, as shown in Figure 12, was widespread, with highest values in the eastern mountains of Arizona and the extreme southeast portion of the state. (Most places in the state did receive some precipitation.)

The storm dissipated on the 9th of October, but intense rainfall was still experienced in an east-west band from the southeastern Arizona border region across extreme southern New Mexico and into Texas (Figure 7). The most intense rainfall occurred on the Arizona-New Mexico border (see Figure 12). In Figure 9, note the extremely localized region of unstable air across southern Arizona, southwest New Mexico, and northern Sonora, Mexico on October 9th. Coincidentally, there was a localized precipitable water distribution (see Figure 10). The key to understanding this distribution is the shunting effect produced by a mid-latitude cyclone cold frontal passage on the 7th and 8th of October across the southwest desert region (Figure 11). The cold front tended to shear off the northeast injection of moisture from Heather and confined the moisture to the U.S./Mexico border region. Thus, although rainfall from the storm diminished on a regional scale, southern Arizona continued to suffer from the flooding that was produced by heavy rainfall through the 9th of October.

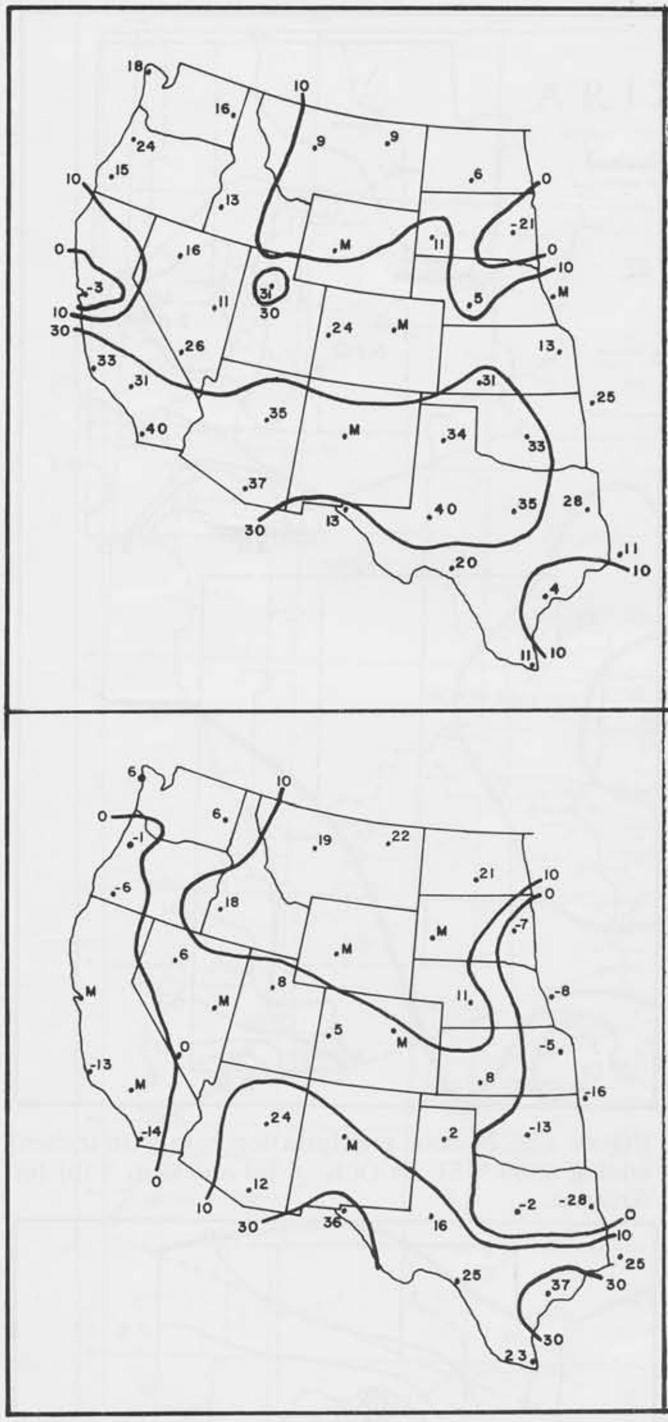

Figure 9. K-index values for Oct. 6 (a) and Oct. 9 (b).

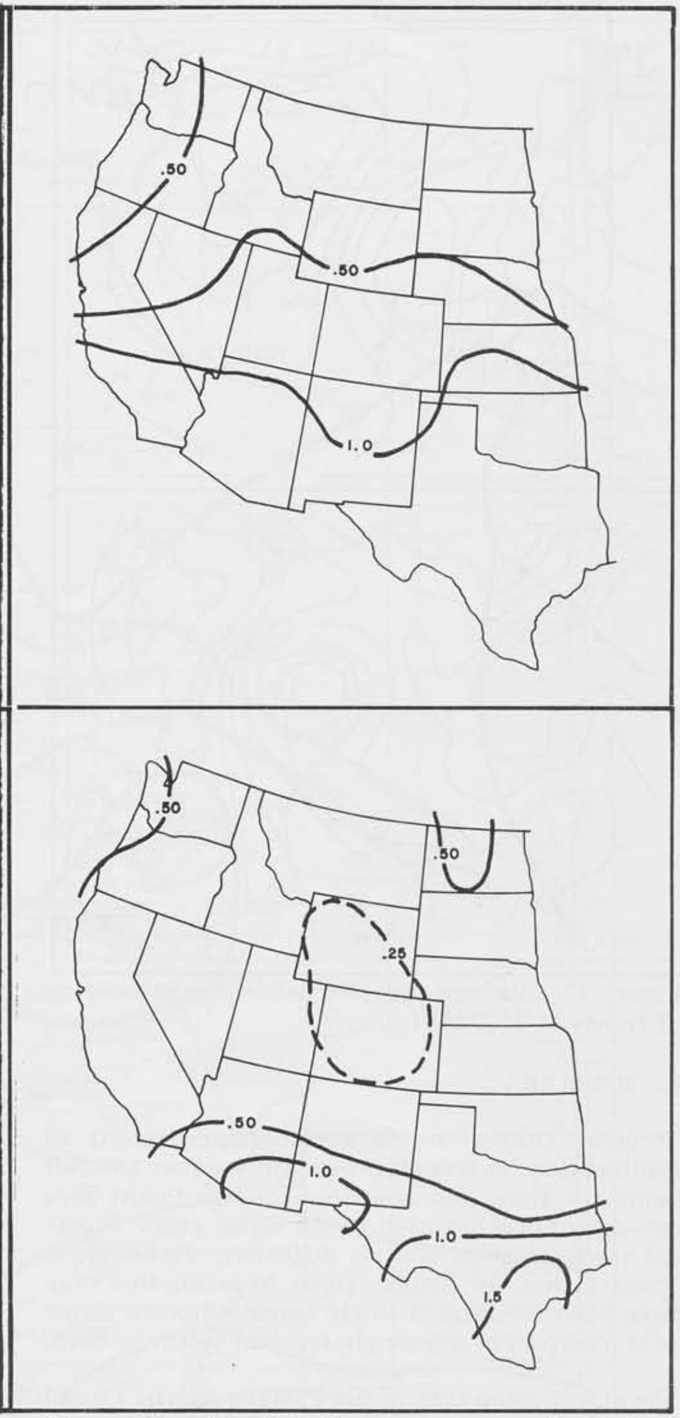

Figure 10. Precipitable water vapor (in inches) for Oct. 6 (a) and Oct. 9 (b).

The regionally confined nature of the precipitation was evident throughout the storm period, with an extremely sharp gradient in precipitation present between the Mexican border and central Arizona. Tucson, Arizona, received only 2.82 inches of rainfall during the entire period while Nogales, only 55 miles to the south, received 8.30 inches (see Figure 13). On the 9th of October, Tucson received only .06 inches of precipitation, whereas locations in the extreme southern portions of the state received almost 2 inches. This large precipitation gradient reflects the impact of the cold frontal passage across the state during this time. Precipitation for the southeast Arizona region during the storm exceeded by four times the typical tropical storm precipitation that normally occurs in a year (Douglas and Fritts, 1973). In fact, for many southern Arizona stations, this one tropical storm contributed more precipitation than the entire annual tropical storm rainfall contribution to annual precipitation totals (see Figure 14).

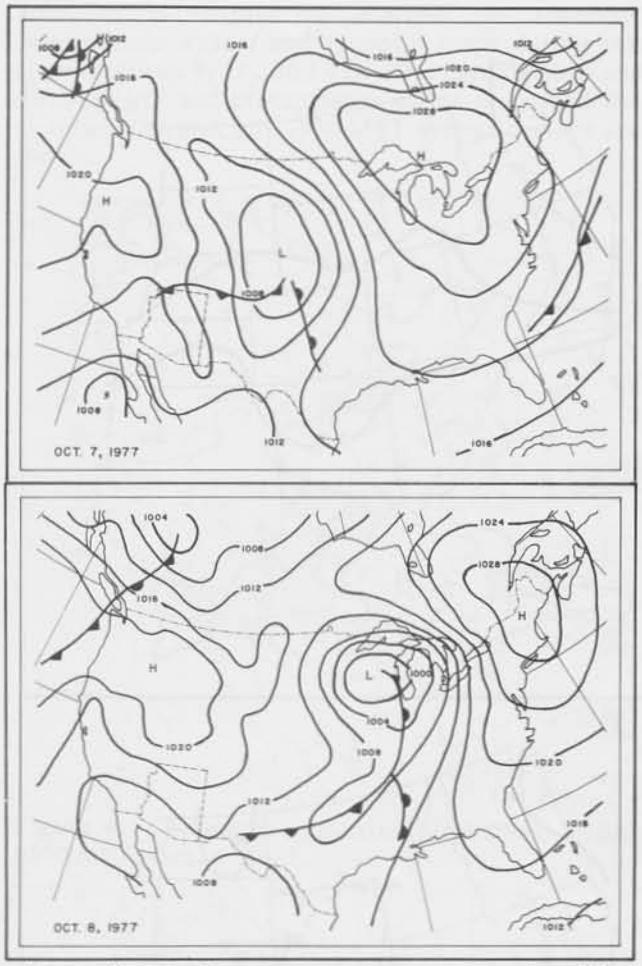

Figure 11. Surface pressure patterns and position of fronts at 0500 MST.

4. SUMMARY

Tropical storms are a considerable hazard to southwestern desert states in late summer and fall months. They also contribute a significant percentage of precipitation to the water year. Tropical storm Heather was no different. However, it appears that for southeastern Arizona, this may have been the largest single contribution to water year moisture of any single tropical storm to date.

The storm came late in the eastern Pacific Ocean hurricane season, but this attribute does not necessarily distinguish it from other storms. The unusual feature was the extremely localized and incessant rainfall in southern Arizona over a 4 to 5 day period that produced severe local flooding, particularly at Nogales, but also at communities to the north along the San Pedro and Santa Cruz Rivers. Although not in the center of most intense rainfall, the largest city affected was Tucson, Arizona, which incurred nearly $3 million worth of damage. The localized rainfall was caused by unique juxtaposition of a mid-latitude cyclone migration across the central U.S. and the influx of warm, moist, unstable air from tropical latitudes associated with Heather.

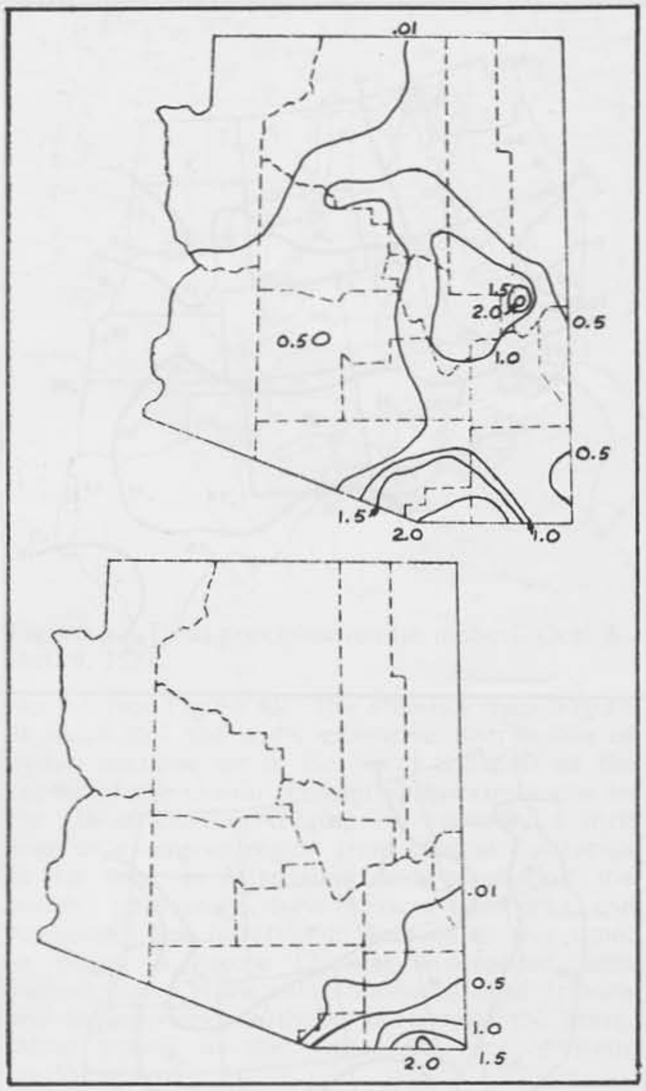

Figure 12. 24-hour precipitation totals (in inches) ending 0500 MST on Oct. 6 (a) and Oct. 9 (b) for Arizona.

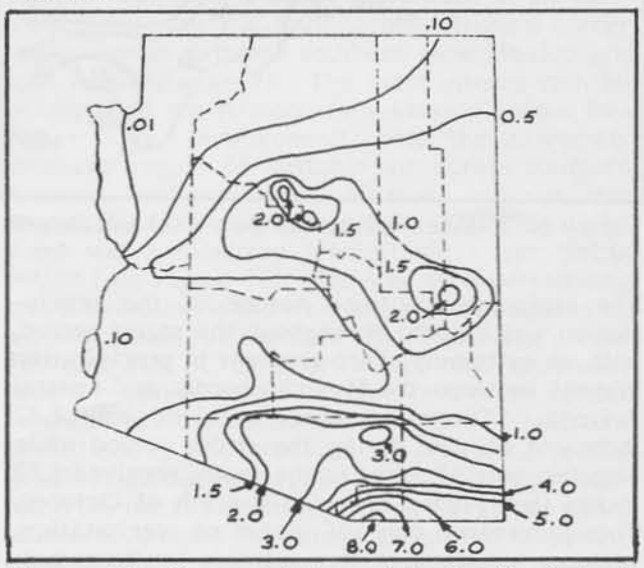

Figure 13. Storm total precipitation (in inches), Oct. 3 - Oct. 9, 1977 for Arizona.

Figure 14. Tropical storm Heather contribution (in percent) to the 1977 annual precipitation for Arizona.

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National Weather Digest

ANALYZING AIRWAYS OBSERVATIONS USING A TIME SHARING COMPUTER

by

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1. INTRODUCTION

The weather forecaster's chief concern is the hour to hour, and sometimes minute to minute weather changes taking place in his forecast area. For the aviation forecaster, ceilings and visibilities are the prime concern since amendments must be issued when weather limits are exceeded. Similarly, the public service forecaster must monitor temperature, dew point, and winds as well as changes in cloudiness, and the onset and type of precipitation, etc. that affect the current forecast or that may require the issuance of special statements, advisories, bulletins, etc. The weather forecaster has a large span of data to survey; nevertheless he must constantly check for significant changes and assess their impact on the forecast product. This article describes a computer program that partly answers the problem of data analysis for the forecaster.

2. DISCUSSION

Figures 1 and 2 are computer formatted lists or files of the aviation observations taken at Newark Airport and at J. F. Kennedy Airport on May 31, 1974. The program to execute this was written in Fortran language on the Univac 1108 Time Sharing System. Two separate files were written by the program and then analyzed by the program (partial listing attached (see Appendix)). The data elements used by the program are shown in the column headings of Figures 1 and 2. Low Middle and High clouds are shown as condition codes (CND) where code 3 indicates scattered clouds, 6 broken and 8 overcast conditions. Heights (HT) are in hundreds of feet. Visibility, pressure, temperature, dew point and wind follow. (Pressure is in millibars with the first 2 digits omitted.)

The program reads the first file (Newark) and prints out the changes during the last 3, 6, and 12 hours. These are shown in Figures 3 and 4 under the Title PROGRAM OUTPUT. In this program, changes in cloud cover conditions are for a period of 3 hours only, but could be extended, if desired. On the top of Figure 3, opposite visibility, the changes for 3, 6, and 12 hours are shown. These values can be checked by referring to Figure 1. At 2000 GMT, visibility was 4.0, and 3 hours later at 2300 GMT it was 7.0 for a 3.0 mile increase. Checking the 12 hour change, it can be seen that at 1100 GMT visibility was 2.5 miles and 12 hours later it was 7.0 miles for an increase of 4.5 miles. Likewise the changes in pressure, temperature, and dew point are also determined and listed. The changes in sky condition and heights were calculated in a similar way. Thus, it can be seen that