# Weather Considerations in Site Selection

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## V.1. INTRODUCTION

One of the many factors to consider when searching for a site to locate any instrument that needs to see the clear sky is how much cloud cover to anticipate. While weather would rarely be THE deciding factor, it is imperative that it be considered to prevent a site being selected that will not allow the necessary operational performance. This report describes how cloud cover was analyzed for eight sites in New Mexico in the process of selecting a site for a long base line interferometer.

Dr. John McGraw (University of New Mexico) and Phillips Lab were looking for a site on which to place the long baseline interferometer proposed by Georgia State Univesity and recognized the importance of finding a site where clouds would have a minimal impact. He asked if PL/WE (Staff Meteorology Office) could assist in determining cloud cover at various sites around New Mexico.

Gary Loos (PL/LIMI) provided a list of eight sites in NM and four other sites. Not all of the sites were under active consideration for placement of an interferometer. For comparison purposes, we analyzed some sites for which cloud cover and operational availability are at least qualitatively known. This provided a baseline against which potential sites could be measured.

The 12 sites, their locations and approximate elevations were:

| Site Name | Latitude | Longitude | Elevation |
|---|---|---|---|
| Anderson Mesa, AZ[1,3] | 35° 05′N | 111° 30′W | 7,000′ |
| Capilla Peak, NM[1,3] | 34° 40′N | 106° 25′W | 9,400′ |
| Chicken Mountain, NM[1,3] | 34° 35′N | 107° 15′W | 7,800′ |
| Mesa Negra, NM[1,3] | 34° 55′N | 107° 45′W | 8,000′ |
| Mesa Prieta, NM[1,3] | 35° 30′N | 107° 05′W | 7,500′ |
| Sacramento Peak, NM[1,3] | 32° 45′N | 105° 30′W | 9,200′ |
| South Baldy, NM[1,3] | 34° 00′N | 107° 15′W | 10,800′ |
| Starfire Optical Range, NM[1,3] | 35° 00′N | 106° 25′W | 6,200′ |
| Very Large Array (VLA), NM[2,3] | 34° 18′N | 107° 31′W | 6,000′ |
| Mauna Kea, HI[2] | 19° 50′N | 155° 30′W | 13,700′ |
| Kitt Peak, AZ[1,3] | 31° 55′N | 111° 35′W | 6,300′ |
| Hark Labor Creek, GA[2,3] | 33° 48′N | 83° 25′W | 700′ |

## V.2. THE CLIMATIC DATABASE

The USAF Environmental Technical Applications Center (USAFETAC) provided data describing the Probability of Cloud-Free Line-of-Site (PCFLOS) for each month for each site. They used three data bases:

**TABLE V.1.** Percent Probabilities of Cloud-Free Line-of-Sight
Location: Box 43, J48 I61 (Anderson Mesa)
for the month of January

| | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° |
|---|---|---|---|---|---|---|---|---|---|
| 00Z | 52 | 51 | 51 | 50 | 50 | 49 | 48 | 46 | 41 |
| 03Z | 56 | 56 | 56 | 55 | 55 | 54 | 53 | 52 | 48 |
| 06Z | 59 | 59 | 58 | 58 | 57 | 57 | 56 | 54 | 50 |
| 09Z | 71 | 71 | 71 | 70 | 70 | 69 | 69 | 67 | 64 |
| 12Z | 61 | 60 | 60 | 60 | 59 | 59 | 58 | 57 | 54 |
| 15Z | 61 | 60 | 60 | 60 | 59 | 58 | 58 | 56 | 53 |
| 18Z | 52 | 51 | 51 | 50 | 50 | 49 | 48 | 46 | 43 |
| 21Z | 47 | 47 | 46 | 46 | 45 | 45 | 44 | 42 | 39 |

Period of Record: 1984 – 1991
Each figure is derived from approximately 243 observations
Source: USAFETAC RTNEPH

1. The Real-Time Nephanalysis (RTNEPH) Climatic Database
2. The 3-Dimensional Nephanalysis (3DNEPH) Climatic Database
3. The DATSAV2 Climatic Surface Database

"The AFGWC RTNEPH model produces cloud cover data for the entire globe, using all available conventional data (surface, upper air, and aircraft) and satellite (DMSP and NOAA) data to produce an analysis every 3 hours (at 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 GMT)." (RTNEPH: USAFETAC Climatic Database Users Handbook, No 1, September 1986) This is a gridded database with grid points approximately 25 nautical miles apart. The period of record (POR) for the RTNEPH data used in this study is 1984 – 1991 (8 years). The sites for which RTNEPH was available are indicated with a "1" above.

The precursor to the RTNEPH was 3DNEPH, with a period of record from 1977 – 1983. 3DNEPH has less vertical resolution than RTNEPH, but since our concerns are from the surface to space, the vertical resolution is not critical. The sites where 3DNEPH were used are annotated with a "2".

USAFETAC also used DATSAV2 (POR: 1973 – 1991) for most of the sites (indicated with a "3" above). "The DATSAV2 Surface Database is composed of worldwide surface weather observations collected and stored from sources such as the Automated Weather Network (AWN) and the Global Telecommunications System (GTS) since 1973." (DATSAV2 Surface, USAFETAC Climatic Database Users Handbook No. 4, USAFETAC/UH-86/004, December 1986.)

Each of these databases could indicate slightly different results for a given site and time, but the general trend will still appear. However, since the purpose of this study was to compare various sites and not various data bases, we stayed with nephanalysis data bases (RTNEPH and 3DNEPH) and did not include the DATSAV2 data in this analysis. Comparison of the databases would be a very interesting study, though.

The PCFLOS data was broken down by elevation angle (in 10° increments) and hour of the day (in three-hour increments). Table V.1 shows that data for Anderson Mesa, the site on which the U.S. Naval Observatory is constructing on astrometric interferometer, in January.

We manipulated the PCFLOS data format in the following ways:

**TABLE V.2.** Percent Probabilities of Cloud-Free Line-of-Sight
Location: Box 43, J48 I61 (Anderson Mesa)
for the month of January

| | 00Z | 03Z | 06Z | 09Z | 12Z | 15Z | 18Z | 21Z | 24Z | 27Z | 30Z | 33Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90° | 52 | 56 | 59 | 71 | 61 | 61 | 52 | 47 | 52 | 56 | 59 | 71 |
| 80° | 51 | 56 | 59 | 71 | 60 | 60 | 51 | 47 | 51 | 56 | 59 | 71 |
| 70° | 51 | 56 | 58 | 71 | 60 | 60 | 51 | 46 | 51 | 56 | 58 | 71 |
| 60° | 50 | 55 | 58 | 70 | 60 | 60 | 50 | 46 | 50 | 55 | 58 | 70 |
| 50° | 50 | 55 | 57 | 70 | 59 | 59 | 50 | 45 | 50 | 55 | 57 | 70 |
| 40° | 49 | 54 | 57 | 69 | 59 | 58 | 49 | 45 | 49 | 54 | 57 | 69 |
| 30° | 48 | 53 | 56 | 69 | 58 | 58 | 48 | 44 | 48 | 53 | 56 | 69 |
| 20° | 46 | 52 | 54 | 67 | 57 | 56 | 46 | 42 | 46 | 52 | 54 | 67 |
| 10° | 41 | 48 | 50 | 64 | 54 | 53 | 43 | 39 | 41 | 48 | 50 | 64 |
| | -07L | -04L | -01L | 02L | 05L | 08L | 11L | 14L | 17L | 20L | 23L | 26L |

Note: This is the same data as in Table V.1 with data transformed, zenith angles changed to elevation angles, and enough "wrap around" added to Z times to capture 00L to 24L.

- Changed zenith angles to elevation angles
- Transposed the data so time is along the abscissa and elevation angle is along the ordinate
- Added "24Z to 45Z" (the same data as 00Z to 21Z)
- Moved the origin in the x-direction so it would be at 00 Local Standard Time

Those changes resulted in a grid, part of which is illustrated in Table V.2.

The data in Table V.2 tell us that at Anderson Mesa at 23L (local time) in January, there is a 59% probability that there will be a cloud-free line-of-sight straight overhead, but near the horizon (10° ), there is only a 50% probability of the same cloud-free line-of-sight. Conditions appear to improve by 02L, but deteriorate near sunrise. This deterioration is likely due to the improved observing conditions near sunrise when observers will be able to see clouds that were not visible in the darker night hours. (Sometimes called the "sunrise surprise".) Later in the day, more clouds form with afternoon heating. While the clouds persist into the evening, they tend to clear out after sunset. This effect is much more pronounced in the summer months.

While the data in Table V.2 are informative, it is not necessarily intuitive when trying to compare sites for cloud-free characteristics. In order to show these cloud-free tendencies at each site, we contoured the PCFLOS values using IDL. Figure V.1 shows the contours for Table V.2 (clipped at 00L and 24L). One of the first things to notice is the tight gradients (indicating rapidly changing cloud cover conditions) from midnight to sunrise. Further, clouds increase (PCFLOS decreases) through the day until mid afternoon when things begin to improve. Again, the build-up of clouds in the afternoon during summer months will be quite obvious when the data is presented this way.

Somewhat arbitrarily, we chose to define "poor", "fair", and "good" conditions with the following definitions:

**Poor:** When the PCFLOS for a given time of day and elevation angle was less than or equal to 50%. That is to say, for a given month, time, and elevation angle, if the probability of cloud-free conditions is 50% or less, that site would be "poor" — expected to be operationally useful less than 50% of the time.

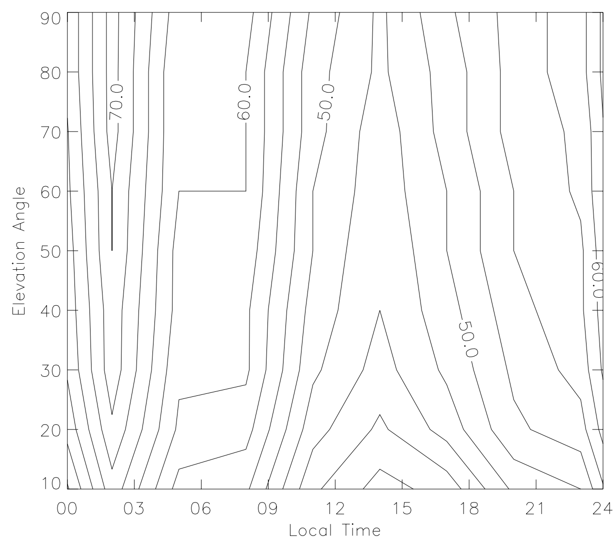


**FIGURE V.1.** PCFLOS as a function of elevation and time of day for Anderson Mesa (January averages).

**Fair:** When the PCFLOS for a given time of day and elevation angle was greater than 50% but less than 60%.

**Good:** When the PCFLOS for a given time of day and elevation angle was greater than or equal to 60%.

Simple qualitative comparison can be misleading, however, since it is attained through the projection of three-dimensional data into two dimensions. When a site is very "good" (e.g., probabilities in the upper 70s to 80% for cloud-free conditions) that site is likely to have a greater operational usefulness. Similarly, one would not expect a site whose PCFLOS drops into the teens to be as desirable as a site whose PCFLOS may be "poor" but only down in the 40% range. Another consideration is the diurnal recovery time for a site once it has a build-up of clouds — usually in the afternoon. A site that goes very "poor", but recovers in time for night-time operations would not necessarily be a bad site. In the following section we make a month-by-month comparison of the 10 sites in New Mexico and Arizona. Hard Labor Creek and Mauna Kea are not addressed here because they are in different climatic regimes.

## V.3. MONTH-BY-MONTH COMPARISON OF SITES

- In **January**, the polar jet is frequently over NM and AZ. Considerable cloudiness is usually associated with the polar jet. Still, Mesa Negra, Chicken Mountain, and South Baldy (and essentially Mesa Prieta) are always above 50% PCFLOS at all elevations. Most of the time, they are above 60% PCFLOS. While the Starfire Optical Range (SOR), the VLA, and Capilla Peak have a small amount of "poor" time, they are still generally above 50% PCFLOS. Anderson Mesa, Kitt Peak, and Sacramento Peak have significant "poor" times.

- In **February**, afternoon heating and the polar jet work together to influence cloud cover to a greater extent. There is a noticeable increase in "poor" time at the SOR, Anderson Mesa, Capilla Peak, Kitt Peak, and Sacramento Peak. (There was no "good" time at the SOR or Capilla Peak.) The other five sites maintain a PCFLOS of >50% through most hours and elevations.
- Though very similar to February, conditions actually improve slightly during **March** as the jet begins to move north and takes its moisture with it.
- Through **April**, the jet continues to move north and afternoon heating is not yet sufficient to form vast amounts of clouds.
- March's and April's improvements continue through **May**.
- **June** is a transition month. The mornings are generally good at all locations, but afternoon heating can cause rapid deterioration of conditions. There are rapid changes from noon to 18L at Mesa Prieta, Chicken Mountain, and South Baldy. Conditions improve rather rapidly after 21L at most sites, except South Baldy, which remains "poor" to "fair" throughout the night.
- **July** is a month of extreme changes in cloud cover. Sites tend to become extremely "poor", then quickly recover following the afternoon heating. Mesa Negra, Chicken Mountain, South Baldy, the VLA, and Mesa Prieta all have large periods of "good" conditions, but there are differences: Mesa Negra and Mesa Prieta begin to recover two to three hours before Chicken Mountain, the VLA, and South Baldy; Mesa Prieta's poorest period in the early evening is significantly deeper than the other three; South Baldy has the period of best conditions, but that occurs in the daylight hours — a useful time of day if one wants to look at the sun.
- **August** is similar to July. At elevations of interest to astronomers (above 30° ), the VLA has the most "good" time during the day. Mesa Negra, Chicken Mountain and South Baldy have a lot of "good" time, but Mesa Negra and Anderson Mesa have the best conditions in the early morning hours (midnight to 06L).
- Conditions begin to improve dramatically in **September**. Once again, though, while Chicken Mountain and South Baldy have the most "good" and least "poor", Mesa Negra, the VLA, Kitt Peak, and Anderson Mesa also have very good conditions. However, Anderson Mesa's rapid deterioration just before sunrise is alarming.
- The atmosphere remains relatively dry in **October**, and PCFLOS is generally good at all sites.
- **November** is essentially a repeat of October.
- In **December**, the return of the polar jet to NM and AZ latitudes begins to influence cloud cover once again. While most locations have a PCFLOS of 50% or greater, Anderson Mesa, Kitt Peak, and Sacramento Peak begin to show significant amounts of "poor" time.

For a variety of reasons, Mesa Negra has to be singled out as a key candidate for the long baseline interferometer. Therefore, we looked at the data one more time in a different way. But this time, we compared Mesa Negra only with existing optical sites — Anderson Mesa, Mauna Kea, Kitt Peak, and Sac Peak.

Figures V.2 and V.3 show cross sections of the PCFLOS at 60° elevation angle for each of these five sites each month. With the exception of Mauna Kea, Mesa Negra consistently has

**TABLE V.3.** Percent improvement in PCFLOS at Mesa Negra when compared to three other operational sites in the area.

| Month/Site | Kitt Peak | Sac Peak | Anderson Mesa | VLA |
|---|---|---|---|---|
| January | 14.7 | 15.6 | 17.9 | 5.7 |
| February | 19.1 | 18.7 | 23.6 | -2.1 |
| March | 9.6 | 16.0 | 20.3 | -2.5 |
| April | 9.4 | 14.7 | 25.2 | -2.5 |
| May | 7.8 | 22.0 | 17.4 | 3.3 |
| June | 2.8 | 24.0 | 4.5 | -8.8 |
| July | 23.6 | 24.1 | 27.9 | 16.9 |
| August | 38.5 | 25.0 | 13.5 | -2.1 |
| September | 8.3 | 20.9 | 14.0 | 11.0 |
| October | 11.7 | 18.3 | 15.8 | -1.0 |
| November | 8.8 | 15.3 | 18.3 | -3.5 |
| December | 19.8 | 18.4 | 21.0 | -4.1 |
| Annual | 14.51 | 19.42 | 18.28 | 1.01 |

a greater overall PCFLOS than the other sites. If we look at the improvement in cloud-free conditions at Mesa Negra when compared to the other sites in the vicinity, we can get a feel for how much more operational time could be achieved at Mesa Negra. In other words, Mesa Negra should experience cloud-free conditions a certain percentage more than other sites. Table V.3 gives percentage of increases in cloud-free condition for Mesa Negra compared to other local sites. As a matter of interest, the VLA was included in Table V.3 though it was not included in these figures.

## V.4. CONCLUSIONS

While there are many factors to consider in selecting a site for interferometric work, the meteorological data points to three sites in New Mexico that seem to be particularly well suited: Mesa Negra, South Baldy, and Chicken Mountain. Meteorologically, there are only minor difference in these sites — differences which can be attributed to inaccuracies in observations or simply lack of data. Mauna Kea had generally better weather conditions, but is of course geographically dislocated from principal players. Mesa Prieta and the VLA also show generally good conditions most of the time. Further comparisons of any of these sites will take more detailed analysis of other weather and location parameters. For example, heating and wind may be factors at any of the sites since optical turbulence could be created in the area or advected into the area from a nearby location.

The Starfire Optical Range, Anderson Mesa, Capilla Peak, Kitt Peak, Sacramento Peak, and Hard Labor Creek did not fare as well meteorologically. However, they are obviously not that bad since many of these sites already have optical facilities on them. Using these known sites as a baseline, we can confidently say from a cloud-cover perspective that any of the three or four best sites would provide an excellent choice for a long baseline interferometer — or any other astronomical instrument.

Since this data and other considerations pointed toward Mesa Negra as a good site, further analysis was done for that site which showed that it should be a very good site meteorologically, with a PCFLOS that compares favorably with all other operational optical sites we studied.

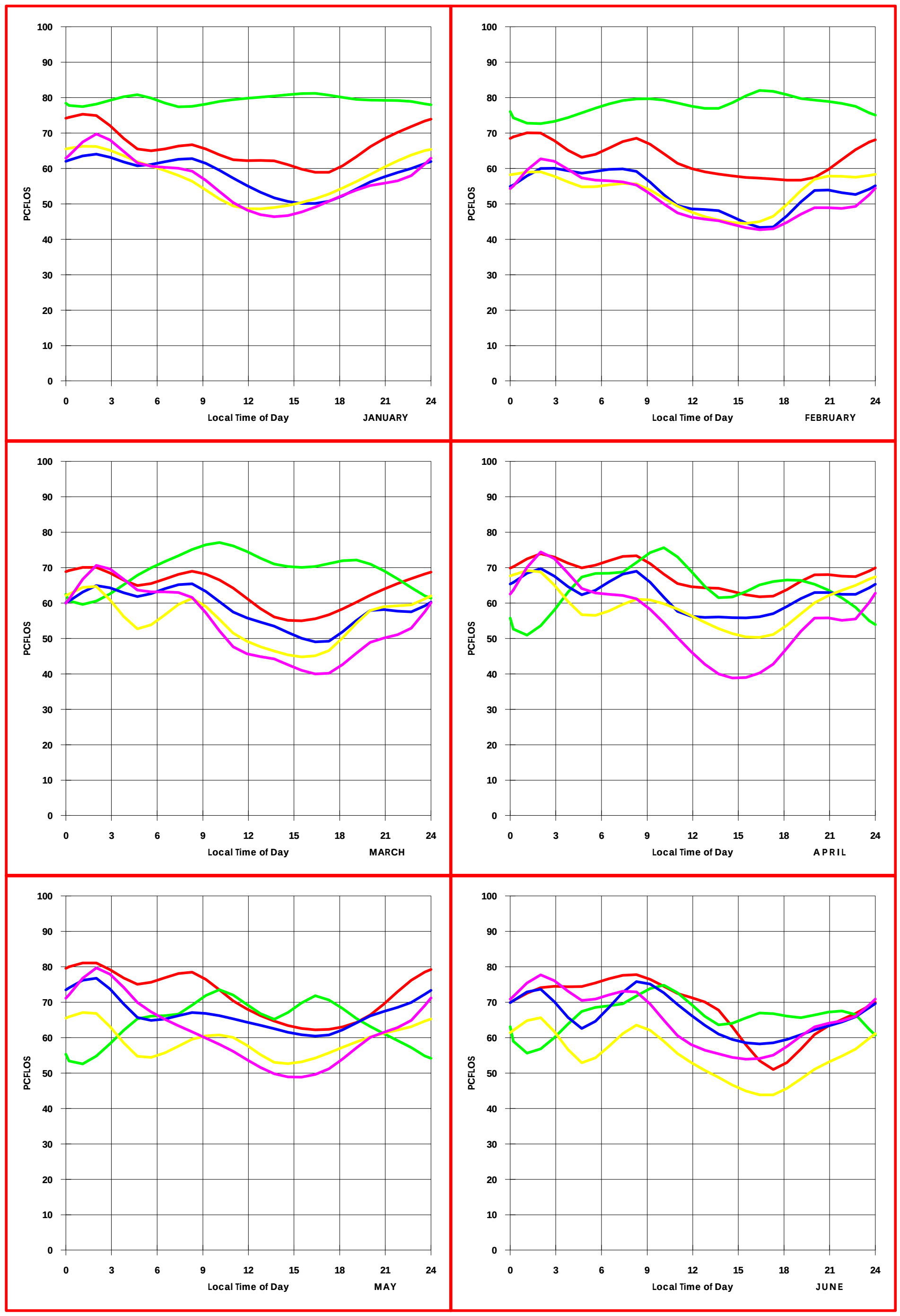


**FIGURE V.2.** Cross sections of PCFLOS at 60° elevation angle for five observing sites, for the months January – June. Sites are as follows: Mesa Negra (red), Mauna Kea (green), Kitt Peak (blue), Sacramento Peak (yellow), and Anderson Mesa (violet).

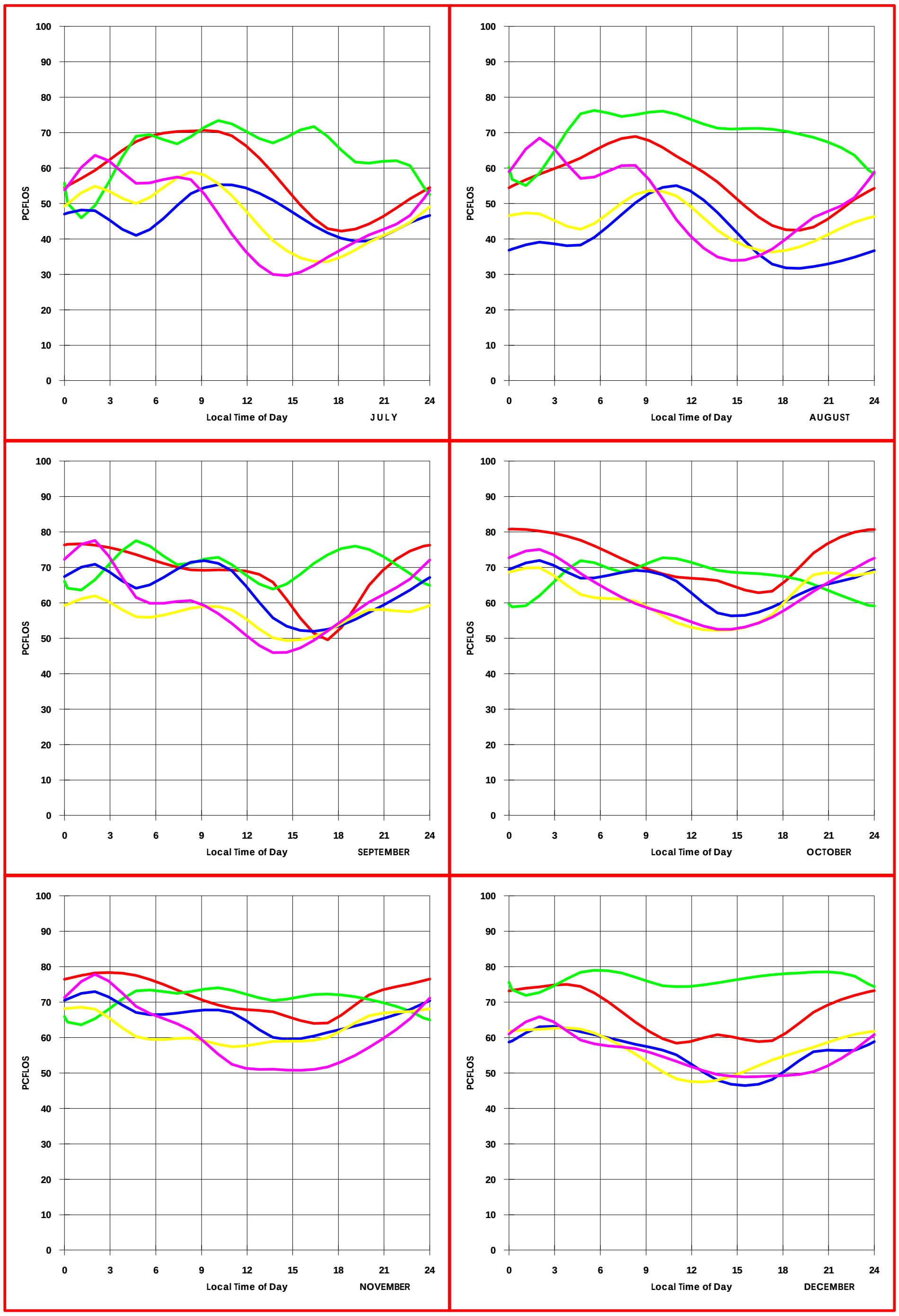


**FIGURE V.3.** Cross sections of PCFLOS as in Figure V.2, for the months July – December.