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Shuttle Landing Facility Cloud Cover Study: Climatological Analysis and Two-Tenths Cloud Cover Rule Evaluation

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Executive Summary

The two-tenths cloud cover rule in effect for all End Of Mission (EOM) Space Transportation System (STS) landings at Kennedy Space Center (KSC) states: "*for scattered cloud layers below 10,000 feet, cloud cover must be observed to be less than or equal to 0.2 at the de-orbit burn go/no-go decision time (approximately 90 minutes before landing time)*". This rule was designed to protect against a ceiling (below 10,000 feet) developing unexpectedly within the next 90 minutes (i.e., after the de-orbit burn decision and before landing). In order to test the validity of this rule, the Applied Meteorology Unit (AMU) developed a database of cloud cover amounts and weather conditions at the Shuttle Landing Facility (X68) for a five-year (1986-1990) period. Once this database was completed a comprehensive statistical and climatological analysis was performed. The data analyzed included both a climatology of the surface observations and observed conditions one and two hours subsequent to given initial conditions. For both analyses the data were categorized by month, season, time of day, daytime hours only, and surface and upper-air wind direction. As a result of these analyses, the AMU developed nomograms to help Spaceflight Meteorology Group (SMG) and Cape Canaveral Forecast Facility (CCFF) forecast cloud cover for EOM and Return to Launch Site (RTLS) at KSC.

The climatological analysis indicates the best time to land the shuttle at KSC is during the summer (80%-85% opportunity) while the worst time is during the winter (65% opportunity). When the data are categorized by time of day, the analysis shows the highest frequency of landing opportunities occurs for the 0100-0600 UTC (80%-85% opportunity) and 1300-1600 UTC (75% opportunity) time periods. The worst time of the day to land a shuttle is near sunrise (1100-1300 UTC) and during the afternoon (1700-2100 UTC). For both time periods, the frequency of landing opportunities is approximately 60%-70%.

A major goal was to determine the validity of the 0.2 cloud cover rule for several stratifications of the data (e.g., seasons, months, time of day, wind direction). To address this question, the analyses focused on comparing the percent of observed weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover below 10,000 feet at X68. These comparisons were performed by using chi-square tests for homogeneity to determine if the percent of weather violations subsequent to the two different initial conditions are the same.

For the majority of these data categorizations there is a significant difference in the proportions of weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover.

In other words, for most categories there is no evidence the 0.2 critical cloud cover amount should be changed to 0.3. However, for the following categories:

- Month of May,
- Month of October,
- 700 mb northerly wind category,
- 1500 UTC category, and
- 1600 UTC category,

there is evidence the proportions of weather violations subsequent to 0.2 and 0.3 initial cloud cover may not be significantly different, thus, the 0.2 rule may be overly conservative for these five categories. Additional investigation is required to determine whether or not the proportions of weather violations for these five categories are significant, and therefore, whether or not the 0.2 cloud cover rule should be relaxed to 0.3 for any of the five categories. However, further analysis requires expansion of the two-tenths cloud cover data base.

If the critical cloud amount was changed from 0.2 to 0.3 for these categories, the number of landing opportunity hours would increase approximately 60-70 hours per year per category.

In order to take full advantage of landing opportunities, new short term local forecasting methods, which can better analyze the current conditions, their interactions, and how those interactions are likely to affect the short term (one to two hours) forecast, must be implemented. Artificial neural networks (ANN) have shown tremendous potential in the area of pattern recognition and data association and are particularly successful when the input data are highly correlated or when the system is highly non-linear.

A proof of concept artificial neural network should be developed which can predict whether or not there will be a constraint violation at the 90 minute forecast time using the data already compiled as a part of this study for training.

In summary, the recommendations from the 0.2 cloud cover rule evaluation are:

- Update the two tenths cloud cover database to include data beyond 1990.
- Re-examine the data for May, October, 1500 and 1600 UTC, and 700 mb northerly winds using the expanded database to determine whether the 0.2 cloud cover rule could be changed for these categories.
- Develop a proof of concept artificial neural network (ANN) to produce a probabilistic estimation of a constraint violation for the shuttle landing forecast. The final product would be used as a forecast tool or aid.

1.0 Introduction

The work described in this report was performed under the National Aeronautics and Space Administration (NASA) AMU Task 003. The purpose of this task is to develop databases, analyses, and techniques leading to the improvement of the 90 minute forecasts for Space Transportation System (STS) landing facilities in the continental United States and elsewhere. This subtask includes evaluation of the validity of the two tenths cloud cover rule and the development of forecast techniques to improve cloud cover forecasting at KSC within the framework of the rule. The rule, which is in effect for End Of Mission (EOM) STS landings at KSC, states the following:

> *"For scattered cloud layers below 10,000 feet, cloud cover must be observed to be less than or equal to 0.2 at the de-orbit burn go/no-go decision time (approximately 90 minutes before landing time) "(1).*

The AMU's work under this subtask is:

1. Develop a database for study of weather conditions relating to marginal violations of this landing constraint,
2. Perform a climatological assessment of the two-tenths cloud cover rule,
3. Develop forecast techniques or rules of thumb to determine when the current conditions are or are not likely to result in an unacceptable condition at verification time, and
4. Validate the techniques and transition to operational use.

The work performed to date includes the development of a X68 database and a climatological assessment of the two-tenths cloud cover rule. In addition, nomograms have been developed for CCFF and SMG forecasters which will help them in making cloud cover forecasts for EOM and RTLS at KSC. Future work on this task will include transitioning nomograms to operational use and developing and validating new forecast techniques and transitioning these to operational use.

Although this study was aimed at the shuttle landing rule stated above, its results could be applied to other STS operations such as RTLS or aid in further understanding of cloud conditions at KSC for launch support. This study also has direct applications for other operations where a climatology database is needed for cloud trend forecasts. The work performed included developing a surface observation database for the X68 (Shuttle Landing Facility (SLF)) and performing a statistical analysis of this data with respect to the weather conditions associated with the two-tenths cloud cover rule at KSC. Data analyzed in this study consisted of surface observations from station X68 for the period 1986 through 1990. Section 2.0 describes the dBASE IV database used to organize the data and the procedures employed to prepare the data for analysis. Section 3.0 describes trends in the weather conditions in the hourly surface observations while Section 4.0 describes trends observed in weather conditions one and two hours subsequent to given initial conditions. Section 5.0 analyzes the persistence of observed weather conditions one and two hours subsequent to initial conditions. Section 6.0 presents the results of a statistical test of observed weather conditions subsequent to initial conditions of 0.2 and 0.3 cloud cover. Section 7.0 discusses the results of analyses performed after excluding the nighttime observations from the database while Section 8.0 describes analysis of categorizing the cloud cover data by upper-level wind direction. Section 9.0 presents nomograms which were developed for the Spaceflight Meteorological Group (SMG) and Cape Canaveral Forecast Facility (CCFF) forecasters. Section 10.0 summarizes the results of the two-tenths cloud cover study and discusses the plans for follow on work to this study.

2.0 Data Preparation

2.1 Surface and Upper-Air Observation Database

Data acquired for the two tenths cloud cover study at KSC included hourly surface observations (no special observations were included) at the X68 Shuttle Landing Facility (SLF) and upper-air observations from the CCAFS (Cape Canaveral Air Force Station-74794) rawinsonde site for the five year period, 1986 to 1990. The X68 surface data were obtained from Marshall Space Flight Center (MSFC). Upper-air observations were obtained from Computer Sciences Raytheon (CSR) Meteorology Section and from the USAF Environmental Technical Applications Center (ETAC). The database was developed using dBASE IV on one of the AMU's PCs. Table 1 lists the data pertinent to the study. In addition to the above data on electronic media, hard copies of surface observations from forms FM10a and 10b were also used for analysis purposes. These forms were obtained from various sources including 45th Weather Squadron, National Climatic Data Center (NCDC) at Asheville, N. C., and ENSCO, Inc.

Table 1. Key Weather Elements Available for Analysis

Year	Visibility	Wind Speed
Month	Present Weather	Temperature
Day	Sea-level Pressure	Total Cloud Cover
Time	Dew Point	Cloud Heights

Ceiling Height	Wind Direction	Cloud Amounts

The need for the form FM 10as and 10bs arises from the lack of precision in the cloud information contained within the MSFC X68 surface database. In this database, cloud amounts are listed as scattered (0.1 to 0.5), broken (0.6 to 0.9), or overcast (1.0). This precision is not sufficient for analysis of the 0.2 cloud cover rule. Fortunately, cloud cover amounts to the nearest tenth are contained within the form FM 10bs for every third hour. The procedure used to enhance the MSFC X68 data base with the additional information contained within the form FM 10as and 10bs is described in the following paragraph.

After the X68 surface observations were loaded into a dBASE IV database, observations which did not violate STS landing weather constraints but yet included clouds with bases below 10,000 feet were extracted. Approximately 22,000 out of 43,821 observations satisfied this criteria. The landing weather constraints used in this analysis were defined as follows:

- Ceilings (cloud cover greater than 0.5) below 10,000 feet at X68.
- Rain, drizzle, thunderstorms, showers, or thunder at X68.
- Sustained cross-winds equal to or greater than 10 knots at X68.
- Visibility less than 7 nautical miles at X68.

It is important to note only X68 observations were used to determine weather constraint violations.

For the selected observations, the form FM 10bs were used to estimate the cloud cover amounts below 10,000 feet. The cloud cover amounts for every three hours were entered into the data base as reported on the form FM 10bs. The cloud cover amounts for the off hours were based upon the form FM 10b data and entered into the database.

The cloud cover estimation for the off hours was somewhat subjective; however, the analyst attempted to follow the hour-to-hour trends in the data. For example, if the clouds were increasing or decreasing over a period of several hours, the analyst would insert values for cloud amounts in the off hours to reflect the upward or downward trend in the cloud amounts. This was not done in an automated fashion or by simple interpolation; each case was analyzed manually. Thus, this methodology could be a possible source of error in determining the cloud amounts below 10,000 feet which are used in this study. In addition to the cloud interpolation for the off hour data, there are two other possible sources or error which may occur in estimating the hourly cloud cover.

First, ceilings could only be measured accurately to approximately 3700 feet above the surface because a laser ceilometer was not installed at X68 until 1991. This could lead to an error in determining whether clouds are above or below 10,000 feet. Secondly, another source of error could be in the actual observed cloud amounts as determined by the weather observers. This error could be as high as +/- 1/10 depending upon how many layers of clouds were present.

2.2 Preparing Data for Analysis

After the X68 surface database was finalized, AMU personnel developed dBASE IV programs to analyze the five years of data. These programs were developed to ingest the surface database and produce analyses correlating initial weather conditions with actual observed X68 weather observations one and two hours after an initial weather condition.

The first set of observations analyzed were the hourly surface observations, which were in turn used as the initial conditions for studying the relationship between initial conditions and the weather conditions at one and two hours subsequent. These data were first examined as a whole and then categorized by each of the following:

- Individual month,
- Months grouped by season,
- Time of day (expressed in UTC),
- Surface and Upper-Air Wind direction, and
- Individual Month (Daytime Only).

The seasons were divided to reflect Florida’s weather (i.e., Summer: June-August; Fall: September-December; Winter: January-March; and Spring: April and May). In addition, since precipitation events are a significant source of weather violations, wind direction sectors were divided to match the Ronald Holle (2) sectors for KSC’s thunderstorm and lightning climatology. These wind sectors were defined as the following:

- North: 339°- 023°
- Northeast: 024°- 113°
- Southeast: 114°- 158°
- South: 159°- 203°
- Southwest: 204°- 293°
- Northwest: 294°- 338°

The hourly surface observation data were categorized by weather condition. Each observation was assigned to exactly one of the categories defined below in Table 2.

Appendix A contains figures illustrating the distribution of the weather condition categories in Table 2 for the different categorizations listed above.

The next step in the study was to analyze the observed conditions one and two hours subsequent (T+1 and T+2 hours) to a given initial weather condition. These data were analyzed for the same categorizations as for the initial weather conditions (i.e., all data, months, months (daytime only), seasons, hours, and both surface and upper-air wind direction). Figures relating the observed conditions at one and two hours from an initial condition for all hours-all months are found in Appendix B, for seasons in Appendix C, for months in Appendix D, for hours in Appendix E, for surface winds in Appendix F, for daytime hours only in Appendix G and for 850/700 mb wind sectors in Appendix I.

Additional analyses of the initial conditions at X68 included examining the persistence for all of the cloud cover groups (0.0 to 0.5 and WX) within each of the categories. This information is contained in Tables 3 and 4 in Section 5.0. Also, a chi-square statistical test was performed to see if there were any significant differences in the number of weather violations between 0.2 and 0.3 of cloud cover. This information is summarized in Sections 6.0, 7.2.2, 7.2.3, and 8.2.2.

Table 2. Weather Condition Categories for Hourly Surface Observations	
Category	**Definition**
Visibility Violation	Visibility less than 7 nautical miles.
Ceiling Violation	Ceiling (greater than 0.5 cloud cover) under 10,000 feet.
WX	Any other weather violation (i.e. cross-winds and precipitation) or a combination of one or more violations.
0.0	Clear Skies with no weather violations.
0.1	1/10 cloud cover with no weather violations.
0.2	2/10 cloud cover with no weather violations.
0.3	3/10 cloud cover with no weather violations.
0.4	4/10 cloud cover with no weather violations.
0.5	5/10 cloud cover with no weather violations.

3.0 Climatology of the Hourly Surface Observations

This section describes the results of a brief climatological study of the weather conditions at X68 as defined by hourly surface observation data. The percent occurrence of weather conditions are compared within each of the following categorizations:

- Time of day,
- Individual months,
- Months grouped by season, and
- Surface wind direction.

Figures illustrating the percent occurrence of weather conditions in the hourly surface observation data for each of the above categorizations are contained in Appendix A. The hourly data, described in this section, are used as the initial conditions for the analyses presented in the next section.

The trends in the percent occurrence of weather conditions reflect the well known trends in the weather patterns typical of Florida's east coast. The actual values of the percent occurrence within each of the categories, however, provide a climatological indication of the probability that landing conditions will be acceptable for a given time of day, season, or wind flow pattern. Key points summarizing the major findings of the study are listed below, followed by a more detailed discussion relating the study's results to Florida's east coast weather patterns.

Key results from these analyses are:

- Fall and winter have a weather violation occurrence percentage ranging from 30% to 40%, the highest within the seasonal categorization.
- The summer months have a weather violation occurrence percentage ranging from 15% to 20%, the lowest within the seasonal categorization.
- The highest percentage of weather violations (30%) occur around sunrise from about 1100 to 1300 UTC. After sunrise, the percent occurrence of weather violations drops to 20% to 25% for several hours (1300 to 1600 UTC) and peaks again in the early afternoon (1700 to 2100 UTC) at 25% to 30%.
- Southeast and south surface wind sectors have the lowest percent occurrence of weather violations at 15%.
- North and northwest surface wind sectors have the greatest percent occurrence of weather violations at 25% - 30%.

3.1 All Data

The total percent occurrence of weather violations for all of the data is near 25% with ceilings and "WX" each having a percent occurrence of approximately 10%. The visibility violation category has a percent occurrence of about 5%. Clear skies below 10,000 feet have a percent occurrence slightly higher than 25%. The cloud cover categories from 0.1 to 0.3 have a total percent occurrence of about 37%, and cloud cover categories 0.4 and 0.5 together have about 13%.

3.2 Monthly and Seasonal

This section describes seasonal characteristics of weather condition percent occurrence. The seasons have been divided to reflect local climatology with winter defined as January through March, spring: April through May, summer: June through August, and fall: September through December.

Figure 1 shows the percent occurrence of weather violations for each month. The highest percentage of weather violations occurs during the winter (30% to 40%) followed by the fall (approximately 30%). Figure 1 shows January has a weather violation percent occurrence of almost 38%, the highest of all the months. In fact, fall and winter together, the months from October through March, have a percent occurrence exceeding 15% for ceiling violations alone. These higher percentages during the cooler winter months are related to the cloud and precipitation events associated with synoptic-scale systems. The winter also has a slightly higher percent occurrence of visibility violations than does the summer. This is due primarily to the fog and stratus seen in the winter months.

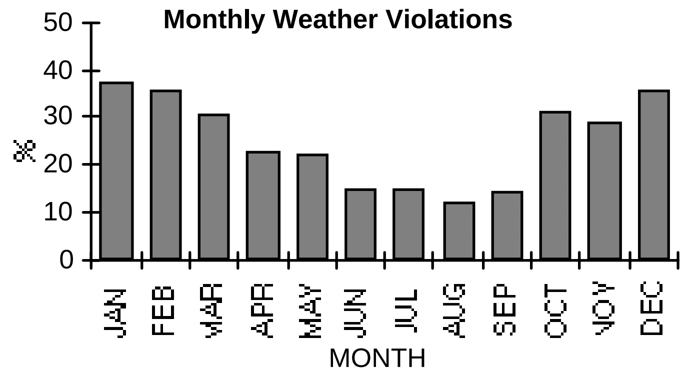


Figure 1. Percent occurrence of weather violations by month.

During spring, the percent occurrence of weather violations drops significantly and is at its lowest point in the summer. The month of August has the lowest weather violation percent occurrence at around 12% (see Figure 1). This decrease during the warmer spring and summer months is related to the lack of synoptic scale storm systems, which produce periods of cloudy and wet weather that can persist for several days. Most of the weather violations in the summer are associated with the normal shower and thunderstorm activity (i.e., unstable atmosphere) which affect the area only a few hours at a time. It is important to note the percent occurrence of ceilings below 10,000 feet is less than 5% for all summer months.

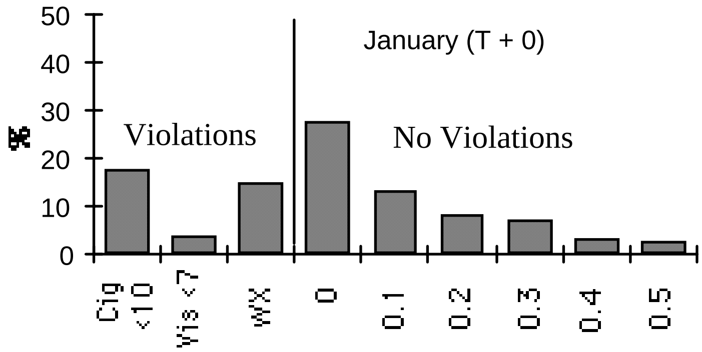


Figure 2. Percent occurrence of weather violations and cloud cover for January.

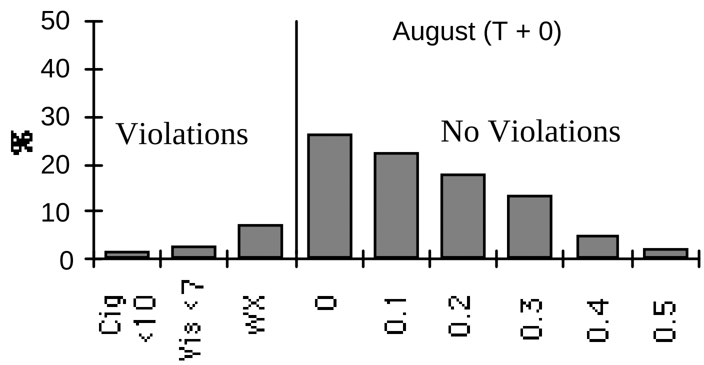


Figure 3. Percent occurrence of weather violations and cloud cover for August.

For more of a detailed breakdown of initial weather conditions, refer to

Appendix A which contains charts showing the distributions of both cloud cover (0.0 to 0.5) and the three weather violation categories (i.e., ceiling below 10,000 feet, visibility less than 7 miles, and all other weather violations). As discussed above, the highest percentage occurrence of weather violations is during the winter and the lowest is during the summer. There are, however, some differences in the distributions of individual cloud amounts. For example, during January (see Figure 2) the 0.1 to 0.3 cloud cover categories all have occurrence percentages of 15% or less; while for August (see Figure 3), these same categories have occurrence percentages ranging from 15% to 25%. Even though there are more weather violations during the winter (especially ceilings), there is less percentage of clouds in the 0.1 to 0.3 cloud cover categories compared to the summer. The most likely explanation of this result is winter is characterized by alternating periods of cloudy and clear weather associated with synoptic-scale systems; while the summer is characterized by ever present clouds, especially during the daylight hours.

Other important characteristics noted include a significant change from season to season in the occurrence percentage of no clouds (cloud cover category 0.0) below 10,000 feet. As shown in Figure 4, the lowest occurrence percentage of clear skies below 10,000 feet occurs during the months September through December (15% to 20%), with the highest percentage of clear skies occurring during the months April and May (30% to 40%) (see Figure 5). In fact, April has approximately a 45% occurrence of clear skies. This anomaly appears to be related to the transition from the winter weather regime to a summer weather regime. Generally by April, most of the stronger synoptic-scale systems do not reach Florida, and deep tropical moisture is not yet present. It is a time when high pressure dominates the weather. There is little cloud cover, and it is dry and breezy a high percentage of the time. During April, X68 averages less than 2 inches of rainfall (see Reference 3).

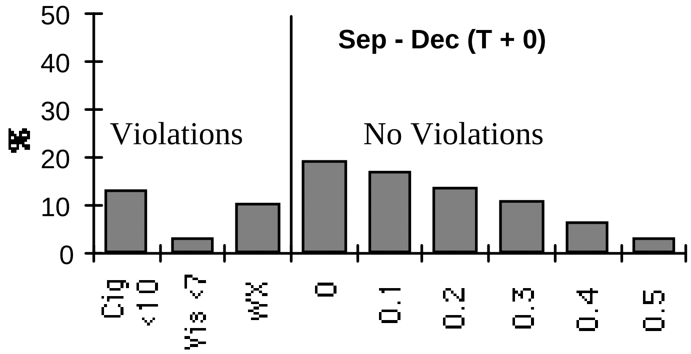


Figure 4. Percent occurrence of weather violations and cloud cover for the fall period.

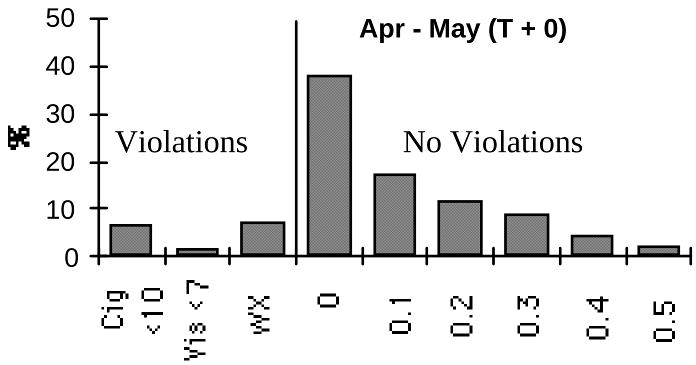


Figure 5. Percent occurrence of weather violations and cloud cover for the spring period.

Another important characteristic in the hourly data is evident in the monthly distributions of weather violations during the transition periods from summer to winter and from winter to summer. During the winter to summer transition (April and May), there is a steady decrease in weather violations. There is a correspondingly steady increase in weather violations during the summer to winter transition (September and October). Figure 1 shows September has weather violation occurrence percentage of 15%, while by October, the number has doubled to near 30%. Most of the increase can be attributed to ceilings below 10,000 feet. This significant change can be linked to clouds from easterly flow conditions, precipitation events from tropical storms, and stalled fronts in the central Florida area. The oceans are still quite warm in October; when cold continental air flows over these warm waters a moist unstable lower atmosphere develops creating considerable cloudiness.

3.3 Time Of Day

The weather violations and cloud cover distribution by hour for the entire database (1986-1990) are described in the following sections. Hours have been grouped together to represent nighttime (0100 to 1000 UTC), sunrise (1100 to 1200 UTC), morning before initial convective activity (1300 to 1600 UTC), afternoon when cloud cover is a maximum associated with showers and thunderstorms (1700 to 2100 UTC), and evening when convective activity decreases (2200 to 0000 UTC).

3.3.1 Nighttime (Hours 0100 to 1000 UTC)

Figure 6 shows the percent occurrence of weather violations is the lowest of the day during the hours 0100 to 0600 UTC, with most hours showing a percent occurrence of less than 20%. The breakdown of individual violations shows ceilings below 10,000 feet have a percent occurrence of about 10%, visibility violations 1% to 3%, and all other weather violations 5% to 7%. The distribution of cloud cover amounts (0.0 to 0.5 clouds below 10,000 feet) remains relatively constant during nighttime and the percent occurrence of clear skies below 10,000 feet is 40% to 45%. Percent occurrence of weather violations starts to increase at 0400 UTC. This is related to early morning development of fog and/or low clouds.

Care must be taken in interpreting nighttime results. The data may be biased towards lower cloud cover amounts because of the lack of visibility of the celestial dome. Also, ceilings could only be measured accurately up to approximately 3700 feet for the data study period of 1986-1990 because a laser ceilometer was not installed at X68 until 1991.

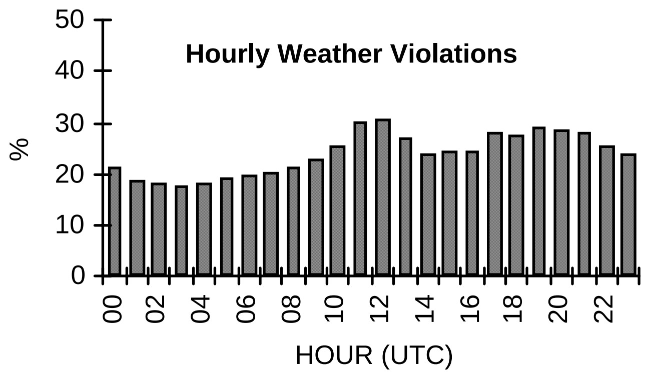


Figure 6. Percentage of hourly weather violations.

3.3.2 Sunrise (Hours 1100 to 1200 UTC)

During the period from 1100 through 1200 UTC, the weather violation percent occurrence is the highest of the day. The high percentage of weather violations near sunrise reflects occurrences of fog and low stratus. This is the time of the day when winds are the weakest and the low-level radiation inversion is the strongest. Both of these factors contribute to the development of fog and stratus. The frequent occurrence of fog and stratus in the early morning hours is reflected by the relatively higher percent occurrence of visibility violations during these hours (e.g., see Figure 7).

3.3.3 Morning (Hours 1300 to 1600 UTC)

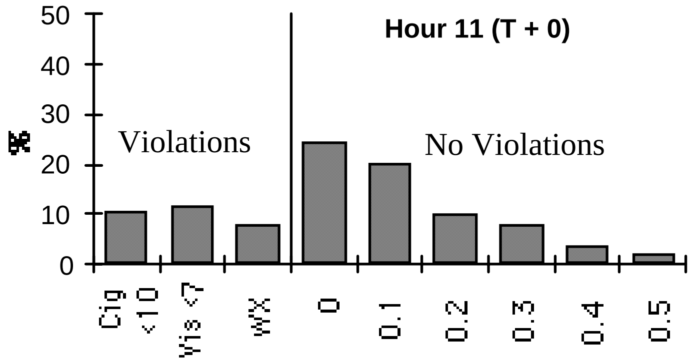


Figure 7. Percent occurrence of weather violations and cloud cover for Hour 11.

The decrease in percent occurrence of weather violations in the morning hours is related to solar warming of the lower troposphere. By 1400 to 1600 UTC, the total weather violation percent occurrence has dropped to less than 25%. Most of the decrease in percent occurrence of weather violations is in the visibility violation category, where it is only 1% to 2%. Around sunrise, the percent occurrence of visibility violations is near 10%, but decreases to 1% to 2% by 1600 UTC. In addition, the percent occurrence of cloud cover amounts of 0.2 and 0.3 below 10,000 feet starts to increase. For example, before 1300 UTC, the 0.0 and 0.1 cloud cover categories have the highest occurrence percentage; by 1400 UTC, the cloud cover categories 0.0 to 0.3 all occur approximately the same percentage of time. This cloud cover increase is due to daytime heating combined with convergent areas resulting from the local sea breeze circulation.

3.3.4 Afternoon (Hours 1700 to 2100 UTC)

By 1700 UTC, the weather violation percent occurrence starts to increase again. This is associated with the development of showers and thunderstorms near the KSC area. Also, the WX violation category (all other weather violations including combinations of ceilings, precipitation, and visibilities) is at its highest between 1800 and 2000 UTC, reflecting the shower and thunderstorm events. By 1700 to 1800 UTC, the 0.2 and 0.3 cloud cover categories show the highest occurrence percentages (15% to 20% respectively), and the 0.0 category shows the lowest. In fact, at 1700 and 1800 UTC the 0.3 cloud cover category occurs about 20% of the time, the highest of any weather condition category. This increase in clouds reflects the developing cumulus field associated with daytime heating. There is also a slight rise noted in the occurrence of 0.4 and 0.5 cloud cover categories.

3.3.5 Evening (Hours 2200 to 0000 UTC)

During this period of time, a gradual decrease in weather violations is noted. In addition, the percent occurrence of the 0.0 and 0.1 cloud cover categories begins to increase. This is probably reflecting the overall reduction in the amount of clouds during the evening hours near sundown. By 0100 UTC, the 0.0 cloud cover category has increased to 35%.

3.4 Surface Wind Direction

In this section, the wind sectors have been defined to match the sectors used by Ronald Holle (2) in his analysis of total area divergence over the KSC/CCAFS area. The sectors have been defined as north (339° to 023°), northeast (024° to 113°), southeast (114° to 158°), south (159° to 203°), southwest (204° to 293°), and northwest (294° to 338°).

The southeast wind sector has the fewest weather violations; its weather violation occurrence percentage is less than 15% (see Figure 8). The north wind sector has the largest number of weather violations, with a percent occurrence of more than 30%, and the northwest, approximately 27%. The high weather violation occurrence percentages with this type of flow are associated with both advection of clouds from the ocean and stratus and fog from the mainland. Although northwest flow conditions have the second largest percent occurrence of weather violations, they also have the highest occurrence percentage of 0.0 cloud cover less than 10,000 feet. This is the result of northwest flow following frontal passages creating clear sky conditions.

Ceilings are the most common weather violations with a north or northwest wind, while other weather violation categories (visibility, precipitation, and a combination thereof) are more common in the northeast and southwest wind sectors. This is expected since northeast flow is associated with showery weather moving in from the Atlantic, and southwest flow is associated with thunderstorms moving in from the mainland.

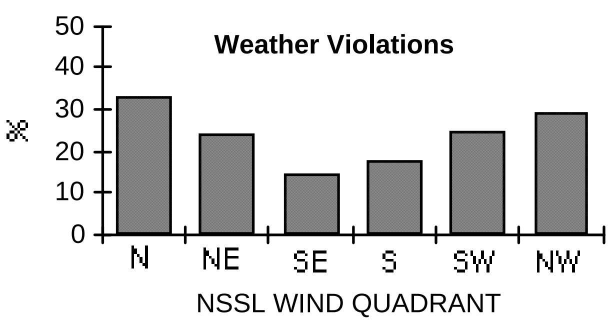


Figure 8. Percentage of weather violations by surface wind direction.

Calm winds have the highest occurrence percentage (around 10%) of visibility less than 7 miles. Most of these low visibility conditions are caused by fog events. Calm winds also have the lowest percentage of clouds in the 0.2 to 0.5 range. This is due to the presence of high pressure dominating the weather with clear skies during most of the day except in the early morning hours when fog and low stratus is more likely to develop.

4.0 Observed Weather Conditions (One and Two Hours) Subsequent to Initial Conditions

This section discusses the relationship between cloud cover amounts at T and the frequency of a weather condition occurring one and two hours subsequently. Charts containing the percent occurrence of weather conditions given an initial cloud cover amount for all of the categories (combined data, seasons, individual months, time of day, and surface wind direction) are contained in Appendices B through F. In all figures, the initial cloud cover amounts are listed in the upper right-hand portion of each plot, weather conditions at T+1 and T+2 hours are given along the y-axis, and the occurrence percentages are given along the x-axis. The 0.0 to 0.5 on the y-axis represent cloud cover amounts with bases below 10,000 feet. The WX on the y-axis contains all of the weather violations.

Key results from these analyses are:

- For initial cloud cover amounts of 0.0 to 0.3, there is at least a 75% to 80% chance of not having a weather violation one and two hours later. (For an initial cloud cover of 0.2 it is generally greater than 80%.)
- For initial cloud cover amounts of 0.1 through 0.5, the winter has the largest percent occurrence of weather violations, and the summer has the least.
- For initial cloud cover amounts of 0.1 through 0.5, the largest percent occurrence of weather violations occur from 1000 to 1300 UTC and the least from 2000 to 2300 UTC.
- For initial cloud cover amounts of 0.1 through 0.5, the highest percent occurrences of weather violations occur with a southwest wind.
- Given initial conditions of cloud cover amounts from 0.0 to 0.3, persistence of the initial condition is the dominating characteristic of the T+1 and T+2 weather conditions.

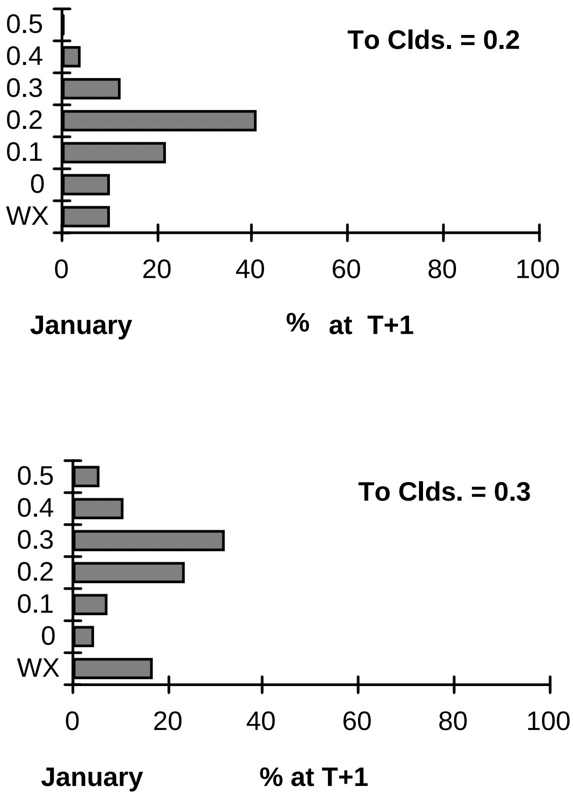
4.1 All Data

Plots of the observed weather conditions (one and two hours) subsequent to initial conditions for all of the hours combined are shown in Appendix B. For initial cloud cover amounts of 0.0 to 0.3 the percent occurrence of no weather violations is greater than 80%. Percent occurrence of no weather violations cases decreases to 60% to 70% for cloud cover amounts of 0.4 and 0.5.

4.2 Monthly and Seasonal

A discussion of the results of seasonal and monthly categorization of the observed weather conditions one and two hours subsequent to initial conditions is contained in this section. As mentioned previously, the seasons were defined as winter: January through March, spring: April and May, summer: June through August, and fall: September through December. Charts of the results of the seasonal and monthly categorizations are contained in Appendices C and D, respectively.

Key results similar to those found for the hourly surface data as a whole (see Section 3.0) are found in the observed conditions one and two hours (T+1 and T+2 hours) subsequent to a given initial condition. For example, for nearly all initial cloud cover groupings (0.0 to 0.5) the highest percentages of weather violations occur during the winter with the least during the summer. This occurs for both T+1 hours and T+2 hours. This can easily be seen by a comparison of data for the initial cloud cover condition of 0.2 for January (Figures 9a and 9b) and August (Figures 10a and 10b). These figures show January has a percent occurrence of weather violations of 10% at T+1 hours and 18% at T+2 hours. However, during August at T+1 hours the percentage of weather violations is near 3% with T+2 hours being approximately 5% for 0.2 initial cloud cover. Similar patterns can also be seen in other winter and summer months. These trends in the data are consistent with the winter months having a higher frequency of ceiling violations persisting over a relatively long period of time. These events are associated with synoptic systems (i.e., low pressure areas, cold fronts, etc.). During the summer months most of the weather violations are associated with the showers and thunderstorms which span relatively short periods of time.



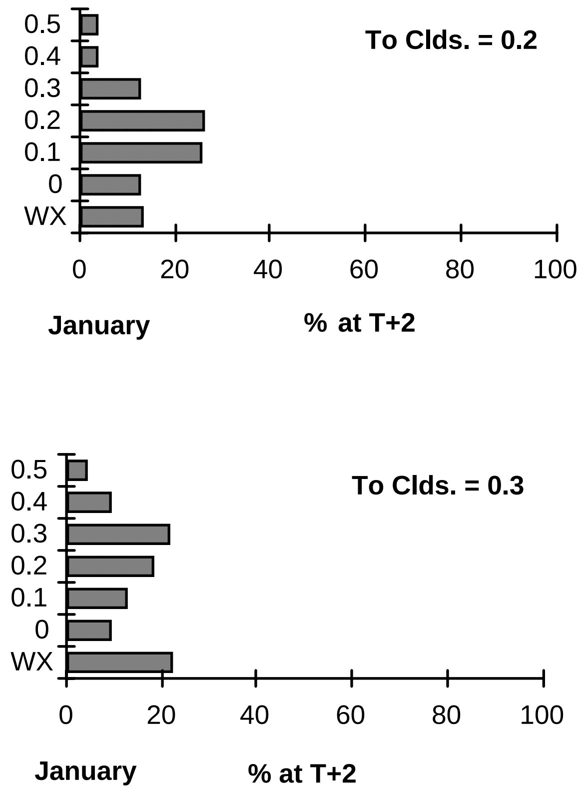


Figure 9a. Percent occurrence of cloud and weather conditions at one hour after initial condition of 0.2 and 0.3 cloud cover.

Figure 9b. Percent occurrence of cloud and weather conditions at two hours after initial condition of 0.2 and 0.3 cloud cover.

Another important characteristic is evident in the percent occurrence of weather violations categorized by month. The data indicate for most months, except January and February, the total percent occurrence of no weather violations is greater than 80% for cloud cover amount groupings of 0.0 through 0.3.

4.3 Time Of Day

This section describes the results of analyses of the time of day categorization of the observed weather conditions one and two hours after a given initial condition. Charts for all of the hours are contained in Appendix E. As mentioned previously, care should be taken in drawing conclusions from the nighttime data due to the possible errors in determining cloud cover amounts during low-light conditions.

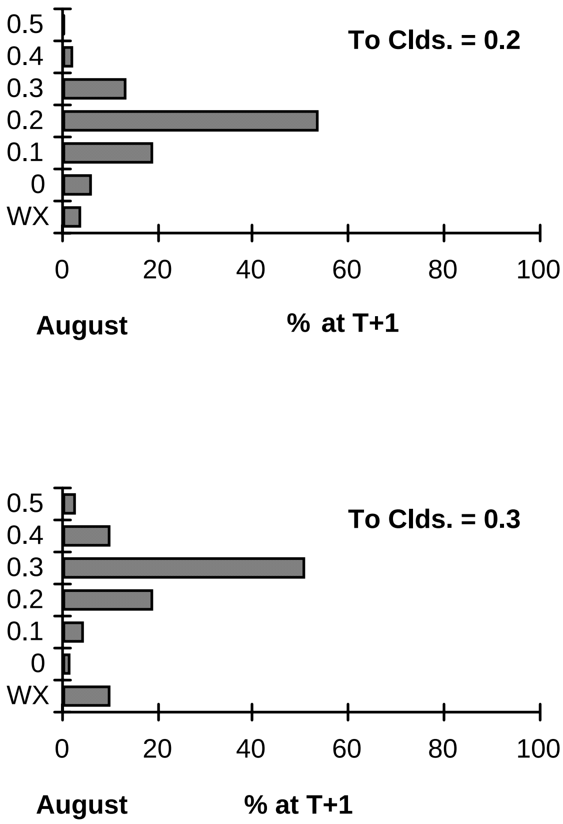


Figure 10a. Percent occurrence of cloud and weather conditions at one hour after an initial condition of 0.2 and 0.3 cloud cover.

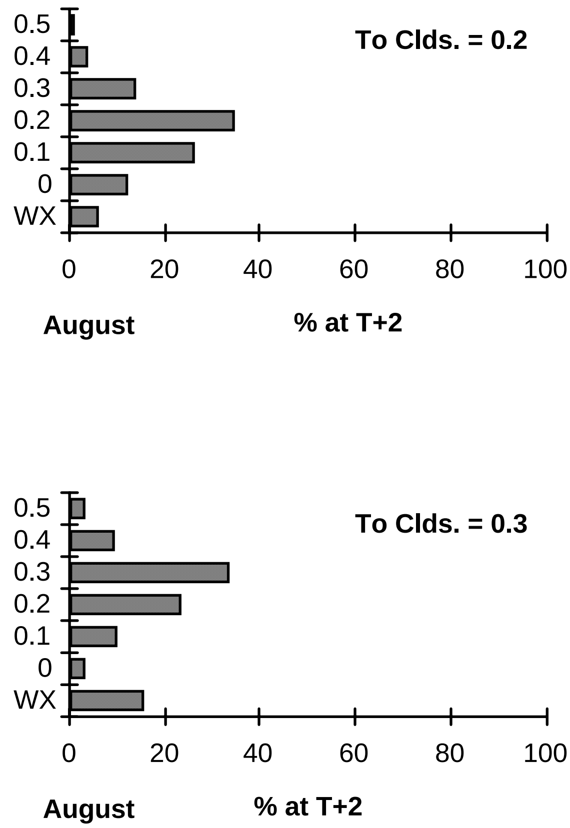


Figure 10b. Percent occurrence of cloud and weather conditions at two hours after an initial condition of 0.2 and 0.3 cloud cover.

Given an initial condition of 0.0 to 0.3 cloud cover, the data indicate the hours near sunrise have the highest percent occurrence of weather violations. The violations start to increase at 0700 UTC and reach a peak near 1200 UTC. For hours 0900 to 1400 UTC weather violations at T+2 hours for initial clouds of 0.2 are 10-20% (see Figure 11). This peak is associated with the fog and low stratus events which are most likely to occur near sunrise (near 1200 UTC).

During most other daylight hours, the percent occurrence of weather violations for cloud cover groupings of 0.0 through 0.3 are less than 20% (for 0.2 it is generally less than 10%), with the smallest percent occurrence of weather violations evident in the late afternoon and evening around 2000 to 2300 UTC (see Figure 12 for T+2 hours at 2300 UTC). This is the result of the decreasing frequency of clouds and precipitation events during this time of the day.

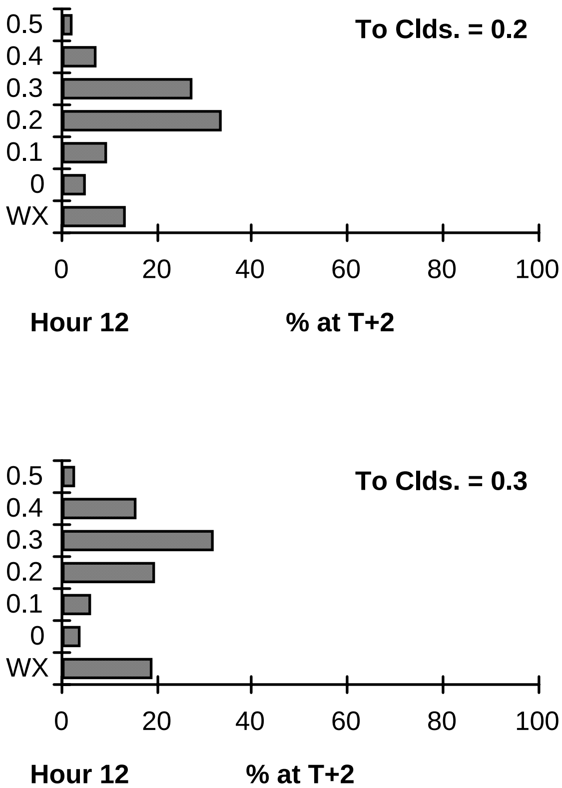


Figure 11. Percent occurrence of cloud cover and weather conditions at two hours after an initial condition of 0.2 and 0.3 cloud cover for Hour 12.

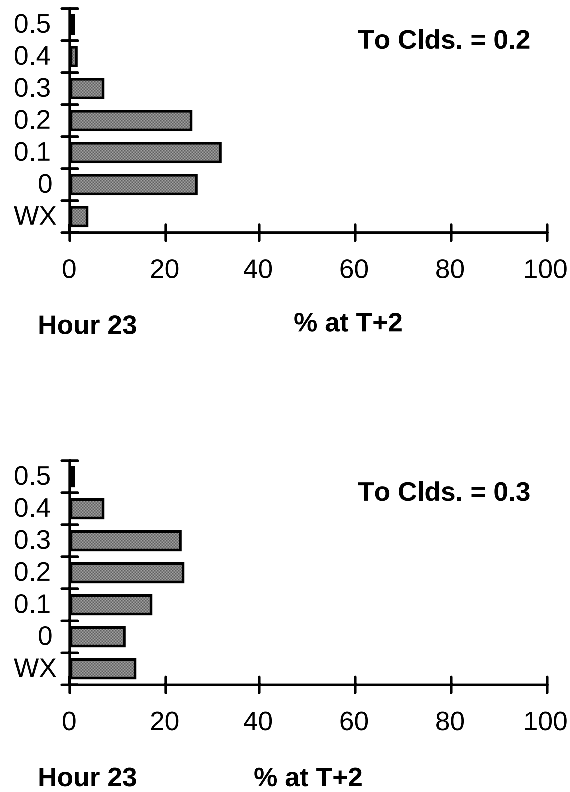


Figure 12. Percent occurrence of cloud cover and weather conditions at two hours after an initial condition of 0.2 and 0.3 cloud cover for Hour 23.

Another important characteristic of the hourly data is the strong tendency for initial conditions to persist. For example, given initially clear skies (below 10,000 feet) during the late afternoon and evening, there is at least an 80% chance of clear skies one and two hours later with some individual hours characterized by percentages exceeding 90% (see Hour 00 in Figure 13). The tendency for initial conditions to persist is also evident in the late morning in the 0.2 and 0.3 cloud cover categories because of the diurnal cumulus field. At 1500 UTC (see Figure 14), persistence of the 0.2 cloud cover group is almost 65% at T+1 hour and approximately 40% at T+2 hours. More detail on the persistence of initial cloud cover conditions is discussed in Section 5.0.

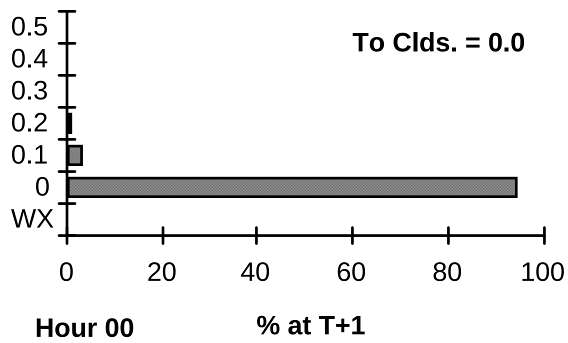


Figure 13a. Percent occurrence of cloud cover and weather conditions at one hour after an initial condition of 0.2 and 0.3 cloud cover for Hour 00.

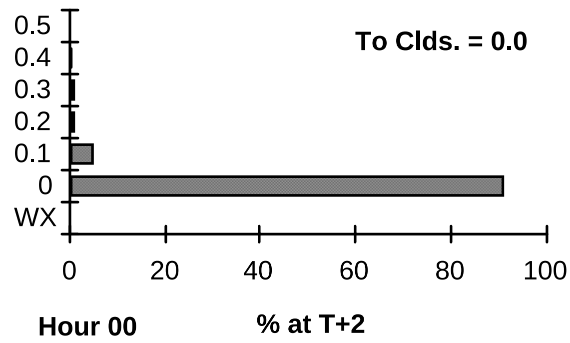


Figure 13b. Percent occurrence of cloud cover and weather conditions at two hours after an initial condition of 0.0 cloud cover for Hour 00.

4.4 Surface Winds

This section describes the observed weather conditions one and two hours after given initial conditions categorized by surface wind flow direction. As discussed in Section 4.0, the wind sectors are based upon Ronald Holle's thunderstorm and lightning climatology report. The sectors have been defined as north (339° to 023°), northeast (024° to 113°), southeast (114° to 158°), south (159° to 203°), southwest (204° to 293°), and northwest (294° to 338°).

For given initial conditions of 0.0 through 0.3 cloud cover, the data indicate the percent occurrence of weather violations is largest for southwest flow and smallest for southeasterly winds. For southwest flow with an initial cloud cover of 0.2 (Figure 15), the T+1 hour weather violation percentage is 5%, and at T+2 hours it jumps to 13%. The reason for the southwest sector having the greatest percent occurrence of violations is related to the high frequency of showers and thunderstorms with this type of flow pattern, especially during the summer. In addition, an early morning southwest (203° to 293°) flow is also conducive to low stratus and fog development or advection from the St. Johns River Valley.

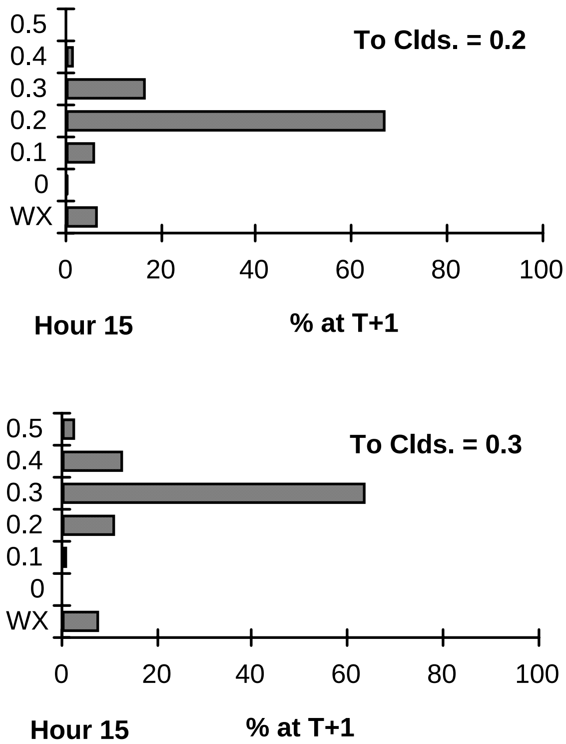


Figure 14a. Percent occurrence of cloud cover and weather conditions at one hour after an initial condition of 0.2 and 0.3 cloud cover for Hour 15.

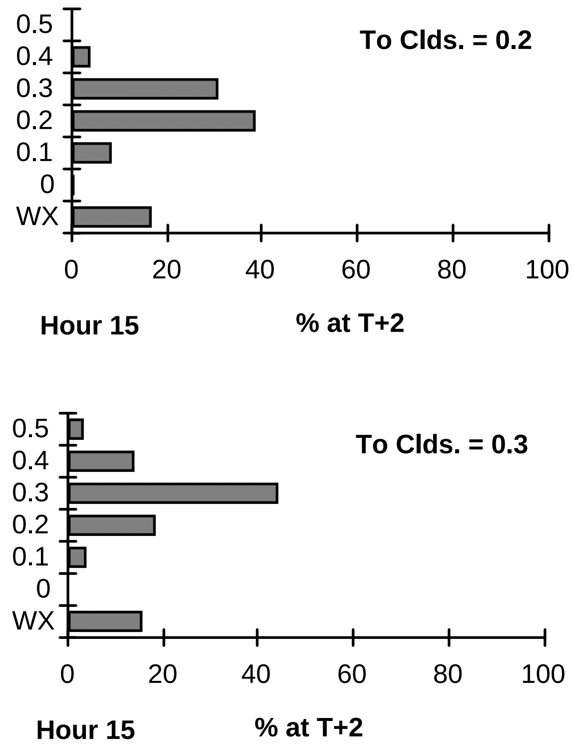


Figure 14b. Percent occurrence of cloud cover and weather conditions at two hours after an initial condition of 0.2 and 0.3 cloud cover for Hour 15.

As mentioned above, the southeast wind sector has the smallest percent occurrence of weather violations with T+1 hours having only 2% and T+2 hours having about 5% (see Figure 16) for an initial cloud cover of 0.2. This is because southeast flow is usually not favorable for low cloud ceilings as compared to northerly or northeasterly flow (i.e. cooler air over a warm ocean), and because southeasterly flow is not favorable for thunderstorm development.

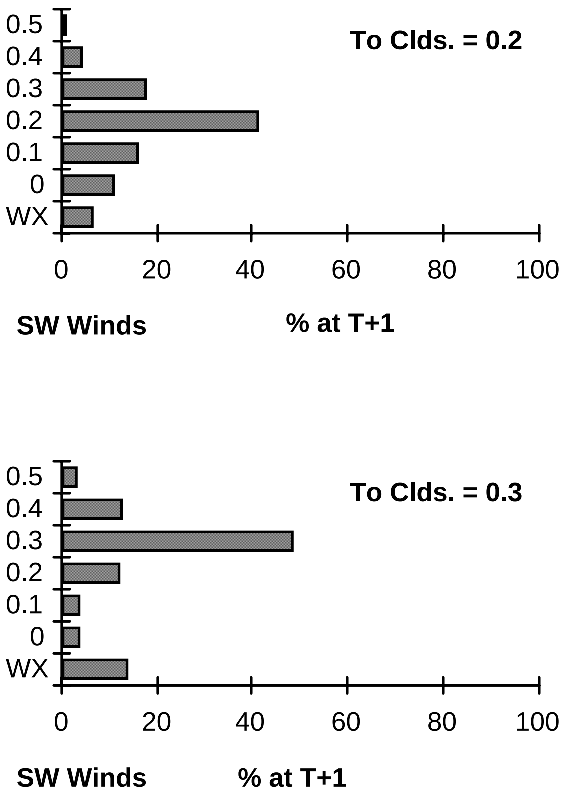


Figure 15a. Percent occurrence of cloud cover and weather conditions at one hour after an initial condition of 0.2 and 0.3 cloud cover for southwest winds.

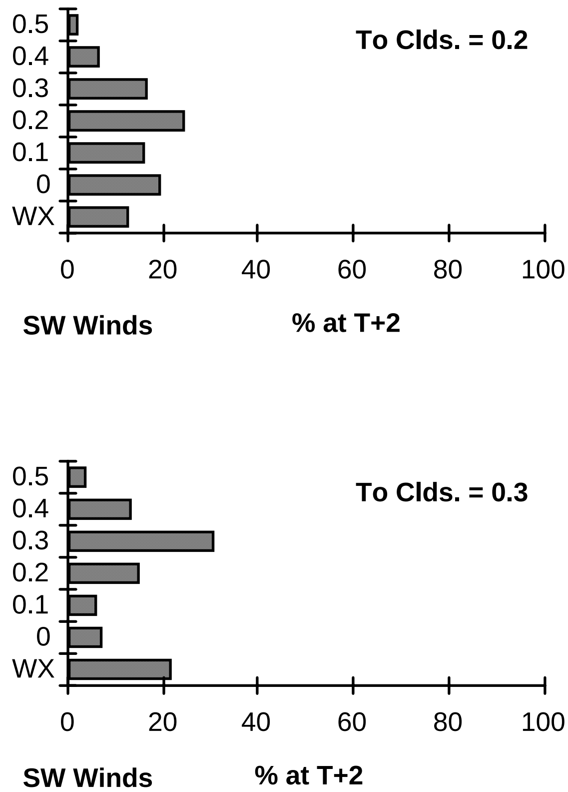


Figure 15b. Percent occurrence of cloud cover and weather conditions at two hours after an initial condition of 0.2 and 0.3 cloud cover for southwest winds.

For almost all wind categories, given an initial cloud cover of 0.0, 0.1, or 0.2, the data indicate 80% of the cases did not have a weather violation at T+1 and T+2 hours. Even for initial cloud cover amounts of 0.0 to 0.3, 75% of the cases did not have a weather violation at T+1 or T+2 hours. Within almost all categorizations, however, there is an increase in weather violations from 0.2 to 0.3 initial cloud cover conditions. Section 6.0 will examine whether the differences between the percent occurrence of weather violations at T+1 and T+2 hours for initial conditions of 0.2 and 0.3 cloud cover are statistically significant.

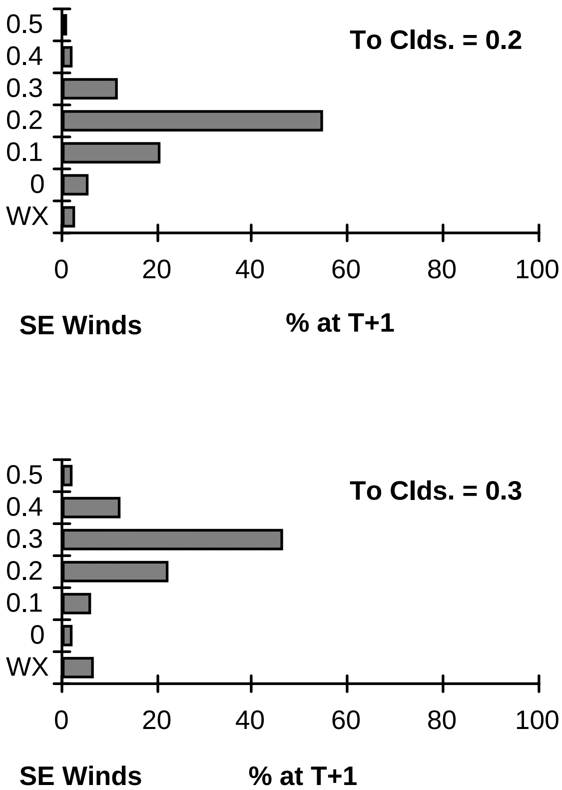


Figure 16a. Percent occurrence of cloud cover and weather conditions at one hour after an initial condition of 0.2 and 0.3 cloud cover for southeast winds.

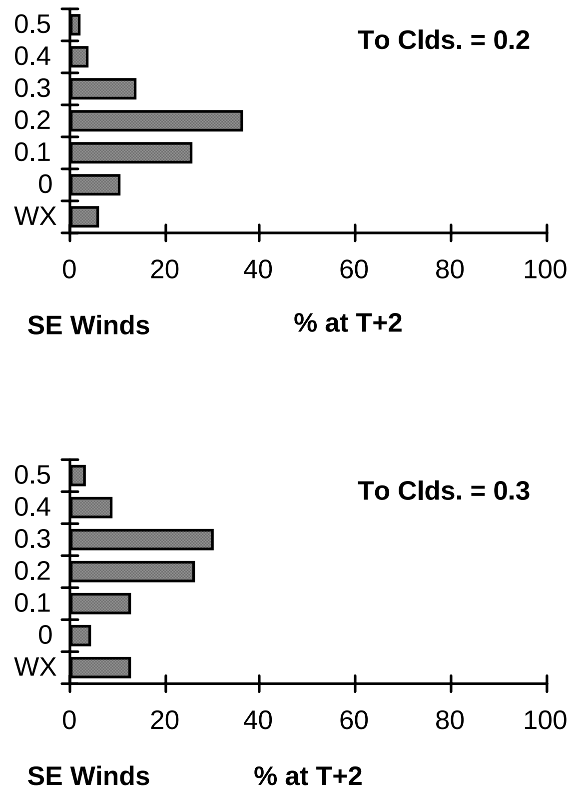


Figure 16b. Percent occurrence of cloud cover and weather conditions at two hours after an initial condition of 0.2 and 0.3 cloud cover for southeast winds.

5.0 Persistence

As discussed previously in this report, persistence of initial weather conditions one and two hours into the future is a dominant characteristic in most of the categorizations (i.e., months, seasons, time of day, and wind direction). This can be seen in the charts in the Appendices and is summarized in condensed form in Tables 3 and 4. These tables show the percentages of persistence of weather violations and cloud cover amounts of 0.0 to 0.5 below 10,000 feet at T+1 and T+2 hours. (Table 5 explains how to interpret the persistence information in Tables 3 and 4.)

There are several important characteristics in the persistence of weather conditions at X68 (see Tables 3 and 4). First, for nearly all categories, given a weather violation existing at time T, a violation was still in effect at T+1 and T+2 hours in more than 60% of the cases. The summer months, when the percentages drop to about 50% at T+2 hours, were the only exception to this relationship. This reduction is related to the very short duration of weather violations associated

Table 3. One Hour Persistence of Weather Conditions															
Initial Weather Conditions															
	Weather Violation		0.0 Cloud Cover		0.1 Cloud Cover		0.2 Cloud Cover		0.3 Cloud Cover		0.4 Cloud Cover		0.5 Cloud Cover	
Category	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count
All	78	10517	81	11497	60	7653	50	5832	44	4610	35	2504	30	1210
Months														
January	86	1387	84	1033	57	491	41	312	32	266	22	133	29	98
February	84	1216	84	1058	51	388	39	269	36	205	31	170	22	78
March	81	1155	82	932	58	520	47	397	41	315	37	253	35	148
April	72	611	87	1645	59	592	44	301	39	239	31	133	32	79
May	66	587	83	1149	62	691	54	571	45	415	39	213	26	94
June	65	544	74	746	63	837	51	658	51	518	36	226	38	71
July	69	550	79	1053	57	721	54	644	49	492	38	194	35	66
August	60	453	77	992	61	845	54	665	51	498	36	187	36	80
September	66	525	71	585	60	733	54	779	47	585	41	285	32	108
October	80	1166	77	577	61	646	45	493	37	378	36	294	25	166
November	83	1038	79	763	61	692	41	400	45	374	32	217	31	116
December	84	1285	83	964	60	497	51	343	41	325	29	199	22	106
Winds														
Calm	73	228	75	495	60	341	45	137	39	77	29	38	30	23
NE	90	2145	79	1711	63	2271	52	2160	44	1645	34	915	28	408
SE	73	778	81	1212	60	1173	55	972	47	703	43	379	44	171
S	72	1103	80	1947	55	1010	48	880	45	724	33	332	25	146
SW	74	2012	82	3082	48	1040	41	730	49	689	33	325	25	175
NW	84	1323	83	1612	64	725	46	309	41	256	28	171	27	77
N	82	1438	82	1438	65	1095	48	644	40	516	35	344	29	210
Hour (UTC)														
0	75	386	94	452	53	475	50	224	45	134	36	91	31	64
1	80	345	89	645	52	341	41	219	32	152	26	87	43	37
2	80	331	86	741	58	303	37	202	29	133	37	79	43	37
3	79	325	86	776	56	334	50	166	32	99	28	85	22	41
4	84	329	86	786	51	292	49	200	31	109	31	71	31	39
5	79	347	87	814	42	271	35	201	28	96	19	59	29	38
6	83	361	88	835	53	253	48	169	36	95	32	71	21	42
7	82	372	86	837	50	242	43	167	31	98	23	71	15	39
8	86	394	83	833	60	234	34	166	23	110	22	60	28	29
9	84	423	76	794	49	288	46	130	43	77	27	67	25	48
10	90	466	58	689	61	275	40	184	40	100	16	70	26	42
11	78	557	59	445	68	372	41	186	34	151	16	74	20	41
12	72	564	76	351	53	479	54	184	49	141	29	75	38	32
13	69	492	67	385	45	362	40	273	49	203	33	73	16	38
14	74	438	63	335	66	290	41	315	42	296	33	115	24	37
15	75	443	68	250	54	357	67	227	64	289	48	165	28	95
16	81	450	70	195	58	276	50	314	58	336	42	184	26	73
17	74	513	78	149	75	231	58	319	52	379	50	171	39	64
18	76	504	84	137	71	272	71	289	58	339	40	209	25	76
19	74	537	93	132	75	244	57	345	41	337	36	164	26	67
20	75	523	82	157	78	280	50	364	38	298	33	148	32	56
21	76	510	95	179	71	427	70	313	61	209	35	119	41	69
22	78	471	89	261	73	375	58	337	39	235	36	90	33	57
23	75	437	90	319	63	380	36	338	31	195	37	106	40	50

Table 4. Two Hour Persistence of Weather Conditions														
	Initial Weather Conditions													
	Weather Violation		0.0 Cloud Cover		0.1 Cloud Cover		0.2 Cloud Cover		0.3 Cloud Cover		0.4 Cloud Cover		0.5 Cloud Cover	
Category	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count
All	68	10517	70	11497	43	7652	33	5832	29	4610	22	2504	17	1210
Months														
January	78	1387	75	1033	38	491	26	312	22	266	14	133	15	98
February	75	1216	75	1058	35	388	29	269	19	205	18	170	10	78
March	72	1155	71	932	42	520	33	397	25	315	20	253	18	148
April	59	611	80	1645	45	592	26	301	24	239	16	133	16	79
May	54	587	74	1149	44	691	39	571	30	415	28	213	19	94
June	48	544	61	746	46	837	33	658	34	518	21	226	17	71
July	53	550	67	1053	41	721	38	644	31	492	19	194	18	66
August	42	453	63	992	42	845	35	665	34	498	21	187	18	80
September	56	525	56	585	43	733	36	779	32	585	26	285	19	108
October	72	1166	67	577	45	646	30	493	24	378	26	294	16	166
November	74	1038	66	763	45	692	29	400	30	374	26	217	22	116
December	75	1285	73	964	47	496	35	343	29	325	18	199	10	106
Winds														
Calm	56	228	62	495	41	341	31	137	25	77	13	38	17	23
NE	80	2145	69	1711	46	2271	36	2160	30	1645	23	915	17	408
SE	61	778	71	1212	44	1173	37	972	30	703	26	379	24	171
S	61	1103	70	1947	36	1010	34	880	28	724	19	332	14	146
SW	62	2012	72	3082	33	1040	25	730	31	689	18	325	11	175
NW	72	1323	73	1612	48	725	32	309	32	256	21	171	10	77
N	70	1438	70	1438	48	1092	31	644	22	516	21	344	17	210
Hour (UTC)														
0	66	386	91	452	35	475	28	224	23	134	11	91	20	64
1	70	345	81	645	39	341	23	219	16	152	15	87	30	37
2	68	331	81	741	43	303	36	202	20	133	20	79	19	37
3	71	325	78	776	37	334	37	166	18	99	16	85	7	41
4	74	329	82	786	33	292	21	200	15	109	14	71	15	39
5	70	347	81	814	34	271	29	201	18	96	19	59	13	38
6	73	361	81	835	36	253	29	169	18	95	18	71	12	42
7	77	372	76	837	45	242	24	167	9	98	11	71	13	39
8	76	394	68	833	43	234	31	166	24	110	15	60	14	29
9	81	423	47	794	43	288	25	130	23	77	16	67	13	48
10	77	466	41	689	53	275	21	184	19	100	11	70	12	42
11	60	557	55	445	41	372	37	186	33	151	20	74	15	41
12	56	564	56	351	31	479	34	184	32	141	24	75	6	32
13	61	492	43	385	36	362	21	273	28	203	18	73	21	38
14	66	438	46	335	42	290	40	315	39	296	37	115	19	37
15	74	443	50	250	34	357	39	227	44	289	32	165	18	95
16	69	450	58	195	47	276	32	314	37	336	32	184	23	73
17	68	513	70	149	61	231	50	319	42	379	32	171	19	64
18	68	504	85	137	57	272	49	289	30	339	24	209	12	76
19	64	537	81	132	60	244	35	345	22	337	15	164	12	67
20	63	523	85	157	58	280	43	364	36	298	24	148	16	56
21	64	510	87	179	56	427	48	313	34	209	18	119	16	69
22	63	471	85	261	51	374	22	337	17	235	19	90	18	57
23	60	437	92	319	37	380	26	338	24	195	19	106	26	50

with summertime showers and thunderstorms. For most of the hourly data, T+1 persistence percentages are 70% or greater with most of the nighttime hours (0100 to 1000 UTC) exceeding 80%. Given a weather violation at time T, 70% to 80% of the cases from the northwest, north, and northeast wind sectors were characterized by a weather violations at T+1 and at T+2. These were the highest percentages from the wind sector categorization. This is not surprising since these flow patterns are associated with a large number of stratocumulus events which have an average life span of more than a day.

The one and two hour persistence percentages for clear skies (0.0 cloud cover below 10,000 feet) were found to be 60% to 70% within most categorizations of the data. The highest clear sky persistence percentages, 80% to 90%, are associated with the nighttime hours. The lowest clear sky percentages are associated with the early morning hours (40% to 50%) and with the summer months (June is near 60%) for T+2 hours. One important point regarding the 0.0 cloud cover group is the rapid change in the total number of clear sky observations between 2300 and 0100 UTC. The number of observations increases from 319 to 645. This increase may be due in large part to the inability to see low cloud cover amounts during low light conditions rather than due to a real decrease in cloud cover.

Another important characteristic of the persistence of weather conditions involves cloud cover amounts of 0.1 through 0.3 during the mid-day hours. For this period, the data indicate an increase in the persistence percentages with time. For example, for an initial cloud cover of 0.2 or 0.3 at 1400 UTC, the persistence percentage is near 42% at T+1 hours. This increases to greater than 60% for 1500 UTC. The percentages are somewhat lower for T+2 hours, but the trend is similar. These persistence percentages remain high through 1700 UTC and then decrease during the 1800 to 1900 UTC time frame. The increases at 1500 UTC are related to the initial development of the cumulus field. The clouds may persist for a couple of hours, but by 1800 to 1900 UTC they will either develop further into significant convective activity or diminish with the reduced afternoon heating. In either case, this would cause a decrease in the persistence percentages at that time.

6.0 Homogeneity Analysis of Observed Weather Conditions Subsequent to Initial Conditions of 0.2 and 0.3 Cloud Cover

This component of the investigation focuses on the comparison of the percent of observed weather violations subsequent (one and two hours later) to initial conditions of 0.2 and 0.3 cloud cover below 10,000 feet at X68. The sample statistics were computed in the following manner. For a given sample with initial conditions of 0.2 cloud cover, the number of weather violations and non-violations one and two hours subsequent to the initial observation were totaled. Then, a similar analysis was performed for initial conditions of 0.3 cloud cover and 2 ∞ 2 contingency tables were constructed (see example in Table 6). These data were then used to perform chi-square tests for homogeneity in the samples. The results of these analyses are presented in Table 7 (T+1 hour - all weather violations), Table 8 (T+2 hours - all weather violations), Table 9 (T+1 Hour - ceiling and precipitation violations), and Table 10 (T+2 Hours - ceiling and precipitation violations).

The chi-square test for homogeneity was used to determine if the percent of weather violations subsequent to the two different initial conditions are the same. After the test statistic was computed (see Tables 7, 8, 9, and 10), it was compared to the 95% χ^2 value for one degree of freedom. If the test statistic exceeded the critical value, the null hypothesis was rejected indicating the proportions of weather violations for the two samples are different. If the test statistic was less than the critical value, the null hypothesis was accepted indicating the proportions of weather violations for the two samples are not statistically different.

Table 6. Contingency Table For All Cases

Initial Condition	Number of Weather Violations at T+1	Number of Non-Violations at T+1	Total
0.2 Cloud Cover	322	5510	5832
0.3 Cloud Cover	522	4088	4610
Total	844	9598	10442

The results of the homogeneity tests are important because they are indicative of the difference in the probabilities of a weather violation occurring at X68 subsequent to initial conditions of 0.2 and 0.3 cloud cover. If the homogeneity test indicates that the proportions of weather violations for the two samples are different, then the probability of a weather violation occurring at X68 subsequent to initial conditions of 0.2 cloud cover is different from the probability for initial conditions of 0.3 cloud cover. More importantly, if the homogeneity test indicates that the proportions of weather violations for the two samples are not different, then the probability of a weather violation occurring at X68 subsequent to initial conditions of 0.2 cloud cover is not different from the probability for initial conditions of 0.3 cloud cover. This result would suggest the 0.2 cloud cover might be overly conservative or inappropriate.

The following sections present the results of the homogeneity analysis. Test statistics are presented in Tables 7, 8, 9, and 10. Values exceeding the critical χ^2 test statistic are annotated with an asterisk. Results discussed in Section 6.1 are based on all weather violations while the results in Section 6.2 are based only on ceiling and precipitation weather violations.

Key results from these analyses are:

- There is a significant difference in the proportions of weather violations (all violations) one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover for the majority of the data categorizations.

- The differences in the proportions of weather violations (all violations) two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are not significant for the months October through December and April.

- The differences in the proportions of weather violations (all violations) one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are not significant for the month of May.

- The differences in the proportions of weather violations (all violations and ceiling and precipitation only) one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are not significant during late morning (1500 and 1600 UTC).

- The differences in the proportions of weather violations (ceiling and precipitation only) one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are significant for the month of May.

- The differences in the proportions of weather violations (ceiling and precipitation only) one hour subsequent to initial conditions of 0.2 and 0.3 cloud cover are significant for the month of October.

- The differences in the proportions of weather violations (ceiling and precipitation only) two hour subsequent to initial conditions of 0.2 and 0.3 cloud cover is not significant for the month of October.

6.1 Chi-Square Analysis based on all Weather Violations

For the majority of the data categorizations (i.e., all, monthly, wind direction, and hour) there is a significant difference in the proportions of weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover. For example, large differences in percent of weather violations between the two initial conditions occur in the months of July through September. For this period, the percent weather violations one and two hours subsequent to initial conditions of 0.3 cloud cover is approximately a factor of two greater than the corresponding value for 0.2 cloud cover. Similar differences are noted for the one hour interval for the total sample and for all of the wind direction categories except north. The two hour interval data show similar results, but the differences generally are not as large. Differences are also large for the morning hours around sunrise (i.e., 1300 and 1400 UTC) and for part of the afternoon and early evening hours (i.e., 1800 to 2000 and 2300 to 0100 UTC).

The large differences in the summer months and the afternoon hours are related to the rapidly developing cumulus field along the sea breeze front and other boundaries on days with mid-afternoon thunderstorm activity. The difference during the early evening hours may be related to early evening thunderstorms associated with the west coast sea breeze. However, further investigation would be required to fully understand the causes of this difference. The large differences noted in most all of the wind categories are probably not related to any one type of meteorological phenomenon but, are rather just a reflection of the large difference in the total sample.

Table 7.

Observed Weather Conditions One Hour Subsequent To Initial Conditions

Category	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at $\alpha = 0.05$
Total Sample	5832	5.52	4610	11.32	116.66*
Months					
January	312	10.26	266	16.92	5.52*
February	269	7.06	205	15.61	8.85*
March	397	5.79	315	11.75	8.06*
April	301	5.98	239	12.55	7.11*
May	571	6.30	415	8.43	1.63
June	658	5.32	518	10.42	10.80*
July	644	4.19	492	12.60	27.31*
August	665	4.06	498	10.24	17.39*
September	779	3.85	585	9.57	18.51*
October	493	8.11	378	12.43	4.44*
November	400	4.50	374	9.63	7.82*
December	343	5.54	325	12.31	9.49*
Expanded Months					
May (4/24 to 6/7)	780	5.64	587	7.67	2.26
October (9/24 to 11/7))	761	6.57	575	11.65	10.59*
Winds					
Calm	137	5.84	77	10.39	1.48
Northeast	2160	5.83	1645	11.37	37.89*
Southwest	730	7.12	689	14.37	19.57*
Southeast	972	3.19	703	7.11	13.64*
South	880	5.45	724	12.29	23.78*
Northwest	309	4.53	256	12.11	10.97*
North	644	6.68	516	11.24	7.50*

* Indicates the proportions of weather violations for the two samples are statistically different.

Table 7.
(Continued)

Observed Weather Conditions One Hour Subsequent To Initial Conditions

Category	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at α = 0.05
Hours (UTC)					
0000	224	4.02	134	10.45	5.77*
0100	219	4.11	152	15.13	13.83*
0200	202	2.48	133	9.77	8.40*
0300	166	6.63	99	7.07	0.02
0400	200	4.00	109	11.01	5.73*
0500	201	7.46	96	13.54	2.81
0600	169	4.73	95	9.47	2.27
0700	167	7.19	98	9.18	0.34
0800	166	6.02	110	12.73	3.74
0900	130	6.15	77	12.99	2.84
1000	184	8.70	100	11.00	0.40
1100	186	5.91	151	13.91	6.20*
1200	184	8.15	141	15.60	4.39*
1300	273	5.13	203	14.78	12.92*
1400	315	5.71	296	14.86	14.01*
1500	227	7.05	289	7.96	0.15
1600	314	9.87	336	10.42	0.05
1700	319	5.96	379	10.55	4.73*
1800	289	6.57	339	12.98	7.09*
1900	345	4.93	337	12.76	13.03*
2000	364	3.85	298	11.07	12.98*
2100	313	4.79	209	8.61	3.09
2200	337	4.45	235	7.66	2.62
2300	338	2.07	195	8.21	11.27*

* Indicates the proportions of weather violations for the two samples are statistically different.

Table 8.

Observed Weather Conditions Two Hours Subsequent To Initial Conditions

Category	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at $\alpha = 0.05$
Total Sample	5832	9.59	4610	16.01	97.67*
Months					
January	312	13.78	266	22.56	7.55*
February	269	15.99	205	29.27	12.07*
March	397	11.08	315	17.46	5.97*
April	301	11.30	239	15.90	2.44
May	571	8.93	415	12.77	3.75
June	658	9.88	518	15.25	7.79*
July	644	7.30	492	17.68	28.91*
August	665	6.47	498	15.86	26.78*
September	779	6.03	585	12.82	18.90*
October	493	13.39	378	13.76	0.02
November	400	10.25	374	14.44	3.15
December	343	11.95	325	16.62	2.97
Expanded Months					
May (4/24 to 6/7)	780	8.59	587	11.75	3.74
October (9/24 to 11/7)	761	11.16	575	13.74	1.94
Winds					
Calm	137	7.63	77	14.29	2.72
Northeast	2160	8.56	1645	13.43	23.23*
Southwest	730	13.15	689	21.92	18.94*
Southeast	972	6.38	703	12.94	21.19*
South	880	11.14	724	18.92	19.26*
Northwest	309	9.06	256	18.36	10.51*
North	644	11.49	516	15.50	4.01*

* Indicates the proportions of weather violations for the two samples are statistically different.

Table 8
(Continued)

Observed Weather Conditions Two Hours Subsequent To Initial Conditions

Category	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at $\alpha = 0.05$
Hours (UTC)					
0000	224	5.36	134	15.67	10.66*
0100	219	5.94	152	16.45	10.78*
0200	202	9.41	133	11.28	0.31
0300	166	10.24	99	9.09	0.09
0400	200	14.00	109	14.68	0.03
0500	201	9.45	96	15.63	2.44
0600	169	8.88	95	16.84	3.72
0700	167	11.98	98	12.24	0.00
0800	166	13.25	110	19.09	1.71
0900	130	13.85	77	23.37	3.06
1000	184	20.11	100	26.00	1.30
1100	186	8.60	151	19.86	8.97*
1200	184	13.59	141	19.15	1.84
1300	273	9.16	203	20.19	11.88*
1400	315	10.16	296	19.59	10.82*
1500	227	16.74	289	15.57	0.13
1600	314	12.74	336	14.88	0.62
1700	319	10.97	379	16.62	4.58*
1800	289	10.38	339	17.11	5.86*
1900	345	6.38	337	16.02	16.02*
2000	364	4.95	298	14.77	18.61*
2100	313	7.03	209	12.44	4.40*
2200	337	6.53	235	8.51	0.80
2300	338	4.14	195	14.35	17.78*

* Indicates the proportions of weather violations for the two samples are statistically different.

Although most of the differences in the percent weather violations are statistically significant, there are some notable exceptions which require discussion and evaluation. First, the differences in the proportions of weather violations two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are not significant for the months October through December. Indeed, the proportions of weather violations for the two hour interval for the month of October are nearly identical. The differences are also not significant for the two hour interval in April and May and for the one hour interval in May. These data indicate a significant difference in the short-term evolution of meteorological conditions in the Cape vicinity in the transition seasons (i.e., spring and fall) as compared to the summer and winter time periods.

By analyzing the chi-square results in Tables 7 and 8, there are a few results which remain unexplained. For example, during October to December, the question arises why the differences in the proportion of weather violations one hour subsequent to initial conditions are significant while the differences at two hours are not significant. Although the answer could be related to a seasonal effect (i.e., summer to winter), it could also be related to some other meteorological phenomenon or perhaps a statistical sampling problem related to having fewer samples during the winter. Further investigation of the expanded two-tenths cloud cover database will be required to resolve this issue.

To further test the significance of the months of May and October, additional analyses were performed for each of these months by extending the analysis time one week surrounding each month (i.e., 24 April to 7 June and 24 September to 7 November). This was done to see how sensitive the analysis was for these specific time periods. The results using these time periods were very similar to actual months themselves. For May (one week either side), the results indicate the differences in weather violations for both one and two hours to initial conditions of 0.2 and 0.3 cloud cover were not significant. For October, the differences were not significant for the two hour interval.

The results also indicate the differences in the proportions of weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are not significant for most of the nighttime hours (0200 to 1000 UTC). However, since the accuracy of estimated cloud cover amounts during the nighttime hours is questionable, these results may not be realistic and should be viewed with skepticism. Finally, the differences in the proportions of weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are not significant during late morning (1500 to 1600 UTC). This is the time of day following morning fog/stratus conditions yet prior to the development of significant convective activity.

6.2 Homogeneity Analysis Based on Ceiling and Precipitation Weather Violations

Since the 0.2 cloud cover rule was written to guard against the development of cloud ceilings below 10,000 feet after de-orbit burn decisions, the homogeneity test was used to analyze the data based on the condition that weather violations only included ceiling and precipitation violations. This includes any time when a ceiling or precipitation weather violation is occurring at X68. It essentially eliminates visibility and cross-wind violations. Tables 9 and 10 show the chi-square results for May, October, and 1500 and 1600 UTC using only the ceiling and precipitation violations. These chi-square results show no significant difference between weather violations (ceiling and precipitation only) at 0.2 and 0.3 initial cloud cover for both the 1500 and 1600 UTC categories. However, during May and October, the differences between weather violations at one and two hours subsequent to initial conditions for 0.2 and 0.3 initial cloud cover (all hours and expanded data sets) are now significant. The only exception to this finding was for October (all hours) when the chi-square analysis did not show a significant difference between the weather violations for 0.2 and 0.3 initial cloud cover for T+2 hours.

Table 9.

Observed Weather Conditions One Hour Subsequent To Initial Conditions (Based on Ceiling and Precipitation Violations Only)

Category	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at $\alpha = 0.05$
Category					
May	552	3.08	406	6.40	6.03*
October	476	4.83	366	9.56	7.22*
1500 UTC	217	2.76	281	5.34	2.01
1600 UTC	301	5.98	326	7.67	0.70
Expanded Months					
May (4/24 to 6/7)	757	2.77	574	5.57	6.70*
October (9/24 to 11/7)	743	4.30	560	9.29	13.12*

7.0 Daytime Data Climatology

During analysis of the hourly data a question arose concerning the validity of the nighttime cloud observations. It is possible the data may be biased towards lower cloud cover amounts due to the lack of visibility of the celestial dome. In addition, cloud ceilings could only be measured accurately up to 3700 feet because a laser ceilometer was not installed at X68 until 1991. On the basis of this information, it is possible the nighttime observations may be masking important relationships in the data or, conversely, may be responsible for false indications of significant relationships. In order to test the effects of the nighttime observations, the monthly data were re-analyzed eliminating the nighttime hours. The daylight hours were determined from X68 sunrise/sunset tables. For this analysis the sunrise/sunset times for the 15th of the month was used to represent the sunrise/sunset for all days of that particular month (see Table 11).

Table 11. Sunrise/Sunset for X68 on the 15th of each month

Month	Sunrise (UTC)	Sunset (UTC)	Hours Used for Daylight Only Analysis (UTC)
January	1217	2247	12-23
February	1202	2312	12-23
March	1132	2331	12-23
April	1057	2349	11-24
May	1031	0007	11-24
June	1024	0023	10-24
July	1034	0023	11-24
August	1052	0002	11-24
September	1108	2327	11-23
October	1124	2253	11-23
November	1146	2229	12-22
December	1208	2228	12-22

Key results from these analyses are:

- Climatology of the daytime data is similar to the complete (24 hour) data.

- Highest occurrence of weather violations is in the winter and lowest is in the summer.

- Daytime data has a less frequent occurrence of clear skies (0.0 cloud cover below 10,000 feet) than the complete data.
  - Daytime data has a higher percentage of clouds in the 0.1 to 0.3 clouds categories than the complete data.

- Observed weather conditions one and two hours subsequent to initial conditions for both the complete and daytime data have similar trends.

  - For initial cloud cover amounts of 0.0 to 0.3, there is at least a 75% to 80% chance of not having a weather violation one and two hours later (daytime data climatology).

  - The differences in the proportions of the weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are not significant for the months of May and October (daytime data climatology).

  - For most all initial conditions, the frequency of weather violations one and two hours subsequent is slightly greater for the daytime data as compared to the complete data.

  - Persistence dominates weather conditions at both one and two hours for initial cloud amounts of 0.0 to 0.3 (daytime data climatology).

- Key results for daytime data using only ceiling and precipitation weather violations are:

  - The differences in the proportions of the weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are not significant for the month of May (all hours and expanded data).

  - The differences in the proportions of the weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are significant for expanded October data.

  - The differences in the proportions of the weather violations one hour subsequent to initial conditions of 0.2 and 0.3 cloud cover are significant for October (all hours).

  - The differences in the proportions of the weather violations two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are not significant for the month of October (all hours).

7.1 Climatology of Monthly Data (Daytime Data Climatology)

This section will briefly describe the monthly climatology of daytime only weather conditions. Figures illustrating the percent occurrence of weather and cloud cover amounts are contained in Appendix A.

Many of the same types of trends present in the complete data climatology are also present in the daytime data climatology. For example, the winter continues to have the highest percent occurrence of weather violations with the summer the least. January daytime data has a weather violation percent occurrence of approximately 40% compared to 38% for the complete data climatology. In addition, the summer months of July and August continue to have the least percent occurrence of weather violations at 15-20% compared to 10-15% for the complete data climatology. These slight increases in weather violations during the daytime are probably the result of ceilings and precipitation events.

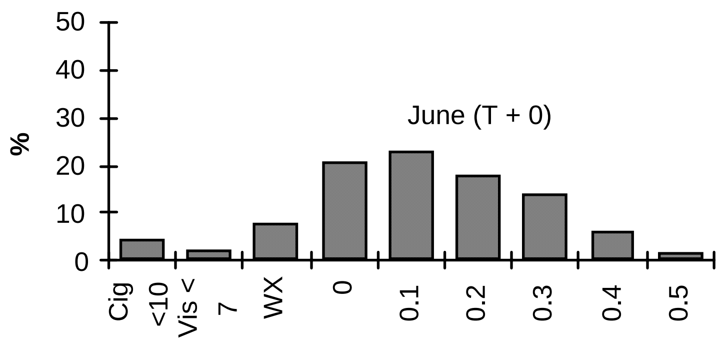


Figure 17. Climatology of weather conditions for June using complete data.

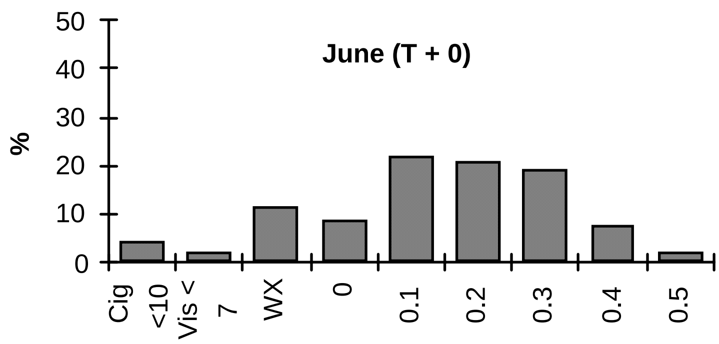


Figure 18. Climatology of weather conditions for June using daytime data.

Another important characteristic present in the climatology of the daytime data is the decrease in the percent occurrence of clear skies (0.0 cloud cover below 10,000 feet) and the increase in percent occurrence in 0.1-0.3 cloud cover categories as compared to the complete data. This is expected since heating during the daylight hours causes more clouds to develop. This occurs during all months but it is more evident during the summer. For example, during June (Figure 17) the percent occurrence of clear skies (0.0 cloud cover) for the complete data climatology is approximately 20% but for the daytime data climatology the percentage decreases to less than 10% (Figure 18). The increase in cloud cover for the daytime data can be seen in both the 0.2 and 0.3 categories. For the complete data climatology the percent occurrence of 0.3 cloud cover is 15% whereas the percent occurrence of 0.3 cloud cover for the daytime data climatology is 20%.

7.2 Observed Weather Conditions (One and Two hours) Subsequent to Initial Conditions (Monthly - Daytime Data Climatology)

This section discusses the relationship between cloud initial cover amounts and the frequency of a weather condition occurring one and two hours subsequent for the daytime data. Charts containing the percent occurrences of weather conditions given an initial cloud cover amount for the daytime data are contained in Appendix G. In addition, bar charts which display the percent occurrence of weather violations for initial cloud cover amounts of 0.0 to 0.5 are contained in Appendix H.

Trends present in the complete data climatology, for observed conditions one and two hours (T+1 and T+2 hours) subsequent to a given initial condition are also present in the daytime data climatology. For example, for all the cloud cover groupings (0.0 to 0.5) the highest percentages of weather violations occur during the winter and the least occur during the summer. This is because the winter months have a higher frequency of ceiling violations associated with synoptic systems while the summer weather violations are associated with shorter duration showers and thunderstorms. In addition, overall weather violation percentages show similar trends between the two climatologies; however, the daytime data weather violation percentages are slightly higher than the complete data percentages. Also, for all months except January, the total percent occurrence of no weather violation conditions is greater than 80% for cloud cover categories of 0.0 through 0.3.

7.2.1 Persistence

As in the complete data climatology, persistence of weather conditions is a dominating characteristic (see Tables 12 and 13) of the daytime data climatology (see Table 5 for an explanation of the data presented in the persistence tables). The frequency of persistence at one and two hours after a given initial condition is generally about the same for both climatologies. The only exception to this trend is for the initial condition of clear skies (0.0) during the summer. As shown in Table 3, the persistence frequency one hour subsequent to initial conditions of clear skies during August for the complete data climatology is 77%. However, for the daytime data climatology (Table 12) this percentage is only 58%. This lower frequency can probably be attributed to rapidly developing cumulus fields during the heating of the day.

Table 12. One Hour Persistence of Weather Conditions														
	Initial Weather Conditions													
T+1 hour Daytime	Weather Violation		0.0 Cloud Cover		0.1 Cloud Cover		0.2 Cloud Cover		0.3 Cloud Cover		0.4 Cloud Cover		0.5 Cloud Cover	
Category	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count
January	82	754	87	313	66	306	45	187	33	161	28	78	33	61
February	80	630	84	337	58	255	53	175	38	146	38	106	21	43
March	78	610	78	265	65	299	55	238	47	223	40	147	40	78
April	70	432	85	689	63	461	42	191	43	168	35	103	36	56
May	63	413	80	381	65	453	56	387	50	310	43	164	24	62
June	64	418	63	205	66	493	52	467	55	433	39	179	35	55
July	69	405	65	239	59	434	57	491	51	411	36	135	40	55
August	60	349	58	207	62	500	58	498	54	421	36	136	34	59
September	66	330	65	96	61	318	55	470	51	453	46	207	36	76
October	79	724	72	116	66	341	52	304	43	254	40	184	22	92
November	79	521	77	151	69	304	52	225	50	246	38	139	30	64
December	80	576	82	266	72	303	61	213	44	187	36	110	20	50

Table 13. Two Hour Persistence of Weather Conditions														
	Initial Weather Conditions													
T+2 hours Daytime	Weather Violation		0.0 Cloud Cover		0.1 Cloud Cover		0.2 Cloud Cover		0.3 Cloud Cover		0.4 Cloud Cover		0.5 Cloud Cover	
Category	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count
January	72	754	81	313	45	306	30	187	23	161	15	78	15	61
February	72	630	76	337	40	255	32	175	17	146	23	106	9	43
March	68	610	68	265	45	299	37	238	29	223	24	147	21	78
April	57	432	78	689	48	461	23	191	24	168	18	103	21	56
May	51	413	70	381	45	453	41	387	34	310	30	164	18	62
June	47	418	42	205	46	493	34	467	37	433	24	179	16	55
July	53	405	44	239	39	434	42	491	34	411	18	135	22	55
August	42	349	37	207	40	500	38	498	36	421	20	136	15	59
September	54	330	50	96	38	318	39	470	36	453	32	207	22	76
October	70	724	63	116	49	341	35	304	30	254	27	184	14	92
November	70	521	64	151	55	304	36	225	36	246	32	139	22	64
December	69	576	74	266	58	302	38	213	32	187	22	110	8	50

7.2.2 Homogeneity Analysis of Initial Conditions of 0.2 and 0.3 Based on All Violations

This section of the report focuses on comparing the percent observed weather violations subsequent (one and two hours later) to initial conditions of 0.2 and 0.3 cloud cover for the daytime data. The sample statistics were computed for the daytime data as were the statistics for the complete data described in Section 6.0. The results of these analyses are summarized in Table 14 (T+1 hour) and Table 15 (T+2 hours).

The results of the chi-square tests for the daytime data are similar to the results for the complete data. Again for most all months, there was a significant difference in the proportions of weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover. The only exceptions to this result were for the months of May and October at T+1 and T+2 hours, for January at T+1 hour and April at T+2 hours. The differences were not statistically significant for these cases.

To further test the significance of the months of May and October, additional analyses were performed for each of these months by extending the analysis time one week surrounding each month (i.e., 24 April to 7 June and 24 September to 7 November). This was done to see how sensitive the analysis was to these specific time periods. For May (one week either side), the results indicate the differences in weather violations for both one and two hours to initial conditions of 0.2 and 0.3 cloud cover were not significant. For October, the differences were not significant for only the two hour interval.

Since the differences in the percent weather violations (i.e., all weather violations) for both the complete and daytime data for May were determined not to be statistically significant, the results instill a higher degree of confidence that during this month the 0.2 cloud cover rule is probably overly conservative. Thus, there is some justification for changing the critical cloud cover amount in the cloud cover rule from 0.2 to 0.3 for the month of May. If this modification to the cloud cover rule was instituted, there would be a substantial increase in the number of hourly landing opportunities during May. For May, changing the critical cloud coverage amount from 0.2 to 0.3 would increase the hourly landing opportunities by 14% or approximately 2 hours per day (see Table 16).

Table 14.

Observed Weather Conditions One Hour Subsequent To Initial Conditions

Category / Months	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at $\alpha = 0.05$
January	187	10.16	161	14.91	1.80
February	175	3.43	146	14.38	12.40*
March	238	5.46	223	10.76	4.38*
April	191	5.24	168	13.10	6.80*
May	387	8.01	310	8.38	0.03
June	467	5.57	433	11.55	10.39*
July	491	4.07	411	13.63	26.46*
August	498	4.82	421	10.45	10.56*
September	470	4.26	453	9.05	8.59*
October	304	9.35	254	13.00	2.88
November	225	4.00	246	9.76	5.98*
December	213	3.76	187	11.76	9.21*
Expanded Months					
May (4/24 to 6/7)	513	7.02	459	7.84	0.24
October (9/24 to 11/7)	466	6.44	403	11.91	7.92*

* Indicates the proportions of weather violations for the two samples are statistically different.

Table 15.

Observed Weather Conditions Two Hours Subsequent To Initial Conditions

Category	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
Months	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at $\alpha = 0.05$
January	187	11.76	161	22.36	6.99*
February	175	6.86	146	19.18	11.08*
March	238	8.82	223	15.25	4.52*
April	191	11.52	168	14.88	0.89
May	387	9.04	310	11.61	1.24
June	467	10.49	433	16.86	7.77*
July	491	8.35	411	18.98	22.07*
August	498	7.43	421	16.86	19.58*
September	470	5.96	453	12.80	12.80*
October	304	11.84	254	14.17	0.67
November	225	7.56	246	14.63	5.90*
December	213	7.98	187	16.04	6.24*
Expanded Months					
May (4/24 to 6/7)	513	8.97	459	10.89	1.01
October (9/24 to 11/7)	466	9.66	403	13.90	3.78

* Indicates the proportions of weather violations for the two samples are statistically different.

Table 16.

Percent Occurrences of 0.2 and 0.3 Cloud Cover

	0.2		0.3			
Month	Count	%	Count	%	Total Cts	Total %
May*	387	18	310	14	697	32

* Statistics based on Daylight hours possible for May.

7.2.3 Statistical Analysis of Initial Conditions of 0.2 and 0.3 Based on Ceiling and Precipitation Violations Only

Since the 0.2 cloud cover rule was written to guard against the development of cloud ceilings below 10,000 feet after de-orbit burn decisions, the homogeneity test was used to analyze the data based on the condition that weather violations only included ceiling and precipitation violations.. This includes any time when a ceiling or precipitation weather violation is occurring at X68. It essentially eliminates visibility and cross-wind violations. Tables 17 and 18 show the chi-square results for May and October. The results of the statistical analysis have shown there is no significant difference between weather violations subsequent to 0.2 and 0.3 initial cloud cover for May daytime data. However, the results for October indicate that there are significant differences between weather violations subsequent to 0.2 and 0.3 initial cloud cover. The only exception to this finding was for October (all hours) when the chi-square analysis did not show a significant difference between the weather violations for 0.2 and 0.3 initial cloud cover for T+2 hours.

Table 17.

Observed Weather Conditions One Hour Subsequent To Initial Conditions (Based on Ceiling and Precipitation Violations Only)

Category	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at $\alpha = 0.05$
Category					
May	368	3.26	302	5.96	2.83
October	296	4.73	242	9.09	4.06*
Expanded Months					
May (4/24 to 6/7)	491	2.85	446	5.16	3.27
October (9/24 to 11/7)	453	3.75	389	8.74	9.15*

Table 18.

Observed Weather Conditions Two Hours Subsequent To Initial Conditions (Based on Ceiling and Precipitation Violations Only)

Category	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at $\alpha = 0.05$
Category					
May	371	5.12	298	8.05	2.36
October	291	7.90	246	11.38	1.88
Expanded Months					
May (4/24 to 6/7)	494	5.46	442	7.47	1.56
October (9/24 to 11/7)	451	6.65	391	11.25	5.53*

8.0 Climatology of Surface Conditions Categorized by Upper-Air Data

This section will summarize the results of analyses based on categorizing the data (all hours of the day and night) by upper-air wind direction sector. The wind sectors have been defined to match the sectors used by Ronald Holle (2) in his analysis of total area divergence over the KSC/CCAFS area. The sectors have been defined as north (339° to 023°), northeast (024° to 113°), southeast (114° to 158°), south (159° to 203°), southwest (204° to 293°), and northwest (294° to 338°). It was decided to use these sectors since Holle’s research indicated a significant correlation between wind flow at these levels and the occurrence of thunderstorms during the warm season (May through September) at KSC. In addition, for simplicity, it was decided to apply these sectors to other times of the year as well.

The data used for this categorization was the early morning rawinsonde release from the Cape Canaveral Air Force Station (CCAFS) for the period 1986-90. To simplify the analysis process, this data was assumed to be representative of wind flow characteristics over the 24-hour period centered at 1200 UTC. It must be noted that this analysis procedure does introduce some error since the winds can change significantly over a 12-hour period especially during rapidly changing synoptic conditions. The analyses discussed in the following sections are based on categorizing the weather conditions at X68 by 850 mb and 700 mb wind direction.

Key results from these analyses are:

- Climatology based on 850 mb and 700 mb (approximately 5,000 and 10,000 feet respectively) wind direction categorizations.
  - •• South and southwest wind sectors for both 700 mb and 850 mb have highest percent occurrence of weather violations (25% to 30%).
  - •• Clear skies (0.0 cloud cover) have highest frequency of occurrence for north and northwest wind sectors, and the lowest frequency of occurrence for northeast and southeast winds.
  - •• Northeast, southeast, and southerly wind sectors have the highest percent occurrences of 0.1 to 0.3 cloud cover.

- Observed Weather Conditions (One and Two hours) Subsequent to Initial Conditions.
  - •• For initial cloud cover amounts of 0.1 through 0.5, the highest percent occurrences of weather violations occur with a southwest wind.
  - •• Given initial conditions of cloud cover amounts from 0.0 to 0.3, persistence of the initial condition is the dominating characteristic of the subsequent weather conditions.
  - •• No significant difference between the percent occurrence of weather violations given 0.2 and 0.3 initial cloud cover for the 700 mb north wind sector.

8.1 Climatology of Upper-Air Wind Direction

This section will discuss the climatology of the hourly surface observation data categorized by 850 mb and 700 mb wind direction according to wind sectors used by Ronald Holle. Figures illustrating the percent occurrence of weather conditions for this data are contained in Appendix A.

As shown in Figures 19 and 20, the south and southwest wind sectors for both 850 mb and 700 mb have the largest frequency of weather violation occurrence (approximately 25% to 30%). These wind regimes are generally associated with cloud and precipitation events which advect over X68 from the mainland. Also, most of these weather violations are probably associated with summertime showers and thunderstorms, but some are related to wintertime frontal systems moving west to east across the state. There is also a minor peak in percent occurrence of weather violations (22%) for the northeast wind sector for 850 mb. This peak is probably reflecting the stratus and stratocumulus cloud events which advect in from the ocean during the cooler months of the year, especially during the fall and early winter. The lowest percent occurrence of weather violations occur with a northerly or southeasterly wind direction (15% to 20%).

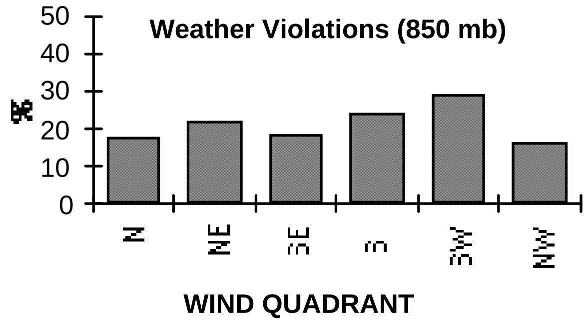


Figure 19. Percent occurrence of weather violations for 850 mb wind sectors.

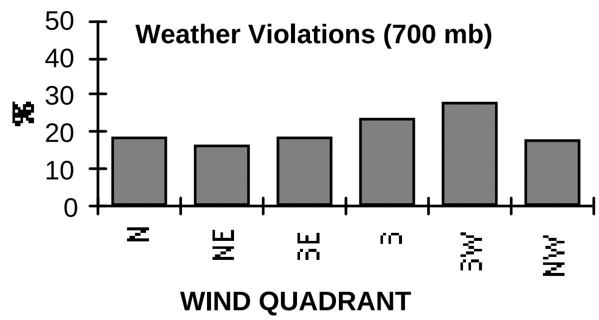


Figure 20. Percent occurrence of weather violations for 700 mb wind sectors.

Another important feature evident in the climatology of weather conditions for the northwest wind sector at 850 mb (see Figure 21) is the high percent occurrence of clear skies (0.0 cloud cover less than 10,000 ft.). Similar results were found for the north wind sector at 850 mb and the north and northwest wind sector at 700 mb. These results are not surprising since a shift to a north or northwest flow often indicates a frontal system has passed bringing drier air to the KSC region. This would substantially reduce the chances of precipitation and ceiling violations at X68. The results also indicate the northeast, southeast (see Figure 22), and south wind sectors have lower percent occurrences of clear skies (0.0 cloud cover less than 10,000 ft.) than the southwest wind sector (see Figure 23). In addition, the highest percent occurrence of clouds in the 0.1-0.3 categories occur with northeast, southeast, and southerly winds. These results are probably related to low-level moisture being available for cloud formation with onshore wind components.

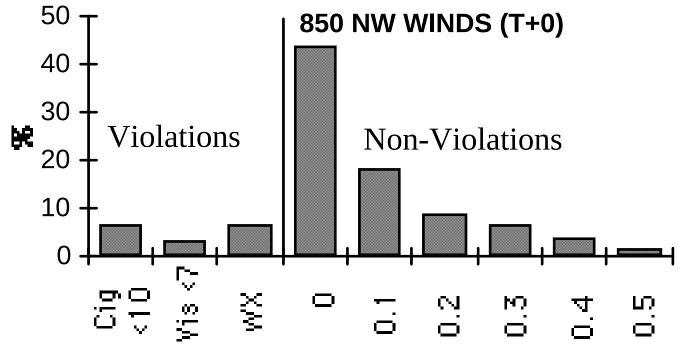


Figure 21. Percent occurrence of weather conditions for 850 mb northwest wind sector.

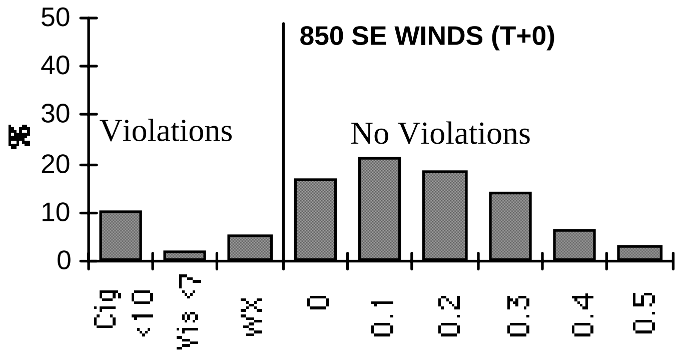


Figure 22. Percent occurrence of weather conditions for 850 mb southeast wind sector.

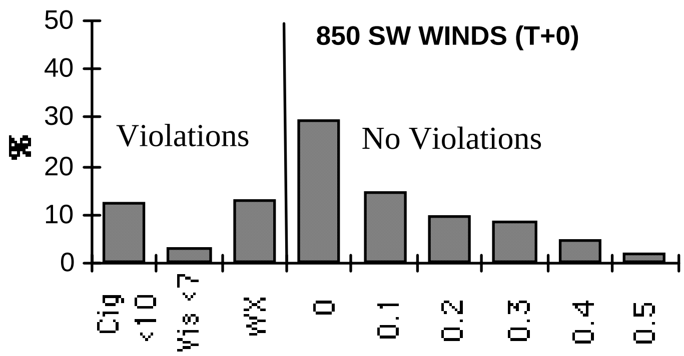


Figure 23. Percent occurrence of weather conditions for 850 mb southwest wind sector.

8.2 Observed Weather Conditions (One and Two hours) Subsequent to Initial Conditions (850 mb and 700 mb)

This section discusses the relationship between initial cloud cover amounts and the probability of a weather violation occurring one and two hours subsequent for the surface observation data base categorized by 850 mb and 700 mb wind direction. Charts containing the percent occurrences of weather conditions given an initial cloud cover amount are contained in Appendix I.

The data indicate the southwest wind sector has the highest percent occurrence of weather violations for initial cloud cover amounts of 0.1 to 0.5. In addition, for initial cloud cover amounts of 0.0 to 0.3, the frequency of occurrence of a no weather violation condition for T+1 and T+2 hours is at least 80% for all wind sectors. The frequency of no weather violation conditions decreases to 60% and 70% for cloud cover amounts of 0.4 and 0.5.

8.2.1 Persistence

As discussed in preceding sections, persistence of initial weather conditions one and two hours into the future is a dominant feature for upper-level wind data categorizations. This is easily seen from the charts in Appendix I and in condensed form in Tables 19 and 20 (see Table 5 for an explanation of the data presented in the persistence tables).

There are several important characteristics in the persistence of weather conditions at X68 (Tables 19 and 20). First, for all of the upper-level wind direction categorizations, the percent occurrence of a weather violation persisting for one or two hours is at least 65%. The percent occurrence of a weather violation persisting is highest with a southwesterly wind and slightly lower with onshore wind sectors (i.e., northeast, southeast). In addition, for clear skies (0.0 cloud cover below 10,000 ft.) the highest occurrence of persistence (75%-85%) is with offshore wind components (i.e., southwest, northwest) while lower percent occurrences (65%-75%) occur with onshore wind components (i.e., northeast, southeast). For cloud categories of 0.1 to 0.3, percent occurrence of persistence are very similar for most wind direction categorizations. However, percent occurrence of persistence for offshore (westerly flow) wind components are slightly lower (5%-8%) than onshore (easterly flow) wind components.

Although the data from most of the wind sectors indicate the predominant characteristic is persistence, there is a least one exception to this trend. For example, for the 850 mb northwest wind sector (Figure 24) with an initial cloud cover of 0.2, the most frequent weather condition at T+2 hours is 0.1 cloud cover and not 0.2 cloud cover. This same pattern exists for initial cloud cover amounts of 0.3 and 0.4 for 850 mb northwest flow. These results appear to be related to improving weather conditions with 850 mb northwest flow.

Table 19. One Hour Persistence of Weather Conditions

	Initial Weather Conditions													
700 mb & 850 mb	Weather Violation		0.0 Cloud Cover		0.1 Cloud Cover		0.2 Cloud Cover		0.3 Cloud Cover		0.4 Cloud Cover		0.5 Cloud Cover	
Category	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count
700 NE	73	962	77	1137	61	1210	53	1061	48	828	36	416	20	146
700 SE	76	481	75	453	64	521	53	452	49	369	44	193	31	75
700 S	77	965	75	726	61	749	51	680	45	513	34	249	34	126
700 SW	80	5527	81	5500	57	3055	47	2175	43	1825	35	1039	29	510
700 NW	79	925	85	1859	64	974	49	572	40	361	31	208	30	117
700 N	71	569	82	841	59	550	46	399	44	329	29	193	35	119
850 NE	76	2042	78	1870	61	1771	53	1552	45	1164	33	635	34	326
850 SE	76	951	73	861	61	1090	52	958	47	745	36	351	32	180
850 S	74	1211	73	934	59	918	52	839	45	604	41	328	28	134
850 SW	80	4470	82	4593	55	2255	44	1531	42	1392	32	763	31	379
850 NW	77	637	88	1678	62	694	44	344	42	263	37	150	27	74
850 N	79	447	86	934	65	506	50	272	43	177	36	119	22	41

Table 20. Two Hour Persistence of Weather Conditions

	Initial Weather Conditions													
700 mb & 850 mb	Weather Violation		0.0 Cloud Cover		0.1 Cloud Cover		0.2 Cloud Cover		0.3 Cloud Cover		0.4 Cloud Cover		0.5 Cloud Cover	
Category	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count	%	Total Count
700 NE	63	962	65	1137	45	1210	37	1061	36	828	24	416	12	146
700 SE	66	481	60	453	48	521	36	452	31	369	28	193	16	75
700 S	66	965	62	726	43	749	33	680	29	513	23	249	17	126
700 SW	70	5527	71	5500	39	3054	32	2175	27	1825	21	1039	13	510
700 NW	67	925	77	1859	50	974	31	572	23	361	21	208	22	117
700 N	60	569	72	841	44	550	32	399	24	329	19	193	28	119
850 NE	68	2042	66	1870	44	1771	38	1552	32	1164	23	635	22	326
850 SE	64	951	59	861	45	1090	37	958	30	745	25	351	20	180
850 S	63	1211	61	934	43	918	34	839	30	604	27	328	16	134
850 SW	70	4470	71	4593	38	2254	28	1531	27	1392	19	763	15	379
850 NW	65	637	81	1678	47	694	26	344	21	263	18	150	9	74
850 N	68	447	77	934	49	506	35	272	28	177	19	119	15	41

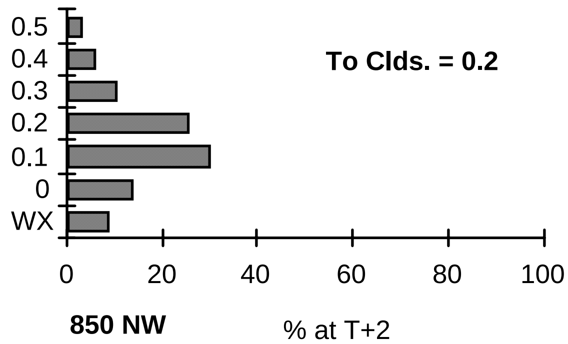


Figure 24. Percent occurrence of cloud cover and weather conditions at two hours after an initial condition of 0.2 cloud cover for 850 mb Northwest wind sector.

8.2.2 Homogeneity Analysis of Initial Conditions of 0.2 and 0.3 Cloud Cover

This section of the report focuses on comparing the percent observed weather violations subsequent (one and two hours later) to initial conditions of 0.2 and 0.3 for each of the 850 mb and 700 mb wind categories. The sample statistics for these categorizations were computed as were the statistics for the complete data described in Section 6.0. The results of these analyses are summarized in Table 21 (T+1 hour) and Table 22 (T+2 hours).

Most of the differences in the percent weather violations are statistically significant for all of the 850 mb and 700 mb wind sectors. However, there are a few instances where the differences are not statistically significant. The differences in the frequency of occurrence of weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover are not significant for north winds at 700 mb. In addition, for T+2 hours the differences for southeast wind at 700 mb and north and northwest wind at 850 mb are not significant. Also, the change in percent occurrence of weather violations from T+1 to T+2 hours for northwest wind at 850 mb for initial conditions of 0.2 and 0.3 cloud cover (Tables 21 and 22), are just about the same (approximately 5%).

Based on these results, there is some statistical evidence which suggests the 0.2 rule may be overly conservative for 700 mb northerly flow. However, due to the potential errors involved in applying the 1200 UTC CCAFS daily sounding to a 24-hour period, further analysis needs to be performed using higher temporal resolution frequent wind data. It is suggested that data from the wind profiler could be used for such a study.

Table 21.
Observed Weather Conditions One Hour Subsequent To Initial Conditions

Category	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
Wind Direction Sectors	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at $\alpha = 0.05$
700 NE	1061	4.35	828	7.97	11.02*
700 SE	452	3.32	369	6.50	4.56*
700 S	680	4.85	513	13.06	25.65*
700 SW	2175	6.94	1825	13.64	49.52*
700 NW	572	4.55	361	8.31	5.56*
700 N	399	6.01	329	9.42	3.00
850 NE	1552	5.41	1164	9.02	13.38*
850 SE	958	3.34	745	8.05	18.22*
850 S	839	6.20	604	14.40	27.17*
850 SW	1531	7.38	1392	14.01	33.98*
850 NW	344	4.94	263	9.13	4.14*
850 N	272	2.94	177	7.91	5.68*

Table 22.
Observed Weather Conditions Two Hours Subsequent To Initial Conditions

Category	Initial Conditions 0.2 Cloud Cover		Initial Conditions 0.3 Cloud Cover		Chi Square Test Statistic
Wind Direction Sector	Sample Size	Percent Weather Violations	Sample Size	Percent Weather Violations	Critical value = 3.841 at $\alpha = 0.05$
700 NE	1061	6.31	828	9.78	7.75*
700 SE	452	6.19	369	8.13	1.16
700 S	680	10.29	513	18.32	15.90*
700 SW	2175	12.18	1825	20.27	48.63*
700 NW	572	7.52	361	11.91	5.11*
700 N	399	9.27	329	12.76	2.27
850 NE	1552	8.76	1164	11.08	4.06*
850 SE	958	5.22	745	13.42	35.11*
850 S	839	10.61	604	11.36	31.64*
850 SW	1531	13.46	1392	19.98	22.41*
850 NW	344	9.30	263	14.07	3.36

850 N	272	4.78	177	8.47	2.50

* Indicates the proportions of weather violations for the two samples are statistically different.

9.0 Nomograms

To assist SMG and CCFF forecasters, nomograms have been developed for use by forecasters in making cloud cover forecasts for EOM and RTLS at KSC. Also, a climatology of weather violations by month vs. groups of hours was developed for SMG and CCFF forecasters as well as STS managers. This tool provides guidance on the best time to land the shuttle from a climatological standpoint.

Appendix J presents charts which contain climatological information for percent occurrence of weather violations by month and hour. Several important features, which have been noted in other sections of this report, can be seen in these charts. These are:

- Fall and winter months have the highest percent occurrence of weather violations (30%-40%) while the summer months have the lowest percent occurrence (10-15%).
- Peak in percent occurrence of weather violations occurs near sunrise (1100-1300 UTC).
- The percent occurrence of weather violations is a local minimum in late morning (1400-1600 UTC).
- The percent occurrence of weather violations increases during late afternoon hours (1800-2200 UTC).
- Early nighttime hours (0100-0600 UTC) have the lowest percent occurrence of weather violations of the day.

The nomograms have been developed from analysis of the observed weather conditions one and two hours subsequent to initial conditions to enhance the forecaster's understanding of cloud cover trends. Appendix K contains the nomograms for the percent occurrence of all weather violations for a given initial cloud cover by month and groups of hours. Appendix L contains the nomograms for the percent occurrence of ceiling and precipitation weather violations only for a given initial cloud cover by month and groups of hours. The nomograms also give the total number of occurrences for each data categorization (month by 6-hour group). This provides the user with an indication of the frequency of the phenomenon. As an example (see Appendix K), for the 0900-1400 UTC period during October with an initial condition of 0.2 cloud cover, the percent occurrence of weather violations is 12% for T+1 hour but increases to 21% for T+2 hours. For both of these categories there were 111 cases of initial cloud cover of 0.2. The nomograms for initial cloud cover of 0.0 to 0.5 will be made available to both SMG and CCFF forecasters via Meteorological Interactive Display System (MIDDS) and hard copy.

10.0 Summary and Conclusions

This section will briefly summarize the results of the analysis of the two-tenths cloud cover data base. In addition, future work areas including a brief description of how artificial neural network (ANN) technology could be applied to the short-term EOM forecast problem at the Shuttle Landing Facility will be presented.

10.1 Summary

The two-tenths cloud cover rule in effect for all End Of Mission (EOM) STS landings at KSC states: "*for scattered cloud layers below 10,000 feet, cloud cover must be observed to be less than or equal to 0.2 at the de-orbit burn go/no-go decision time (approximately 90 minutes before landing time)*". This rule was designed to protect against a ceiling (below 10,00 feet) developing unexpectedly within the next 90 minutes (i.e., after the de-orbit burn decision and before landing). In order to test the validity of this rule, the AMU developed a database of cloud cover amounts and weather conditions at the Shuttle Landing Facility (X68) for a five-year (1986-1990) period. Once this database was completed a comprehensive statistical and climatological analysis was performed on the data. The data analysis included both a climatology of the surface observations and observed conditions one and two hours subsequent to given initial conditions. For both analyses the data were categorized by month, season, time of day, daytime hours only, and surface and upper-air wind direction. A summary of these results are presented in Sections 10.2 and 10.3. In addition, as a result of these analyses, the AMU developed nomograms to help SMG and CCFF forecast cloud cover for EOM and RTLS at KSC.

10.2 Analysis of Landing Opportunities

Based upon the climatological analysis of the hourly data, several recommendations can be made regarding the best and worst times to land the shuttle at KSC. These times, along with their corresponding percent occurrence of no STS landing weather violations, are listed in Table 23. The climatological data indicate the best time of the year to land the shuttle at KSC is during the summer (80%-85% opportunity) while the worst time is during the winter (65% opportunity). When the data are categorized by time of day, the analysis has shown the highest frequency of landing opportunities occurs for the 0100-0600 UTC (80%-85% opportunity) and 1300-1600 UTC (75% opportunity) time periods. In fact, the frequency of landing opportunities exceeded 90% for many of the spring and summer months for the 0100-0600 UTC period. The worst time of the day to land a shuttle is near sunrise (1100-1300 UTC) and during the afternoon (1700-2100 UTC). For both of these time periods, the frequency of landing opportunities is approximately 60 to 70%. It is important to note that near sunrise for the months of December to February the frequency of landing opportunities is only 50%. These low percentages are generally associated with fog and stratus which occur more frequently during the winter in the early morning hours. The decrease in landing opportunities during the afternoon are associated with the development of cloudiness and convective type precipitation events especially in the warmer months of the year.

By categorizing the data by surface wind direction, analysis of the data indicates the highest frequency of landing opportunities occur with a southeasterly or southerly wind flow (85% opportunity) while the lowest are associated with a northwesterly or northerly wind component (65%-70% opportunity). For upper-level wind direction (850 mb and 700 mb), most wind sectors have frequency of landing opportunities of 80%. However, for both 850 mb and 700 mb, the wind sector with the lowest landing opportunity (approximately 70%) is southwest.

Table 23. STS Landing Opportunities

Category	%	Category	%
May-August	80-85	December - February	65
1400-1600 UTC	75	1100-1300 UTC	60-70
0100-0600 UTC	80-85	1700-2100 UTC	70
S & SE Surface winds	85	N & NW Surface winds	65-70
		SW 850 mb & 700 mb winds	70

10.3 Evaluation of Two-tenths Cloud Cover Rule

One of the major goals of this study was to determine the validity of the 0.2 cloud cover rule for all stratifications of the data (i.e., seasons, months, time of day, wind direction, etc.). To address this question, analyses in this report (Section 6.0, 7.2.2, 7.2.3, and 8.2.2) focused on comparing the percent of observed weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover below 10,000 feet at X68. These comparisons were performed by using chi-square tests for homogeneity to determine if the percent of weather violations subsequent to the two different initial conditions are the same.

Statistical tests were performed between 0.2 and 0.3 initial cloud cover for all data categorizations (i.e., seasons, months, time of day, daytime only, surface and upper-air wind direction). For the majority of these data categorizations there is a significant difference in the proportions of weather violations one and two hours subsequent to initial conditions of 0.2 and 0.3 cloud cover. However, for a few categories the statistical analysis has shown some evidence that the 0.2 critical cloud amount might be changed to 0.3 These categories included the entire months of May and October, and hours 1500 and 1600 UTC, (all months), and 700 mb northerly winds (all hours, all months). However, before these recommendations can be made further investigation will be required once the two tenths cloud cover data base is updated.

If the rule change was made, the question then arises, "*How many more landing opportunities will occur for KSC landings?*". To answer this question, a comparison of landing opportunities (i.e., no weather constraint violations) using both a 0.2 and 0.3 cloud cover rule is shown in Table 24. The current 0.2 rule assumes landing opportunities for initial cloud cover of 0.0 to 0.2 while a 0.3 rule would mean landing opportunities for initial cloud cover of 0.0 to 0.3. Changing to a 0.3 cloud cover rule for each of these categories will increase the number of landing opportunity hours by approximately 60-70 hours per year per category (Table 24). The largest increase in hourly opportunities occurs during May with about 80 hours per year. Even though the number of hours are not large, they could result in additional landings at the SLF.

Table 24. Comparison of 0.2 and 0.3 Cloud Cover Rules (All hours)						
	0.2 Rule (0.0-0.2)		0.3 Rule (0.0-0.3)			
Category	Good Landing Hours	Percent of Total Hours	Good Landing Hours	Percent of Total Hours	Hour Change (5-year period)	Total Hours (5-year period)
May	2411	65	2826	75	415	3720
October	1716	46	2094	56	378	3720
700 mb North	1790	60	2119	71	329	3000
1500 UTC	834	46	1123	62	289	1826
1600 UTC	785	43	1121	61	336	1828

10.4 Suggestions for Future Work

Based upon the analysis of the two-tenths cloud cover database, we recommend three specific areas for future work. These are:

- Develop a proof of concept artificial neural network (ANN) to produce a probabilistic estimation of a constraint violation for the shuttle landing forecast. The final product could be used as a forecast tool or aid.

- Update the two tenths cloud cover database to include data beyond 1990.

- Re-examine the data to determine whether the 0.2 cloud cover rule could be relaxed for the following categories.

  - May,
  - October,
  - 1500 UTC,
  - 1600 UTC, and
  - 700 mb northerly wind.

Each of these future work areas is discussed below.

This study has associated the probability of landing constraints with varying amounts of cloud cover (below 10,000 feet) for different types of the day, year, and for various surface and upper-air flow regimes. In order to take full advantage of the potential landing opportunities which are delineated in this report, new short term local forecasting methods, which can better analyze the current conditions, their interactions, and how those interactions are likely to affect the short term (one to two hours) forecast, must be implemented. Artificial neural networks have shown tremendous potential in the area of pattern recognition and data association and have already been applied to thunderstorm forecasting by the National Severe Storms Forecast Center. They have been particularly successful compared to other statistical techniques when the input data are highly correlated or contain significant amounts of missing values, or when the system is highly non-linear.

Artificial neural networks can easily be applied to predicting constraint violations for the EOM mission landing. As a result of this study, there are more than sufficient amounts of training and testing data already available in the AMU for developing a neural network for predicting constraint violations. The input data, consisting of current weather conditions, time of day and year, flow conditions, etc., are highly correlated. An artificial neural network would be able to analyze the interactions between the input data and predict whether or not a constraint violation would occur. Additional information on the basics of ANN and how they have been applied to various types of problems can be found in Appendix M.

A single neural network for predicting the probability of landing constraint violations could use single point forecasting information from station X68 as inputs and the type(s) of violations (if any) existing at the forecast valid time as outputs. The X68 data for training and testing the neural network is already available as a result of this study. The input data would consist of past and current surface weather conditions reported by X68 as well as past and current rawinsonde data. Including both past and current surface weather conditions in the input buffer allows the artificial neural network to take into account temporal relations between input data and the probability of violations. After initial prototype development, the neural network could be enhanced by including additional input data sources such as surface observations from surrounding stations and forecast grid data. This would allow the ANN to take into account both temporal and spatial relations.

A proof of concept artificial neural network should be developed which can predict whether or not there will be a constraint violation at the 90 minute forecast time using current weather conditions as input. The output of the neural network could aid the forecasters in their decision making as are outputs from other numerical models.

In order to enhance the two-tenths cloud cover database, we recommend that it be continually updated with current data. This would include incorporating X68 surface observations from NCDC as well as CCAFS rawinsonde data. In addition, cloud amounts below 10,000 feet at X68 would be extracted from Forms 10a and 10b and input into the database.

Finally, as noted in Section 10.3, there was some evidence that the 0.2 critical cloud amount might be changed to 0.3 for several categories. However, additional investigation would be required to determine if these recommendation should be made. Thus, once the two-tenths database has been updated, we recommend the data for May, October, 1500 UTC, 1600 UTC, and 700 mb northerly winds be analyzed to address whether the 0.2 cloud cover rule could be changed for these categories.

11.0 References

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