4.11 A CLIMATOLOGICAL STUDY OF NIGHTTIME RAPIDLY DEVELOPING LOW CLOUD CEILINGS IN A STABLE ENVIRONMENT

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1. INTRODUCTION

Forecasters at the Space Meteorology Group (SMG) issue 30 to 90 minute forecasts for low cloud ceilings at the Kennedy Space Center Shuttle Landing Facility (TTS) to support space shuttle landings. Mission verification statistics have shown ceilings to be the number one forecast challenge for SMG. More specifically, forecasters at SMG are concerned with any rapidly developing clouds/ceilings below 8000 ft in a stable, capped thermodynamic environment. Therefore, the Applied Meteorology Unit (AMU) was tasked to examine archived events of rapid stable cloud formation resulting in ceilings below 8000 ft, and document the atmospheric regimes favoring this type of cloud development.

2. BACKGROUND

In the first phase of this project, the AMU examined the cool season months of November to March during the years of 1993–2003 for days that had low-level (below 8000 ft) temperature inversions and rapid, stable low cloud formation that resulted in ceilings violating the Space Shuttle Flight Rules. The AMU identified low-level inversions from the morning Cape Canaveral Air Force Station (CCAFS) radiosonde (identifier XMR) during the cool season and output pertinent sounding information. They then parsed all days with cloud ceilings below 2438 m (8000 ft) at TTS, forming a database of possible rapidly-developing low ceiling events. For the first phase, an event was defined as a low cloud ceiling developing suddenly (an hour or less) in a stable environment. A non-event is a low cloud ceiling in a stable environment, occurring either as a result of the advection of low clouds or widespread cloudiness for much of the day. Days with precipitation or noticeable fog burn-off situations were excluded from the database. In the first phase of this work, only the daytime hours were examined for possible ceiling development events since low clouds are easier to diagnose with visible satellite imagery. For the daytime cases, the distinguishing factor between the event and non-event days appeared to be the vertical wind profile in the XMR sounding. Eighty-five percent of the event days had a clockwise turning of the winds with height in the lower to middle troposphere whereas 83% of the non-events had a counter-clockwise turning of the winds with height or negligible vertical wind shear.

For the second phase of this project, the nighttime cases, the AMU analyzed both the morning and evening soundings from the XMR radiosondes. Unlike the daytime study, days without a low-level inversion were retained to create a larger nighttime database. Similar to the daytime study, the AMU used satellite imagery to determine whether low ceilings are due to cloud development or the advection of low clouds. Since the higher-resolution visible images are not available, special infrared enhancements were employed to help visualize the nocturnal low clouds. The authors will summarize the work from the nighttime cases and describe a sample case from this data set.

3. METHODOLOGY

SMG indicated that they have observed nighttime rapid low cloud development events in the cool season. The nighttime events are difficult to identify with infrared satellite imagery since developing low, warm clouds can be challenging to identify in the infrared imagery. Therefore, the AMU collected data from the evening and morning XMR radiosonde and hourly surface observations at TTS between 2200–1200 UTC during the cool season months of November to March 1994–2005, for a total of 12 cool seasons. Due to the large number of cool-season days to examine for stable low-cloud formation, the AMU devised an objective method to parse through all data and

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retain only days with observed cloud ceilings below 2438 m (8000 ft) at TTS.

3.1. Sounding Availability and Parameters

Archived sounding data were obtained from Computer Sciences Raytheon for the months and years listed above. For this phase of the study, soundings at 2200 UTC and 1000 UTC were required for the nighttime potential events. If one of the soundings was missing for any potential event, the date was not considered. Since the first phase of this study found low-level inversions to be an important parameter for rapid cloud development, the software developed for this phase of the work output the base, depth, and magnitude of the inversions for the soundings at 2200 and 1000 UTC. Also, the program would output data every 305 m (1000 ft) beginning at the surface up to 2438 m (8000 ft) including altitude, pressure, wind direction, wind speed, shear, temperature, dew point, relative humidity, and the cumulative mean wind direction and speed. These parameters were used to help narrow down the number of potential days meeting the pre-defined criteria for the study, as well as provide output for assessing potential rapid low-cloud development events.

3.2. Identify Ceilings

The AMU wrote software to analyze the frequency of ceilings at and below 2438 m (8000 ft) and 1524 m (5000 ft) at TTS, for the years 1994–2005. The program also determined which ceilings were due to rain or fog. Output from the program was used to identify possible events, in which low clouds developed rapidly in a stable environment.

The following criteria were used to identify the beginning of a possible event:

- No low ceilings, precipitation, or fog occurred within the three previous hours,
- An event must start between 2200 UTC and 1200 UTC, since only nighttime events were considered,
- Events in which high clouds would obscure low clouds were not used, because it would be impossible to distinguish between low cloud rapid development and advection in the satellite imagery, and
- Events in which low clouds developed over several hours were thrown out, since only rapid development is a concern in this task.

The following criteria were used to identify the end of a possible event:

- Precipitation or fog occurs within three hours,
- Events must end by 1200 UTC, since only nighttime events are considered, and
- The ceilings dissipated or rose to above 8000 ft.

3.3. Develop Database of Possible Events

A subjective analysis of the output from the identification of low-level inversions and ceilings was then conducted to identify potential case days. Through this analysis, the database was further narrowed to exclude events with reports of showers or showers in the vicinity of the TTS observation. All potential low-cloud formation days were entered into an Excel spreadsheet for record-keeping. At this point in the analysis, about 30 possible events per year were identified – about 360 total events. Of those 360 possible events, the AMU had archived infrared satellite imagery for 48 events. However, only 37 of the possible events with archived infrared satellite imagery had both a 2200 and 1000 UTC XMR sounding. The AMU ordered additional satellite imagery from the NOAA Comprehensive Large Array-data Stewardship System (CLASS) archive for possible events in which archived satellite imagery was missing. Unlike the archived AMU satellite imagery, the CLASS infrared satellite imagery was generally only available in 30-minute increments. By adding the CLASS satellite imagery to the dataset, a total of 86 possible events were identified for the years 2000-2005. Based on the number of cases and events in the first phase of this work, the AMU decided not to obtain additional satellite imagery and focus time and effort analyzing the 86 possible events.

3.4. Examine Infrared Satellite Imagery

The only way to confirm whether or not a possible event was a rapidly developing case rather than advection situation was to examine the satellite imagery. The AMU first restored archived satellite imagery onto the Meteorological Interactive Data Display System (MIDDS). For the remaining possible events, satellite imagery was ordered from CLASS, downloaded and loaded onto MIDDS. All imagery was viewed with MIDDS software and images were saved in JPEG format for future reference. Finally, after examining satellite imagery for all 86 possible events, there were only 6 identified as rapid low-cloud formation events. The remaining 80 possible events were clearly advection situations.

4. 28 JANUARY 2004 EVENT

The rapid low cloud development began on 8 January 2004 at 2343 UTC and ended 9 January 2004 at 0400 UTC. Florida weather was controlled by a high pressure system centered over northern South Carolina (Figure 1). This pattern resulted in a stable atmosphere across central Florida with a light northerly surface wind at KSC/CCAFS. The sounding from the evening radiosonde at XMR at 2200 UTC 8 January 2004 had a relatively low-level moist layer from 900 to 860 mb and an inversion with a base at 860 mb and a top at 820 mb and a strength of 4.1 ºC (Figure 2). The winds below the inversion were light northerly at the surface and veered northeast near the top of the inversion then backed to the west northwest above the inversion. The average layer relative humidity from the surface to 820 mb (1340 m or 4396 ft) was 84%.

At 2202 UTC, clouds were evident in north Florida and Georgia while areas of low clouds were found to the east of the KSC SLF in the Atlantic Ocean (Fig. 3a). Thirty minutes later, at 2232 UTC, the low clouds had not started to form over land yet near KSC SLF (Fig. 4b). However, by 2302 UTC, low clouds had rapidly developed over the KSC/CCAFS area south of the SLF (Fig. 4c). These clouds did not advect in from the east over the Atlantic Ocean. By 2332 UTC, 11 minutes before a ceiling is reported at the SLF, the low clouds had rapidly developed over almost the entire KSC/CCAFS area.

This case shows the conditions associated with one rapid low ceiling development event but because there were only six events identified in this dataset it may not be representative of the conditions required for a majority of nighttime events. This case is similar to the conditions prevalent in the daytime events identified in the first phase of this project. Of the other five rapidly developing cases in this dataset, four had low-level inversions and three had veering winds. The next section summarizes the composite results of all rapidly developing low ceiling events, and compares/contrasts the meteorological and thermodynamic conditions of event days to non-event days when low ceilings existed, but did not rapidly form.

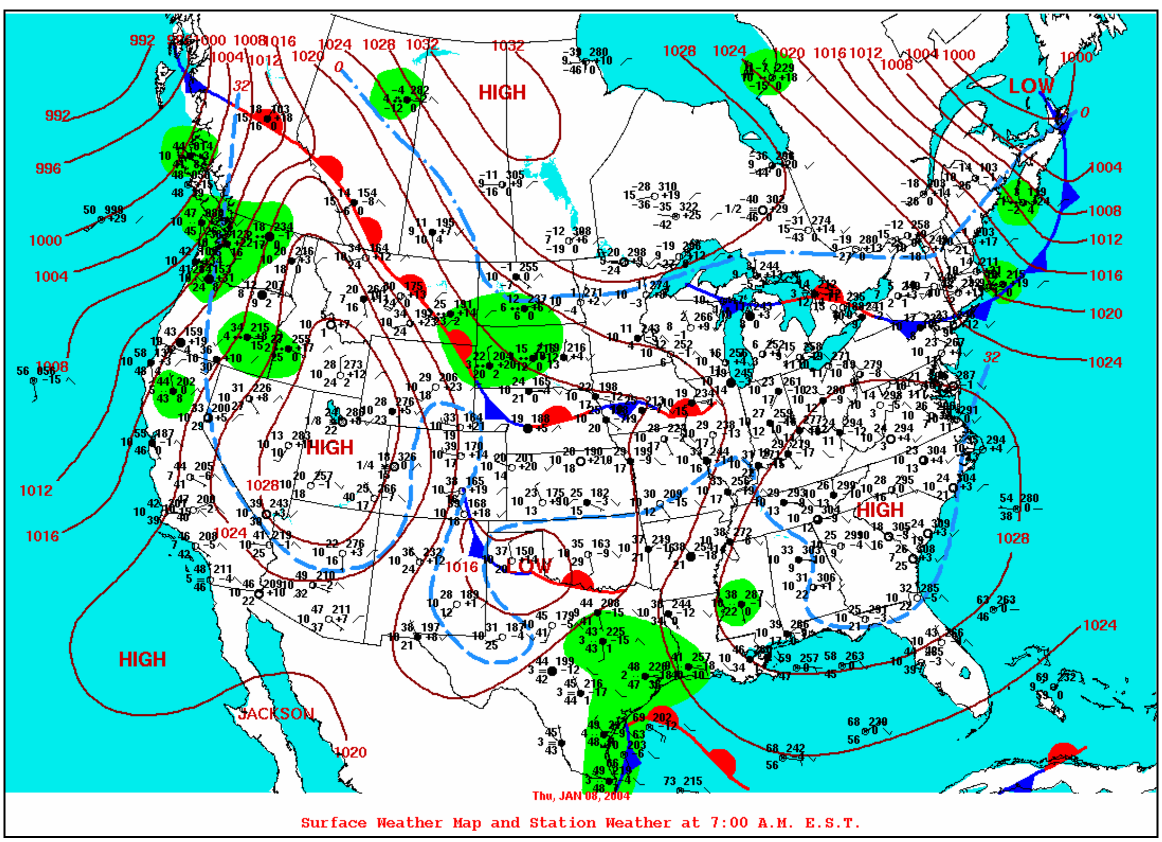


Figure 1. Surface analysis at 1200 UTC 8 January 2004.

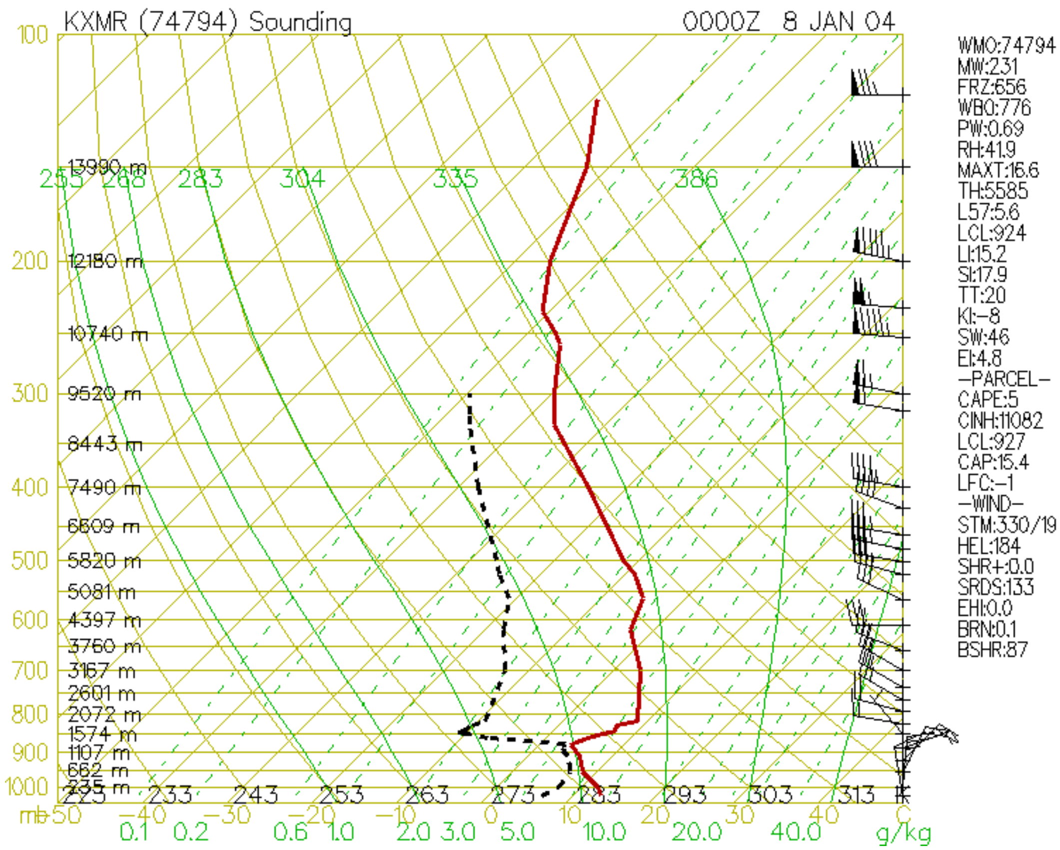


Figure 2. XMR sounding at 2200 UTC 8 January 2004. Note the strong low-level inversion and veering winds from the surface to the top of the inversion at 820 mb.

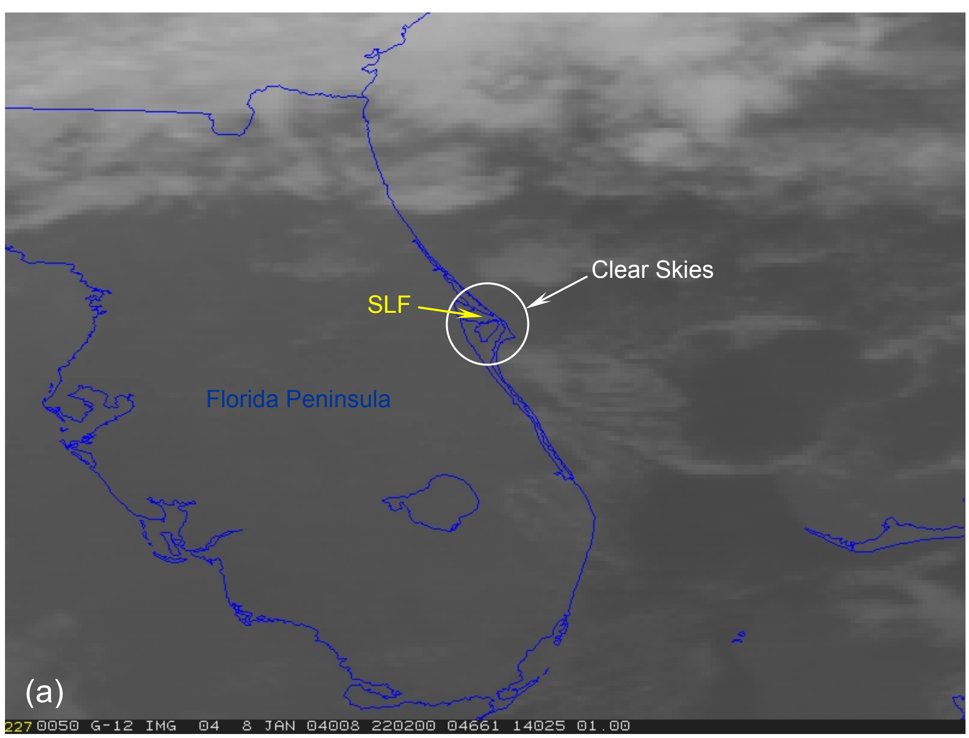
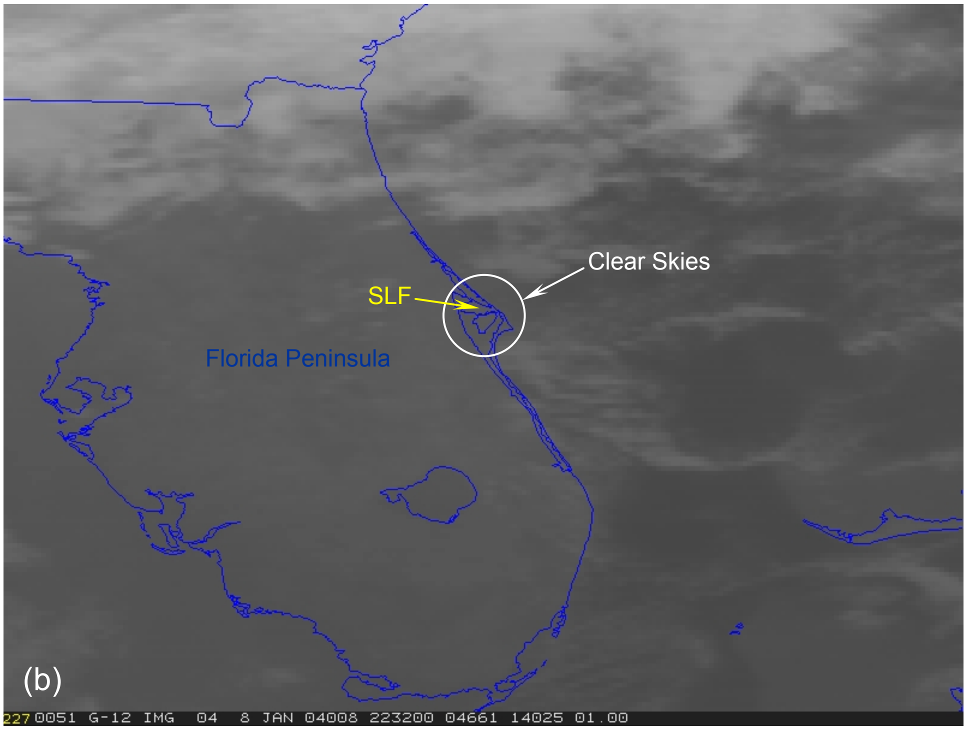


Figure 3. Infrared satellite imagery from 8 January 2004, valid at (a) 2202 UTC, (b) 2232 UTC, (c) 2302 UTC and (d) 2332 UTC.



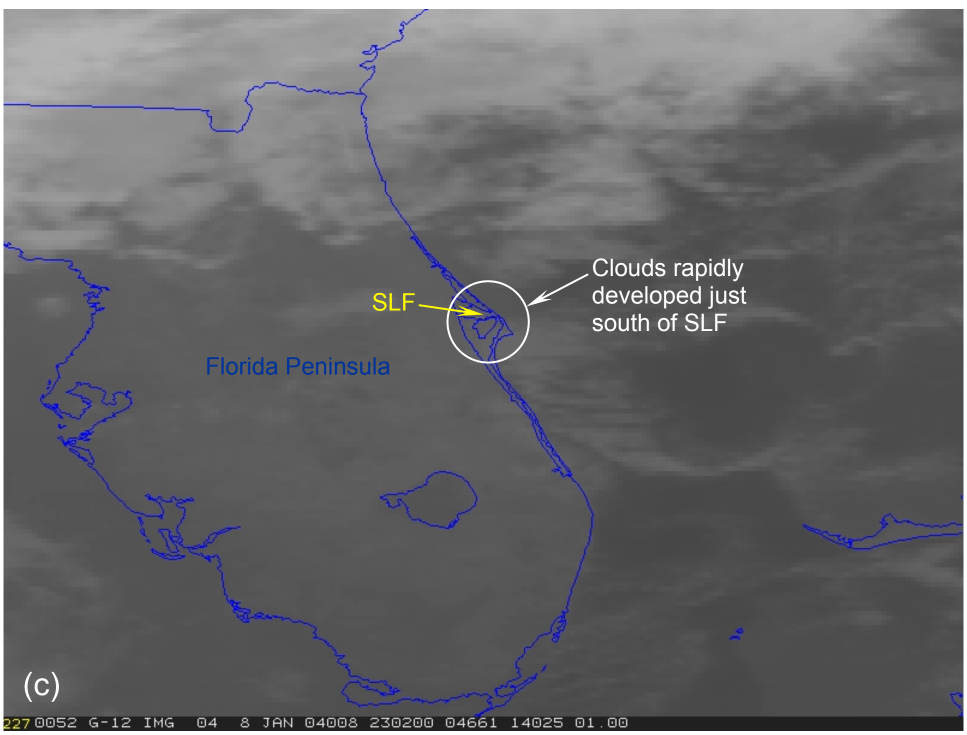


Figure 3 (continued)

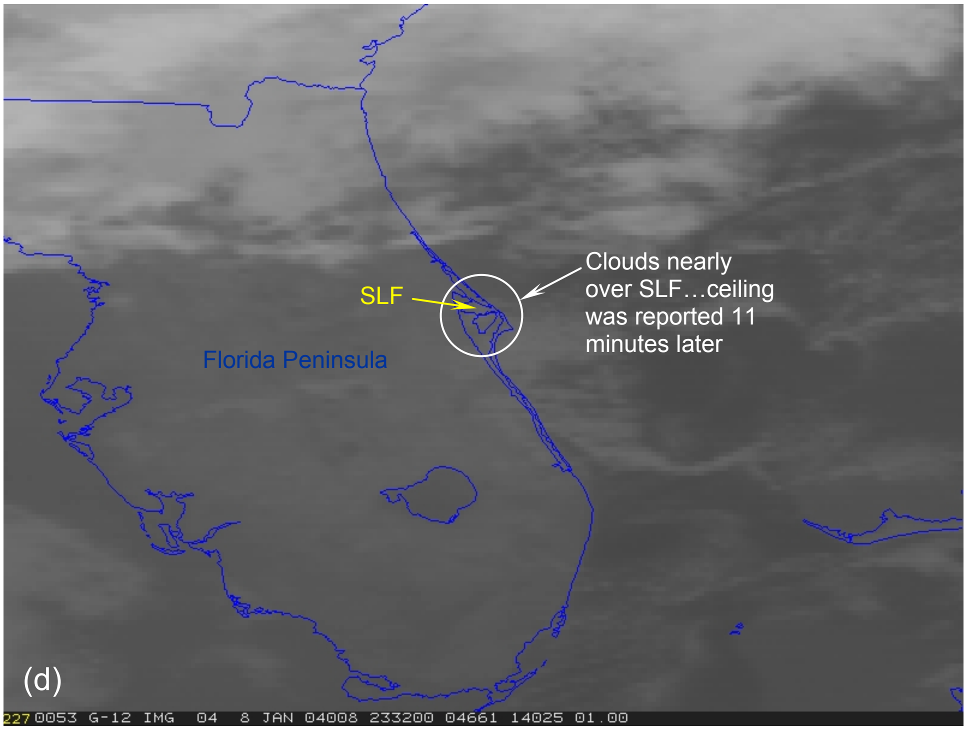


Figure 3 (continued)

5. COMPOSITE RESULTS

This section presents the meteorological characteristics of the 6 rapid, stable low cloud development days, and compares the characteristics between the 6 event and 80 non-event days.

5.1 Summary of Rapid Low Ceiling Development Events

By definition, the rapid, stable low cloud development events consisted of observed ceilings at and below 2438 m (8000 ft) and 1524 m (5000 ft) at TTS, for the years 1994–2005 between the hours of 2200 and 1000 UTC. Potential events with ceilings due to rain or fog were not considered. Potential events without soundings available at both 2200 and 1000 UTC were not considered. Other characteristics investigated included the amount of moisture in the boundary layer and the shear in the vertical wind profile from the surface to 2438 m (8000 ft).

Unlike the daytime events, only 7% of all nighttime potential events were identified as rapidly developing events. Of the 68 potential daytime events, 29% were identified as rapid development cases. The other 93% of the nighttime potential events were clearly identified as advection situations. While it was very difficult to use infrared satellite imagery to identify rapid developing events, it was not difficult to identify ceilings due to advection of low clouds. This implies nighttime rapidly developing stable low cloud events do not happen very often – certainly not as often as the daytime events. A summary of the meteorological characteristics of each event is given in Table 1. The inversion strengths in Table 1 may be under-estimates of the actual magnitude because the sounding data interpolated to 305-m levels were used to obtain the values shown. In some instances, the inversions may have been less than 305 m deep and the interpolated sounding data may have consequently smoothed out the maximum magnitude of the inversions, especially for inversions based above the surface. Because there are only 6 events, the data in Table 1 cannot be considered statistically significant. As a matter of fact, there is no commonality among the parameters from 6 events which provides little help to the SMG forecaster.

5.2 Comparison of Characteristics in Event / Non-Event Days

Since by definition all 86 days had both low cloud ceilings at TTS and no rain or fog within 3 hours of the ceiling event, one would expect that many meteorological characteristics would be similar between the 6 rapid development days and the 80 non-development days. Figures 4 through 6 illustrate these common meteorological characteristics between event and nonevent days. Both event and non-event days had a wide ranging inversion height (Figure 4), inversion strength (Figure 5), and generally had mean relative humidity above 65% (Figure 6). No distinguishable differences existed between any of these criteria. These conditions appear to be the fundamental criteria needed for nighttime low cloud ceilings in east-central Florida under a stable regime. The real challenge to the forecaster is discerning whether low cloud ceilings will form when ceilings do not already exist in this type of environment. All of the 80 non-event situations were classified as such after examining the infrared satellite imagery. All of these non-events had an obvious advection signature, typically off of the Atlantic Ocean, or else had widespread cloud ceilings that would be easy to discern as a "No-Go" condition for a space shuttle landing at KSC. As stated in the Introduction, advection scenarios are not a concern to forecasters since they can monitor the continuity of the low cloud ceilings with sufficient lead-time for landing predictions. The 6 nighttime events typically experienced rapid cloud formation in 30 minutes or less time, with no prior extensive cloud decks present over east-central Florida. Table 2 shows a summary of meteorological parameters for the 6 event days versus 80 non-event days. Unfortunately, there are no distinguishable characteristics between the event and non-event days. However, like the results of the first phase of this work for the daytime events, the vertical wind profile in the lower levels indicates a veering wind profile about two-thirds of the time. Such a profile represents a warm advection pattern that favors rising motion, and thus, cloud formation in a moist environment. Therefore, when a clear advection event is not in progress, a forecaster should be aware of the fact that nighttime rapid low cloud development is more likely with winds veering with height. The veering wind profile also makes physical sense since veering winds contribute to large-scale rising motion and cloud development.

Table 1. Summary of the 6 rapid low ceiling development events and accompanying meteorological characteristics. The mean quantity of relative humidity is given for all levels at and below 2438 m (8000 ft). The wind direction change with height was determined by examining the sounding data from the surface to 2438 m (8000 ft).

Event Date	Onset Time (UTC)	Dissipation Time (UTC)	Highest Inversion Height (m)	Inversion Strength (ºC)	Mean RH (%)	∆ Wind Direction w/Height
1/29/2002	0200	0400	surface	0.6	100	backing
11/12/2002	1038	1400	surface	1.1	69	backing
11/27/2003	0545	0700	none	-	83	veering
1/8/2004	0215	0600	1524	4.1	98	veering
3/11/2005	1100	1600	surface	2.4	90	veering
11/12/2005	1004	1500	surface	1.0	80	veering

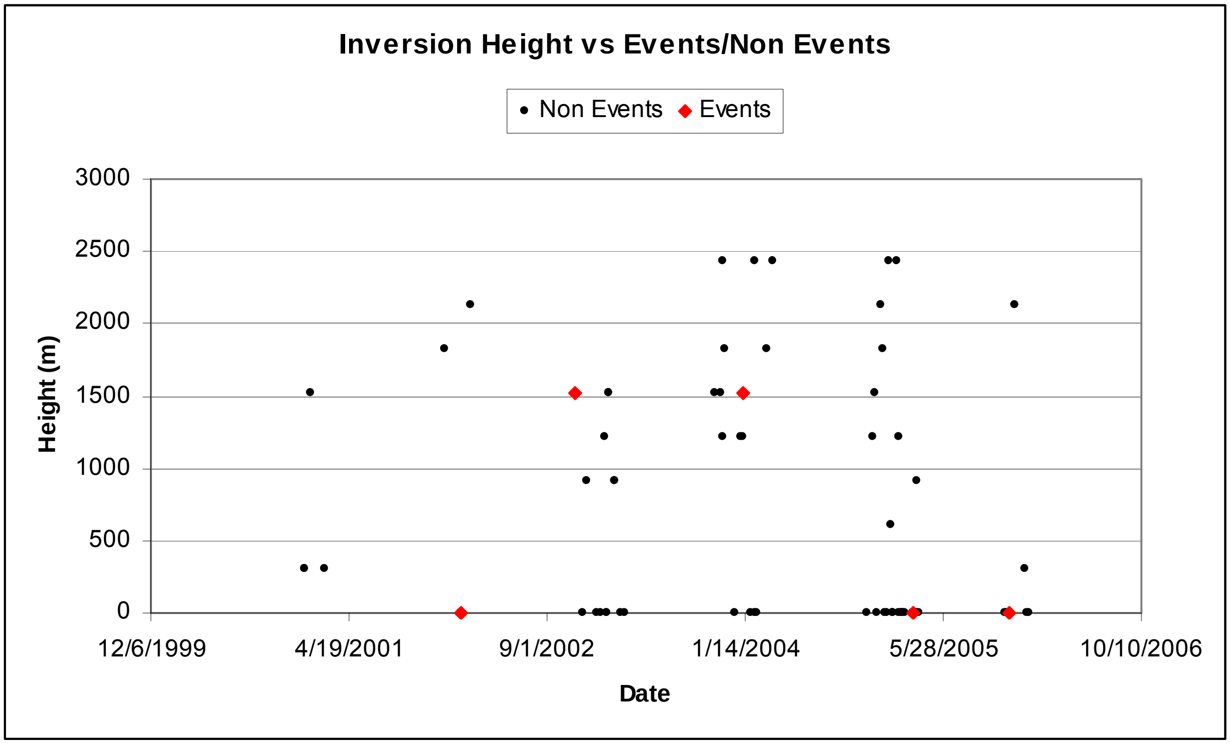


Figure 4. Scatter plot of the inversion heights (m) during event (large diamond) and non-event nights (small circle).

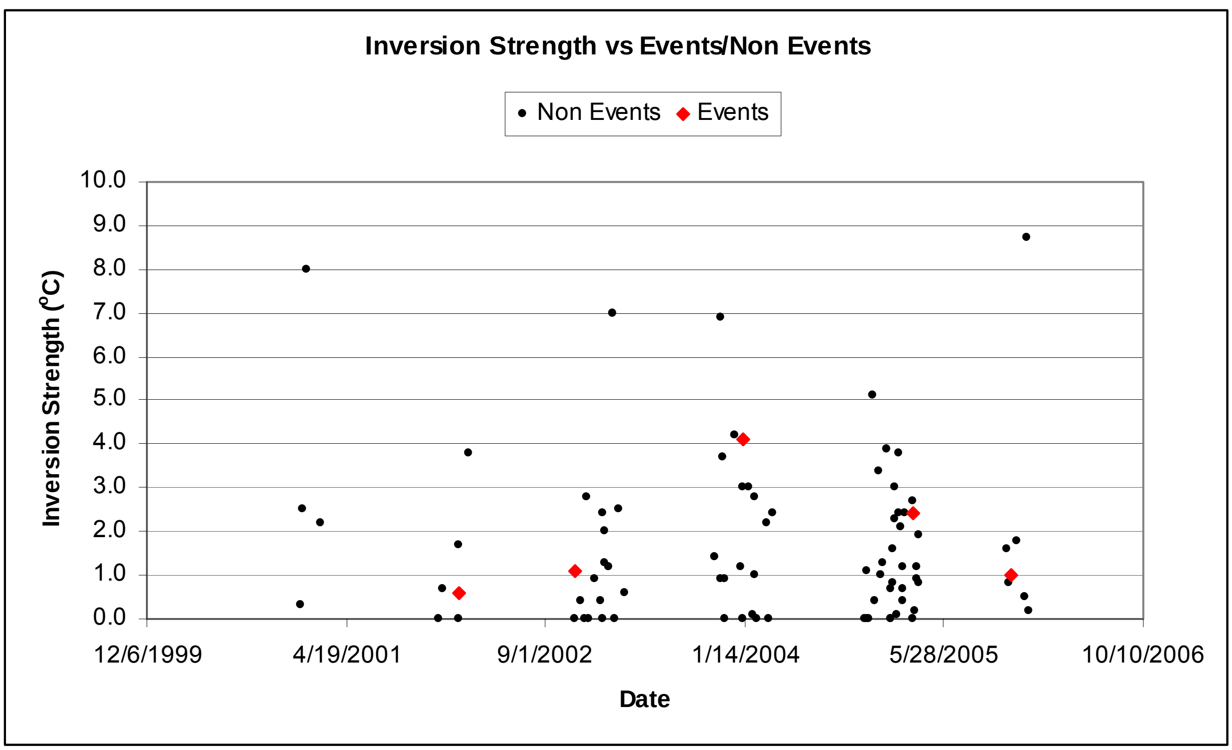


Figure 5. Scatter plot of the inversion strength (in °C) during event (large diamond) and non-event nights (small circle).

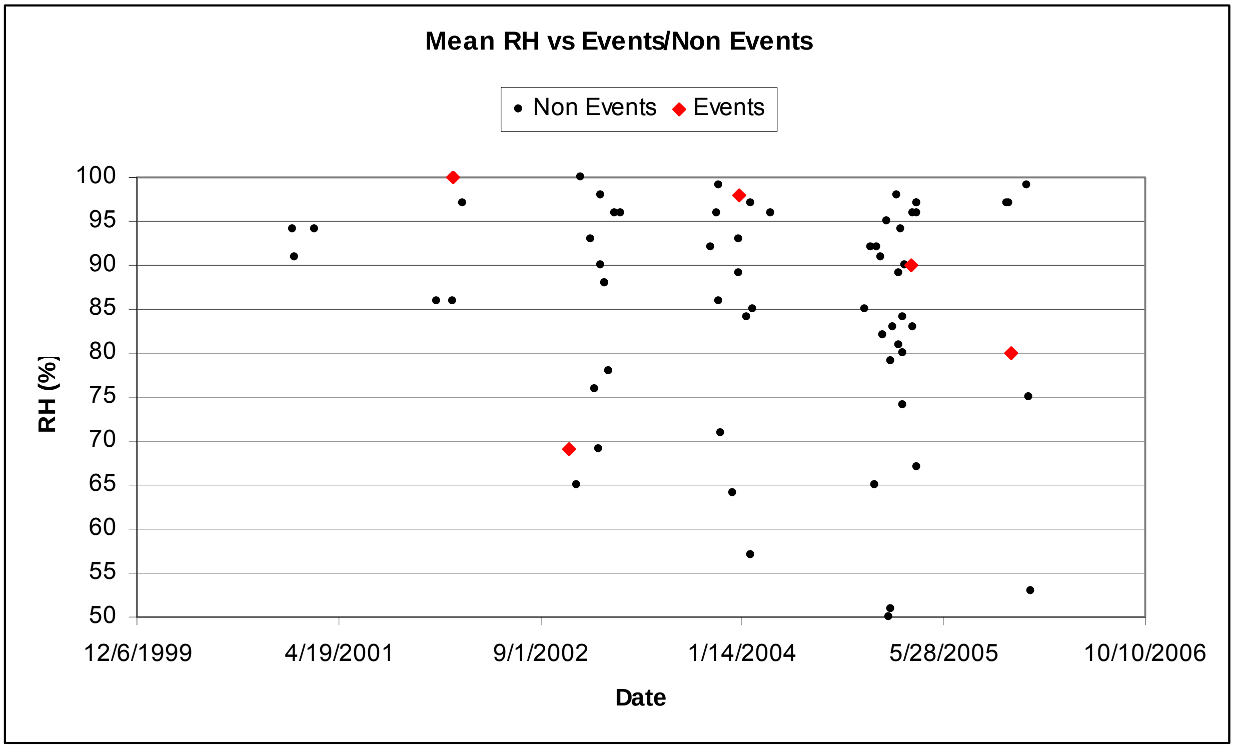


Figure 6. Scatter plot of the mean relative humidity (in %) below 2438 m (8000 ft) during event (large diamond) and non-event nights (small circle).

Table 2. Summary of meteorological parameters associated with event and non-event cases.

Parameter	Events	Non Events
Frequency of inversions	83%	86%
Mean inversion base height	607m	725m
Mean inversion strength	1.8ºC	2.2ºC
Mean RH below inversion	86%	82%
Frequency of events with winds veering with height	67%	69%

6. SUMMARY

This paper described the AMU work done in developing a database of potential nighttime events that experienced rapid low cloud formation in a stable atmosphere, resulting in ceilings below 2438 m (8000 ft) at TTS. The paper also documented the meteorological conditions favoring rapid, low ceiling formation. Meteorological parameters were summarized for 6 nighttime events with rapid low cloud ceiling formation and 80 nighttime nonevents consisting of advection or widespread low cloud ceilings. The meteorological conditions were quite similar for both the events and non-events, as expected, since both types of days experienced low cloud ceilings. Both types of nighttime cases had a relatively moist environment below 2438 m (8000 ft). There were no obvious distinguishing factors between the ordinary low cloud ceilings cases, and the nights that had rapid development. One key parameter appears to be the vertical wind profile in the XMR sounding. Sixty-seven percent of the rapid development events had veering winds with height in the lower levels. Veering winds indicate a warm-advection regime, which supports large-scale rising motion and ultimately cloud formation in a moist environment.

7. DISCLAIMER

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8. REFERENCES

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