**8.10** AN ANALYSIS OF LIGHTNING RISK AND CONVECTIVE CLOUD COVER FOR TWO PROPOSED COMMERCIAL SPACEPORT SITES

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## 1. INTRODUCTION

A climatological study was performed for two proposed commercial spaceport locations. Frequency of natural lightning, percent of cloud cover, and cloud top temperatures were analyzed to determine the risk of natural or triggered lightning to anticipated suborbital launch activity at these sites. Diurnal and seasonal variability of natural cloud-to-ground lightning at the proposed spaceports was compared to existing federal launch ranges at Cape Canaveral, Florida (CAPE) and Vandenberg Air Force Base, California (VAFB) in order to assess relative lightning risk. The site of the proposed Southwest Regional Spaceport (SWRS) is in New Mexico, approximately 45 miles north of Las Cruces, 30 miles east of Truth or Consequences and just outside the western boundary of the White Sands Missile Range. The Oklahoma Spaceport (OS) is being developed at the former Clinton-Sherman Air Force Base (CSAFB) at Burns Flat, Oklahoma, approximately 100 miles west of Oklahoma City. The southern portion of White Sands Missile Range (WSMR) -approximately 40 miles distant from SWRS -was also included in this study.

## 2. DATA

A nearly fifteen year lighting climatology [Schaub, 1996] of all cloud-to-ground lightning strikes detected by the National Lightning Detection Network (NLDN) within a 100 km radius from the latitude and longitude coordinates in Table 1 was collected. The climatology includes periods before and after the NLDN system upgrade in 1995. Only periods after the upgrade were selected for further analysis.

The 15-year climatology suggested that January and July would provide the greatest spread in seasonal behavior. The January and July 1999 periods were selected for further analysis at both potential sites. July 1999 appeared to be an anomalously lightning-prone month at SWRS and an anomalously lightning-free month at CSAFB.

Table 1
Site Coordinates and Cloud to Ground Lightning Occurrence within 100 km

| | CSAFB | SWRS | WSMR | CAPE | VAFB |
|---|---|---|---|---|---|
| Lat | 35.3 N | 32.8 N | 32.3 N | 28.4 N | 34.7N |
| Lon | 99.2 W | 107 W | 106.5W | 80.6 W | 120.5W |
| 1990-2004 tot | 1825240 | 2123004 | 968680 | 3268359 | 14076 |
| Jan Tot | 7991 | 1232 | 542 | 24 | 216 |
| Jan Avg | 533 | 82 | 36 | 2 | 14 |
| Jan 199 | 137 | 22 | - | - | - |
| Jan 2004 | 3 | 46 | - | - | - |
| July Total | 287810 | 745058 | 356042 | 813906 | 3091 |
| July Avg | 19187 | 49671 | 23736 | 54260 | 206 |
| July 1999 | 6068 | 63932 | - | - | - |
| July 2004 | 61473 | 30336 | - | - | - |

Data were also collected for January and July 2004, and the result was opposite from 1999. CSAFB had nearly twice as many cloud to ground strikes as SWRS in July 2004.

Cloud data from the Cloud Depiction and Forecast System (CDFS2) [Zamiska and Giese, 1996] were also used to investigate the relationship between the occurrence of convective clouds and lightning and the applicability of cloud-based lightning launch commit criteria (LLCC).[1] CDFS2 is a global cloud analysis product, which uses sensor

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[1] LLCC are a set of eleven rules developed to avoid natural and triggered lightning during launch of expandable and reusable launch vehicles on the federal ranges.

data from the Defense Meteorological Satellite System (DMSP). It identifies clouds by types, percent coverage, and top and base heights for up to four layers.

Temperatures from the European Center for Medium Range Forecasting (ECMWF) global analysis model grid were also used.

The following analysis uses data from three independent databases. While the data can give the locations and times that clouds and lightning were observed, they cannot establish that a particular cloud generated lightning. The temperatures were obtained from a global analysis model and cannot be expected to exactly represent the actual temperatures within a cloud.

### 3.1 Lightning Climatology

The climatology of naturally occurring cloud-to-ground lightning at all five sites was examined for seasonal and diurnal variability. Vandenberg is shown likely to be lightning-free year round. Cape Canaveral is less than 80% likely to be lightning-free for day-of-year (DOY) ~150-280 (May 30 – October 7) or ~130 days a year. CSAFB is less than 80% likely to be lightning-free for DOY ~145-250 (May 25 – September 7) or ~105 days a year. The proposed SWRS is less than 80% likely to be lightning-free for (DOY) ~170-275 (June 19 September 27) or ~105 days a year.

Despite their proximity, significant differences in the lightning climatology for WSMR and SWRS were seen. WSMR experienced roughly half as many lightning strikes as the proposed SWRS. Notably, the number of days that a site will be lightning-free is not strongly dependent on the total number of lightning strikes at that site. The likelihood that WSMR will be lightning-free on any given day is similar to that for SWRS, except the duration of the lightning season lasted approximately two weeks longer (Sep 17 – Oct 2) for SWRS.

The natural lightning seasons at the two potential spaceport sites are nearly one month shorter than for Cape Canaveral, the most lightning-prone existing launch site. Even though CSAFB and SWRS had identical lightning probabilities, the area near the proposed SWRS experienced twice the number of lightning strikes and for more hours per day (in season) as CSAFB.

### 3.2 Local Effects

Initially, coordinates of the southern end of the WSMR had been used as a proxy for the proposed SWRS location. The two sites were expected to be similar as they are adjacent and have similar elevations. However, to rule out localized effects, the climatology was later compiled using the exact coordinates of the proposed SWRS. The result showed that the proposed SWRS had roughly twice as many lightning strikes in 1999-2004 than the southern end of WSMR.

Table 2
Approximate Days with Less than 80% Probability of Being Lightning-free
(Greater than 20% chance of lightning within 100 km on that day of year)

| Site | DOY | Dates | # Days w/ High Ltg Prob |
|---|---|---|---|
| VAFB | N/A | N/A | 0 |
| CAPE | 150 – 280 | May 30 – October 7 | 130 |
| CSAFB | 145 – 250 | May 25 – September 7 | 105 |
| SWRS | 170 – 275 | June 19 – October 2 | 105 |
| WSMR | 170 – 260 | June 19 – September 17 | 90 |

Table 3
Times of minimum and maximum probability of naturally occurring lightning in July[2]

| Site | Min (UT) | Min (LT) | Max (UT) | Max (LT) |
|---|---|---|---|---|
| CAPE | 0900 | 0400 | 2000 | 1500 |
| WSMR | 1500 | 0800 | 2200 | 1500 |
| SWRS | 1500 | 0800 | 2200 | 1500 |
| CSAFB | 1600 | 1000 | 2300 | 1700 |

The site of the proposed SWRS is near a bend in a small mountain range on the western edge of WSMR. The mountain range between the WSMR and the SWRS appears to block the flow of monsoonal moisture from the southwest. The monsoonal flow is primarily responsible for

[2] VAFB is omitted because it is nearly lightning-free in July.

mesoscale convective systems in southwestern continental US (CONUS). A graph of the latitude and longitude coordinates of measured lightning strikes near SWRS in July 1999 [Figure 1] illustrates this effect. The density of lighting strikes is much higher to the west of the proposed SWRS and the mountain range. Even the northeastward bend in the mountain range near SWRS is apparent in the lightning statistics; the boundary between the lightning prone and non-lightning prone areas also bends to the north-northeast there. WSMR, which is inside of a protected valley, experienced much fewer lighting strikes in the same time period.

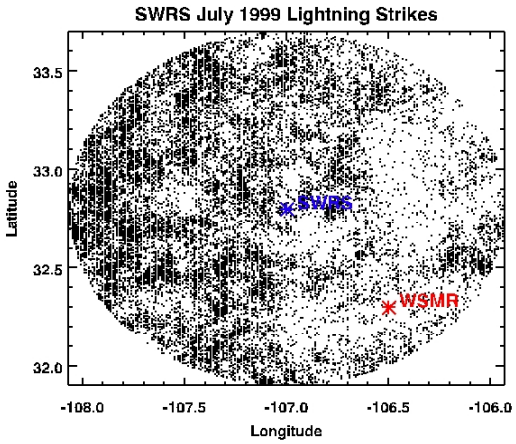


Figure 1. Each small black dot represents one lightning strike observed by the National Lightning Detection Network (NLDN) during July 1999, which was a very stormy period in the area. Lightning occurs much less frequently in the WSMR valley floor than at SWRS.

## 4. CLOUDS AND LIGHTNING

Several LLCC [Krider, 1999] developed for Expendable and Reusable Launch Vehicles on the federal ranges require that launches be delayed if lightning storms are in the area and if the associated clouds remain in the vicinity of the launch area. Lightning and convective cloud data were combined to clarify the correlations. The dates and hours of observed convective clouds (black crosses) and lightning strikes (red diamonds or triangles) within a 100 km radius circle of the proposed SWRS and CSAFB were plotted.

Between 1999 and 2004, CDFS2 cloud analysis became available hourly instead of 3 hourly. Times are rounded *down* to the next whole hour (or 3 hour) time period. In general, lightning is observed during or following times in which convective clouds are observed.

As expected, there was a correlation between observation of cumulus and cumulonimbus clouds and lightning occurrence. However, a high correlation was also observed between altocumulus clouds and lightning occurrence even though altocumulus clouds are not generally associated with natural lightning. The CDFS2 system possibly misidentifies cumulus clouds as altocumulus clouds because satellite cloud identification can sometimes incorrectly locate the cloud top heights by up to three kilometers too high [Naud *et al.*, 2004].

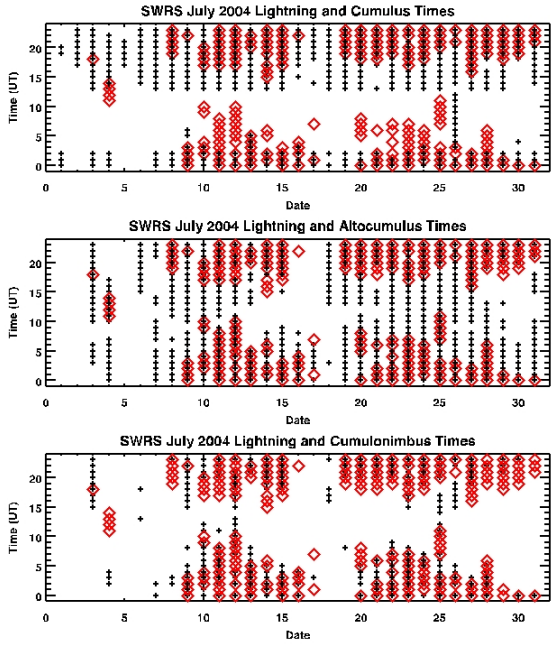


Figure 2. July 2004 dates and hours (UT) that convective clouds (black +) and lightning (red diamonds) were observed within 100 km of SWRS. Local time is UT minus 7 hours.

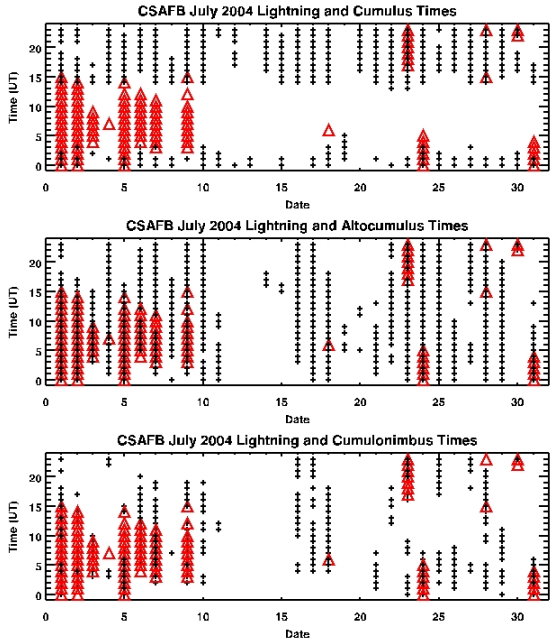


Figure 3. July 2004 dates and hours (UT) that convective clouds (black +) and lightning (red triangles) were observed within 100 km of CSAFB. Local time is UT minus 6 hours.

## 5. CLOUD TEMPERATURE-BASED LLCC

Some of the cloud-based LLCC are based on cloud microphysical properties. Cloud electrification peaks where water and ice are both present, around -10ºC. Existing cloud-based LLCC also specify that the flight path must not come within 0, 5 or 10 nautical miles of cumulus clouds with cloud tops higher than the -5ºC, -10ºC and -20ºC isotherms, respectively. Since this required knowledge of the heights of the isotherms at specific times and places and CDFS2 does not give cloud temperature information, incorporation of a third database was required. The European Center for Medium Range Forecasting (ECMWF) global analysis model grid was used.

The data at the tiles containing CSAFB and the proposed SWRS were vertically interpolated to obtain the isotherm geopotential heights for 5°C, -5°C, -10°C, and -20°C (red, green, aqua, blue lines) (Figures 4 and 5).

Where the surface temperature is colder than 5°C, the 5°C isotherm line (shown in red) is set at 0. The terrain elevation of CSAFB grid tile is 590 m. Terrain elevation at SWRS grid tile is 1534 m. This is an average over the entire tile and not the actual elevation at the site. In general, wintertime surface temperatures are lower at CSAFB than at SWRS.

Comparison of the July 1999 and 2004 data show that the cumulus (and possibly also the altocumulus) cloud tops at the proposed SWRS reach the -10°C, and -20°C isotherm altitudes more frequently than those at CSAFB. This increases the chances of violating the LLCC dependent on cloud top temperatures. There were no noticeable differences for cumulonimbus cloud top temperatures.

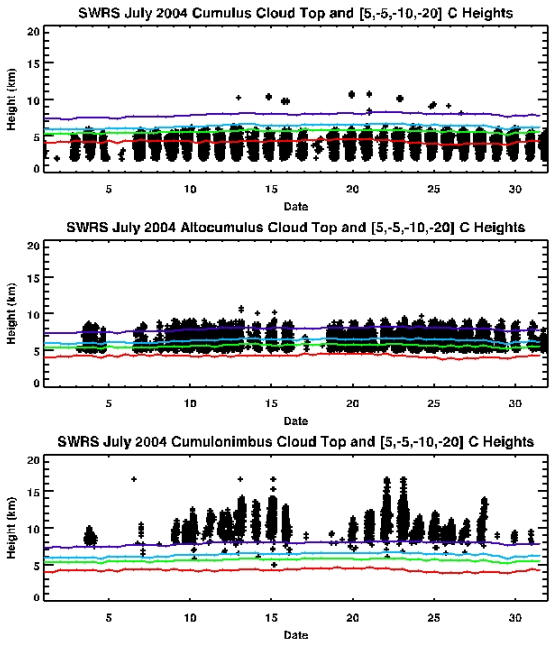


Figure 4. Cloud top heights for selected cloud types are shown in black (+). Isotherm heights for 5, -5, -10 and -20 C are shown in red, green, aqua and blue respectively.

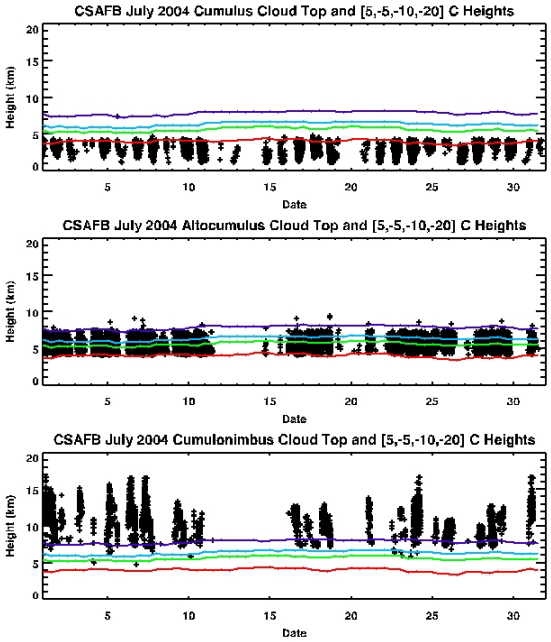


Figure 5. Cloud top heights for selected cloud types are shown in black (+). Isotherm heights for 5, -5, -10 and -20 C are shown in red, green, aqua and blue respectively.

## 6. SUMMARY

A nearly 15-year climatology of naturally-occurring cloud-to-ground lightning strikes showed that the proposed SWRS experiences significantly more lightning strikes overall than CSAFB. However, year-to-year variability is high, and cloud-to-ground data from July 2004 indicated twice the amount of lightning strikes at the proposed OS than at the proposed SWRS.

Both proposed launch sites are more than 20% likely to experience lightning for roughly the same number of days a year (105), but the peak season begins at the end of May and lasts through early September in Oklahoma, and in New Mexico begins in mid-June and lasts until early October.

A more detailed discussion with many additional graphs can be found in the final report for this study [Krider *et al.*, 2005].

## 7. ACKNOWLEDGEMENTS

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## 8. REFERENCES

Clothiaux, E. E., T. P. Ackerman, G. G. Mace, K. P. Moran, R. T. Marchand, M. A. Miller, and B. E. Martner, Objective Determination of Cloud Heights and Radar Reflectivities Using a Combination of Active Remote Sensors at the ARM CART Sites, *J. Applied Meteorology*, 39, 645-665, May 2000.

Ely, B.L., and R.E. Orville, High Percentage of Positive Lightning Along the USA West Coast, Geophys. Res. Lett., 32, 2005.

Krider, E. P., Koons, H. C., Walterscheid, R. L., Rust, W. D., Willett, J. C., Natural and Triggered Lightning Launch Commit Criteria, The Aerospace Corporation Report. No. TR-99(1413)-1, Jan 1999.

Krider, E. P., Willett, J. C., Peng, G. S., Roeder, J. L., Simmons, F. S., Law, G. W. and Seibold, R. W., Triggered Lightning Risk Assessment for Reusable Launch Vehicles at the Southwest Regional and Oklahoma Spaceports. Final Report, U. S. Department of Transportation Contract DTRS57-99-D-00062, Task 12, The Aerospace Corporation Report. No. ATR-2005(5195)-1, 2005.

Naud, C. M, J-P Muller, and E. E. Clothiaux, Comparison Between Active Sensor and Radiosonde Cloud Boundaries Over the ARM Southern Great Plains Site, *J. Geophys. Res.*, *108*(D4), 4140, 2003

Naud, C. M, J-P Muller, Haeffelin, M., Morille, Y., and Delaval, A., Assessment of MISR and MODIS Cloud Top Heights Through Inter-comparison with a Back-Scattering Lidar at SIRTA, *Geophys. Res. Letters*, 31, L04114, 2004.

Roeder, W. P., J. E. Sardonia, S. C. Jacobs, M. S. Hinson, A. A. Guiffrida, and J. T. Madura, Lightning Launch Commit Criteria at the Eastern Range/Kennedy Space Center, 37th AIAA Aerospace Sciences Meeting and Exhibit, AIAA-99-0890, January 11-14, 1999.

Schaub, W. R., Jr., Lightning Climatology for Holloman AFB, New Mexico, Air Force Combat Climatology Center Report AFCCC/TN-96/005, March 1996.

Schaub, W. R., Jr., Nationwide Lightning Climatology, Air Force Combat Climatology Center Report AFCCC/TN-96/002, Feb 1996.

Zamiska, A., and P. Giese, RTNEPH AFCCC Climatic Database Users Handbook No. 1, Air Force Combat Climatology Center Report USAFETAC/UH-86/001, Sept 1986 (Revised Nov 1996).