Cost-Benefit Analysis: Evaluating a Potential Weather Radar Tool for Space Vehicle Lightning Launch Commit Criteria

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Outline

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- Project Goal
- Candidate Cases and Data
- Methodology
- Manual Calculations
- Results
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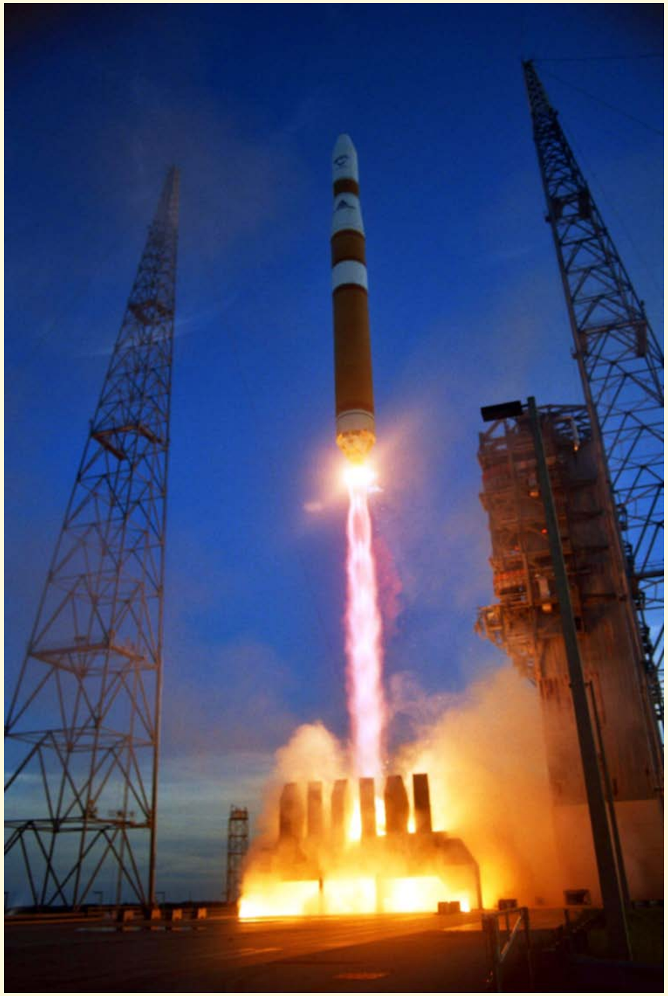
Pad 39-A, 14 Nov 1969
36.5 sec after Apollo 12 liftoff
Saturn V at 6,000 ft altitude

Background

- Lightning Launch Commit Criteria (LLCC)
  - Designed to prevent space launch vehicles from flight through environments conducive to natural or triggered lightning
  - Used for all launches at U.S. government and civilian ranges
- LLCC for anvil cloud
  - To avoid triggered lightning
  - High false alarm rate
  - Excessively conservative
  - Upgraded in 2005 based on the Airborne Field Mill experiment
    - LLCC based on Volume Averaged Height Integrated Radar Reflectivity (VAHIRR) product would pose negligible risk
    - Kennedy Space Center (KSC) Weather Office may seek funds to develop automated VAHIRR algorithm for weather radars

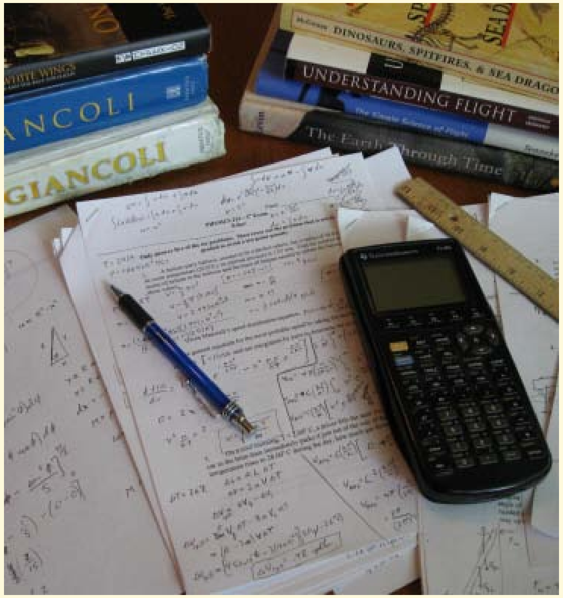
Project Goal

Using data from previous launches, manually calculate VAHIRR to determine the frequency with which VAHIRR would have allowed a launch to safely proceed during weather conditions otherwise deemed "red" due to anvil cloud LLCC by the Launch Weather Officer



Candidate Cases and Data

- Launch weather summaries impacted by LLCC
  - The 45th Weather Squadron (45 WS) at the Eastern Range (ER) provided summaries from 14 launch countdowns
  - The 30th Weather Squadron (30 WS) at the Western Range (WR) provided summaries from 5 launch countdowns
  - December 2001 – June 2007
- Manual VAHIRR calculations
  - Completed for 6 ER launch countdowns
    - Radar data not always available when anvil cloud was observed
    - Some launch summaries missing details of LLCC type
  - No WR launch countdowns
    - No LLCC violations due to anvil cloud



Methodology

- Manually Calculate VAHIRR using 45 WS process
  - Do conditions violate the Anvil Rule for anvil (attached or detached) within 5 NM or fly through?
  - Is the anvil cloud within 5 NM of the flight path located at altitudes < 0° C?
  - Is significant attenuation taking place due to intervening storms or by water on

Table 1. Criteria used to calculate VAHIRR. The first row shows the average cloud thickness and the second row shows the maximum reflectivity permitted for the corresponding cloud thickness in that column.

Average Cloud Thickness (ft)	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000	11000	12000
Maximum Reflectivity Allowed (dBZ)	33.00	16.50	11.00	8.25	6.60	5.50	4.71	4.13	3.67	3.30	3.00	2.75

  - Determine the maximum reflectivity in the specified volume
  - Using the cloud thickness, determine if the max reflectivity > max allowed
    - If the max reflectivity is less than that in Table 1, VAHIRR provides relief
    - If the max reflectivity equals or exceeds that in Table 1, VAHIRR does not provide relief

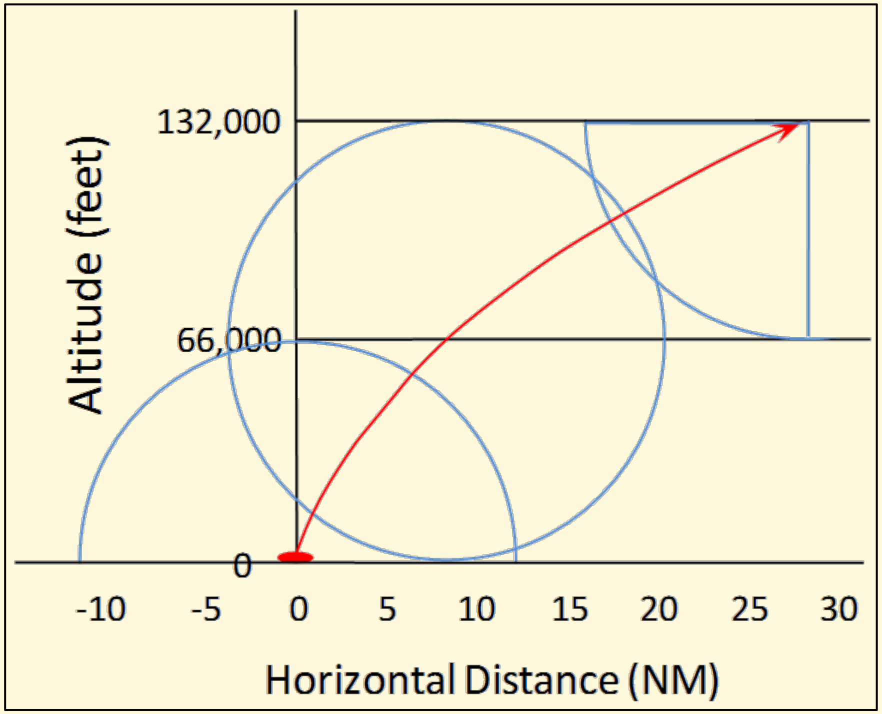
Manual Calculations

- Data sources
  - Level II reflectivity volume scans from Melbourne, Florida WSR-88D
  - 0°C level from ER (XMR) rawinsonde
  - CG strikes from ER Cloud-to-Ground Lightning Surveillance System
- Software
  - GR2Analyst
    - Reads archived WSR-88D Level II files
    - Cross section capability to determine cloud thickness
    - 3-D radar volume scans to locate anvil cloud
  - Universal Rawinsonde Observation (RAOB)

Manual Calculations

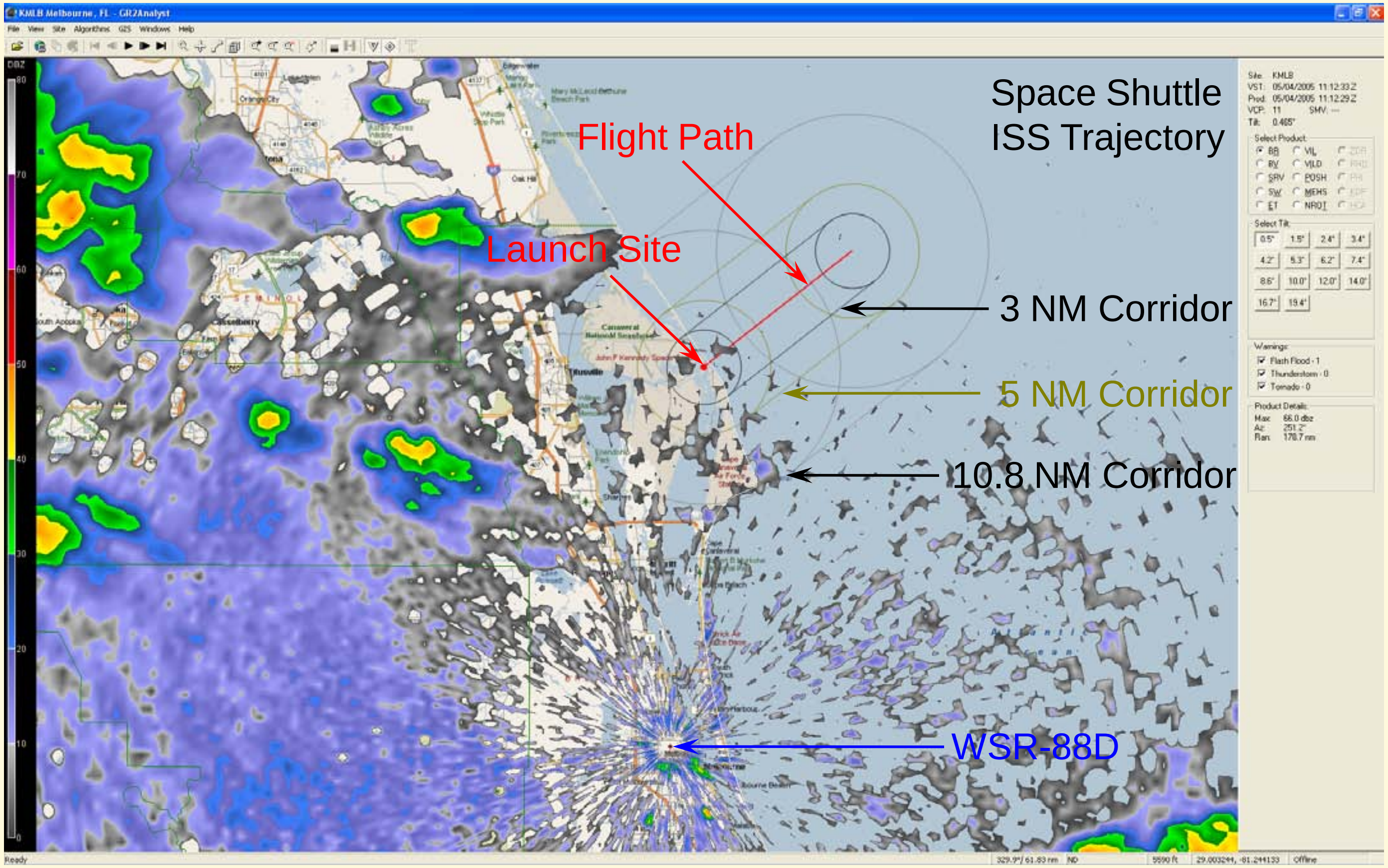
- Stand-off criteria used to calculate VAHIRR requires horizontal and vertical vehicle clearances - results in a spherical stand-off region
- No lightning within 10.8 NM from any point along the trajectory
- Stand-off sphere moves with the vehicle as it moves downrange
- Altitude at which VAHIRR can no longer be calculated is ~66,000 ft

Conceptual diagram of a Space Shuttle trajectory to the International Space Station (ISS)



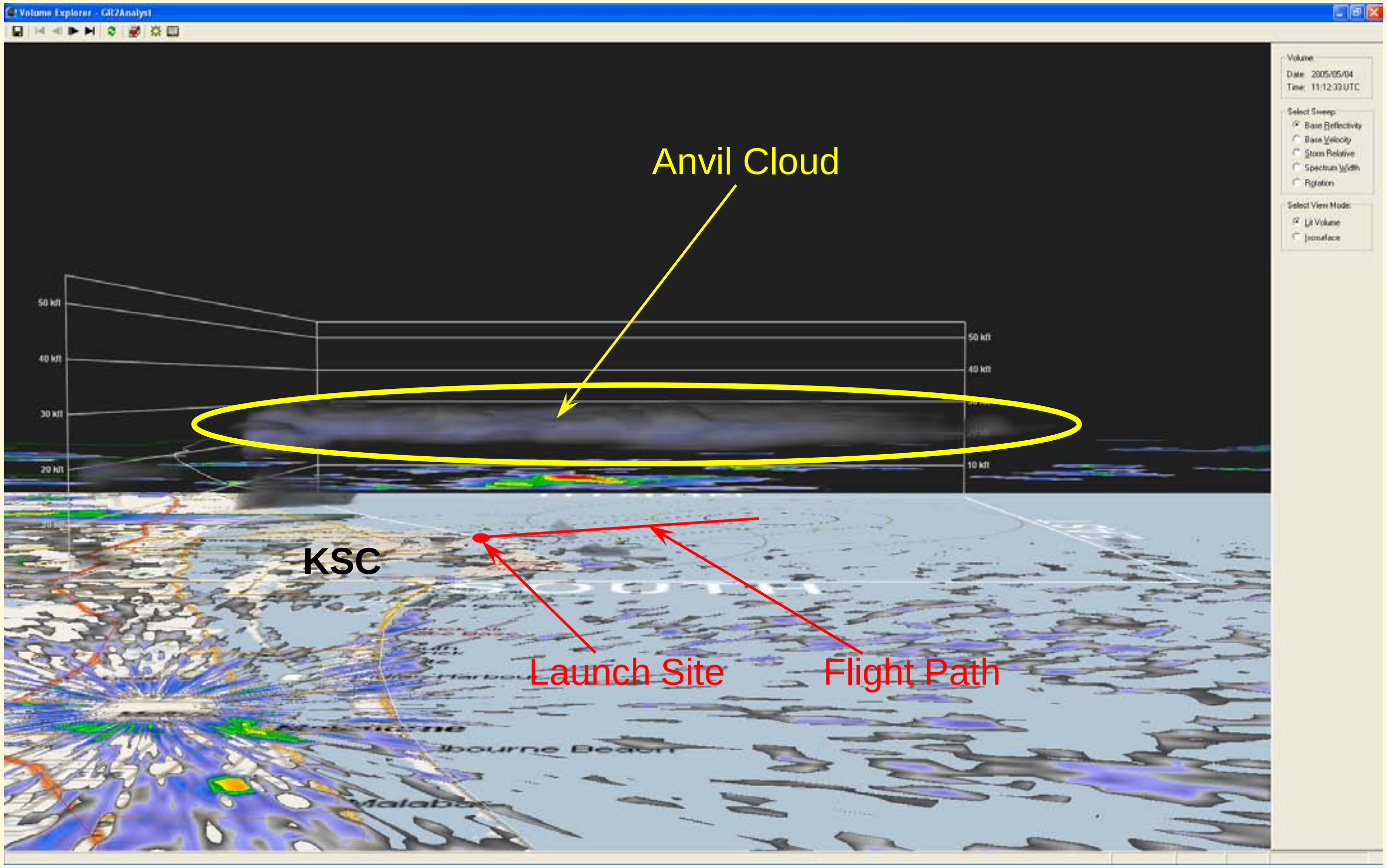
Manual Calculations

- Developed a graphic to use as a VAHIRR overlay in GR2Analyst with radar and lightning plots



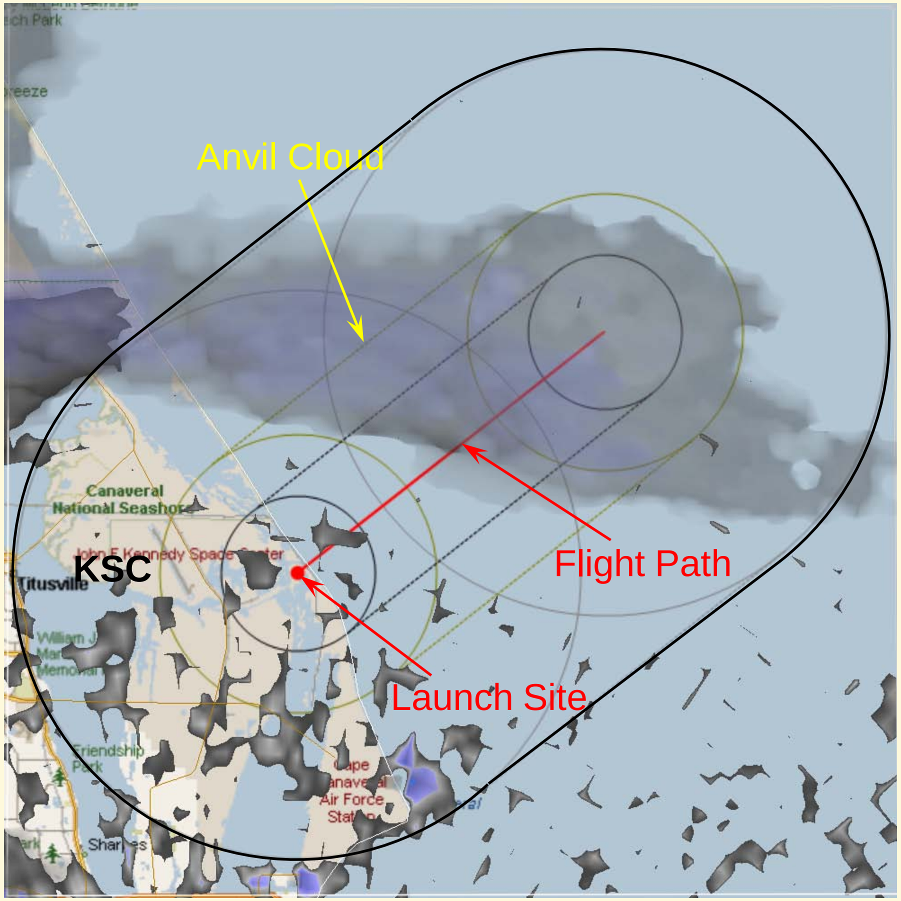
Manual Calculations

- Determined anvil cloud location using GR2Analyst Volume Explorer



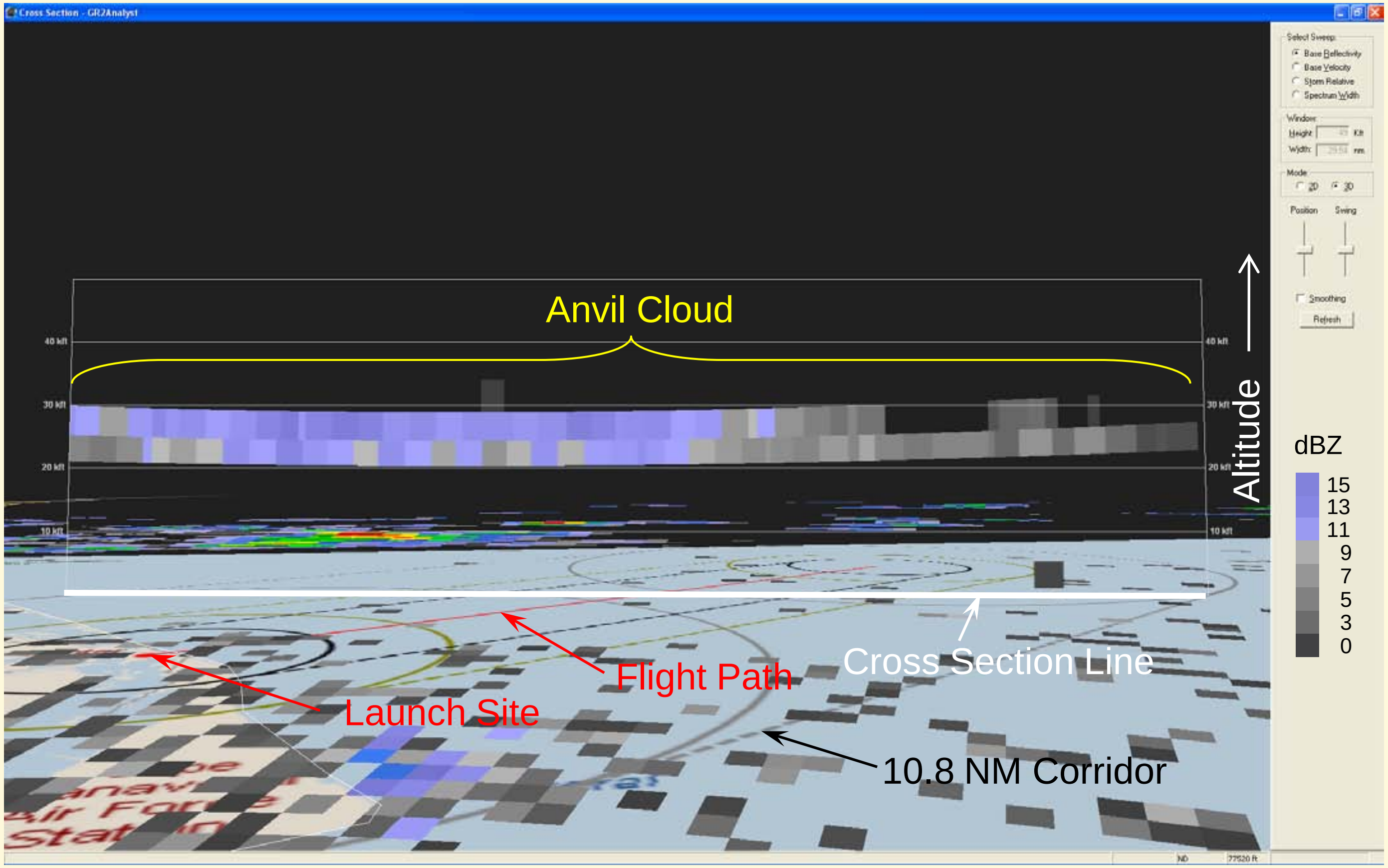
Manual Calculations

- Plan view of radar reflectivity shows the location of the anvil cloud relative to the flight path and stand-off regions



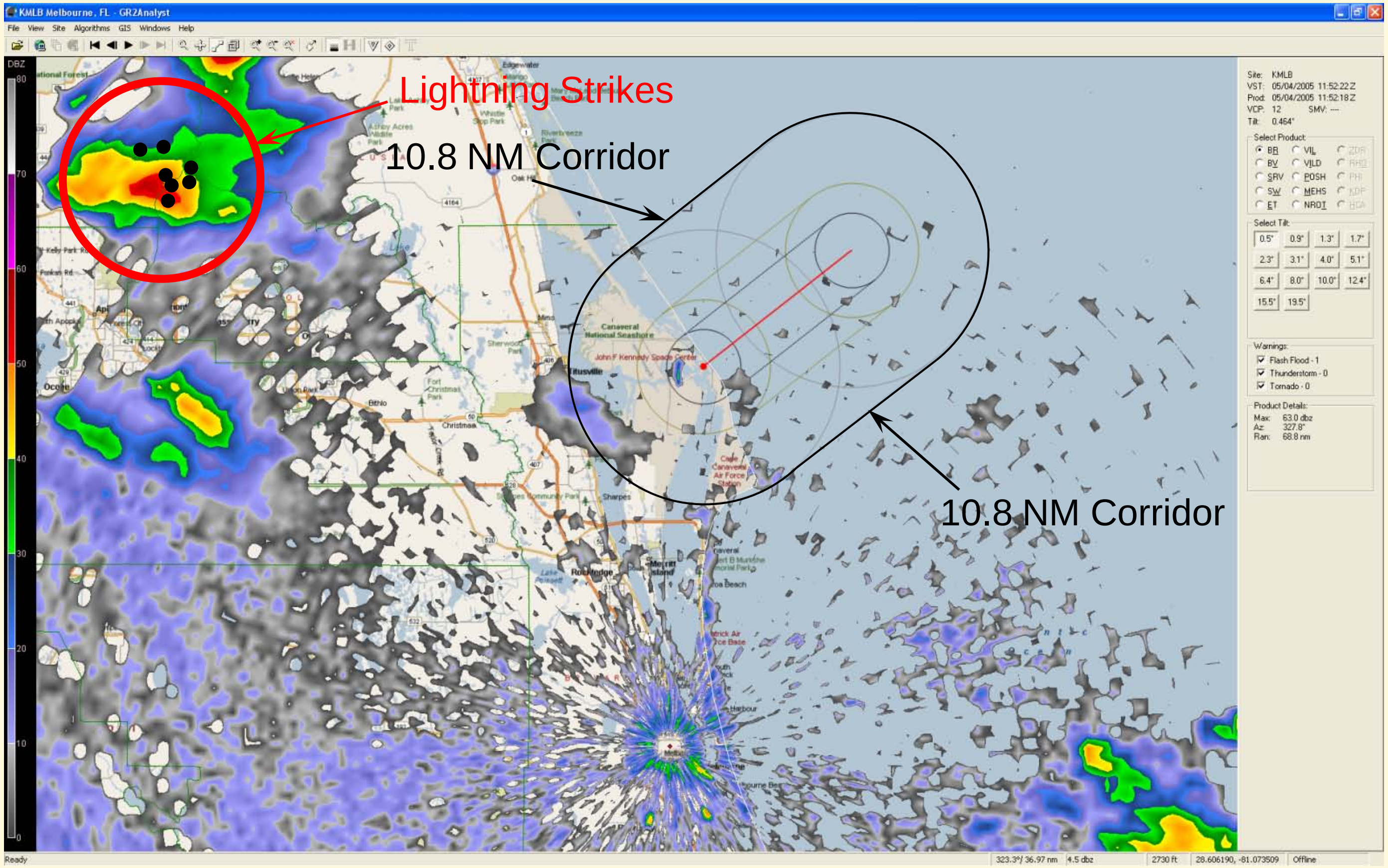
Manual Calculations

- GR2Analyst cross section within 10.8 NM corridor used to determine max/min reflectivity and reflectivity < 35 dBZ



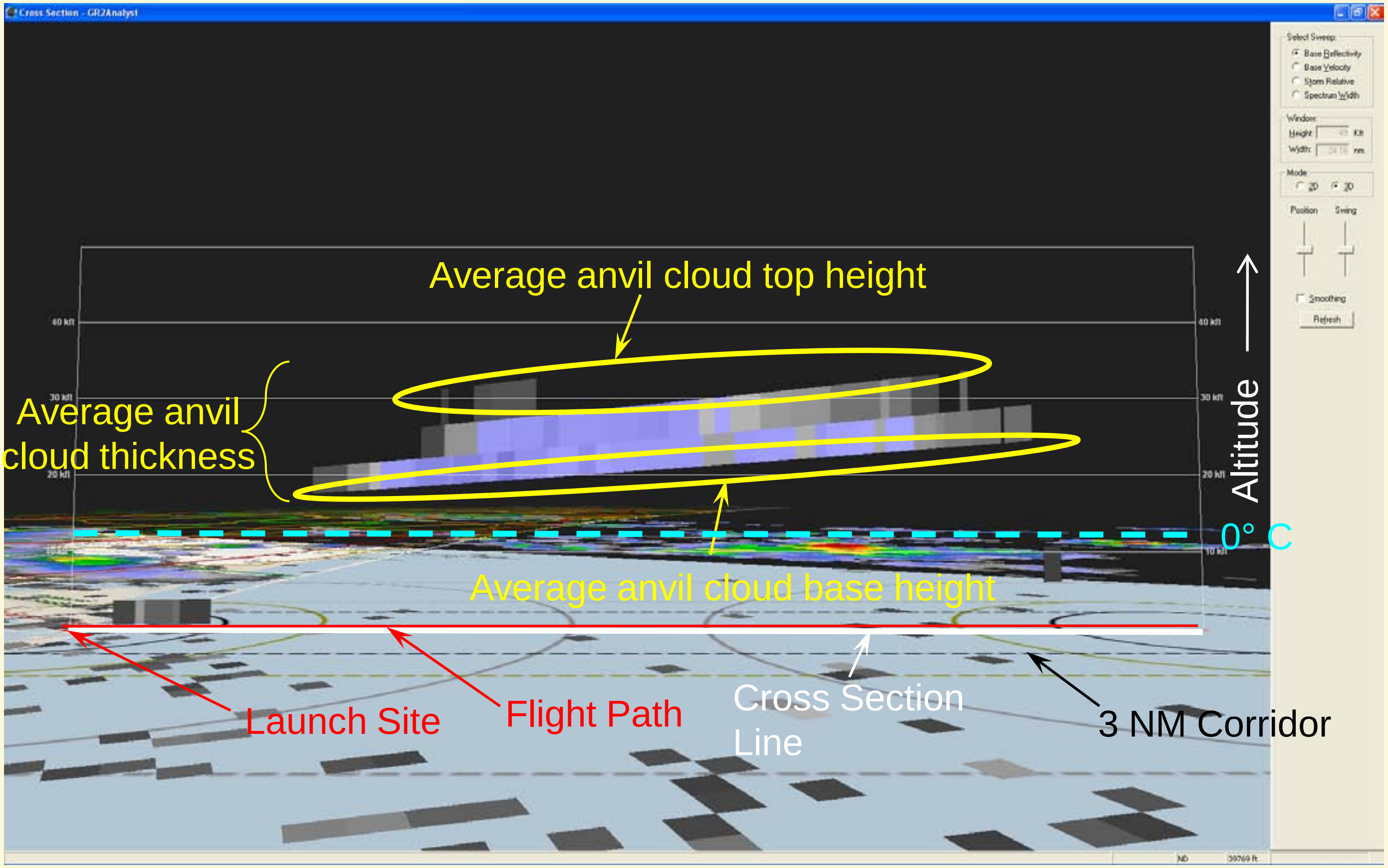
Manual Calculations

- CG strikes overlaid on the VAHIRR graphic used to determine location relative to10.8 NM corridor



Manual Calculations

- Vertical cross section within the 3 NM corridor used to determine anvil cloud thickness

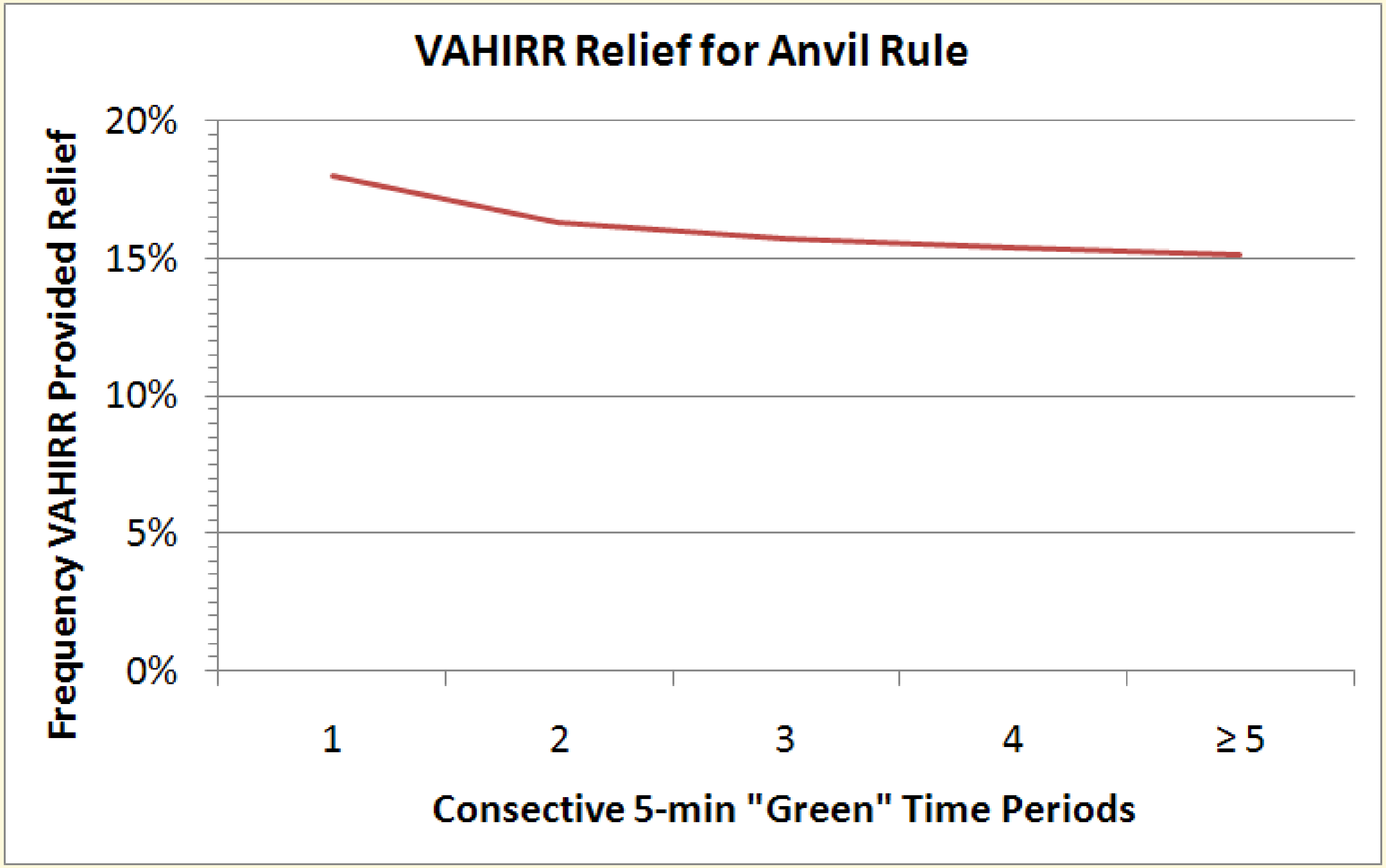


Results

- Did not take into account if other weather LCC violations were occurring at the same time as the anvil cloud LLCC
- Calculated VAHIRR for every available WSR-88D volume scan when the launch weather summaries indicated a red condition for anvil cloud
  - Anvil cloud LLCC were red for 2,314 minutes
  - All data were available 74% of that time
  - 344 usable 5-minute volume scans
  - VAHIRR not calculated for 95 volume scans due to CG violation and/or reflectivity > 35 dBZ within 10.8 NM of the flight path
  - VAHIRR calculated for 217 volume scans
    - Values too large to provide relief from the anvil cloud LLCC violations in 155 but small enough in 62 cases
    - The 62 cases contained single and multiple 5-minute periods

Results

- How much time do launch and flight directors require to make a decision from “NO-GO” to “GO” based on VAHIRR



Summary and Conclusions

- LLCC are designed to prevent space launch vehicles from flight through environments conducive to natural or triggered lightning
- VAHIRR has the best correlation of operational weather observations to electric fields capable of rocket triggered lightning in anvil clouds
- Manual calculations indicated VAHIRR provided relief from anvil LLCC between 15% and 18% of the time for varying 5-minute time periods
- Time to calculate VAHIRR manually: 7-8 minutes per volume scan, not suited for operations with 2-5 minute volume scans
- An automated algorithm would assist Launch Weather Officers in evaluating anvil cloud LLCC
- KSC Weather Office may seek funds to develop automated VAHIRR algorithm for weather radars

VAHIRR References

Dye, J. E., M. G. Bateman, D. M. Mach, C. A. Grainger, H. J. Christian, H. C. Koons, E. P. Krider, F. J. Merceret, and J. C. Willet, 2006: The Scientific Basis for a Radar-Based Lightning Launch Commit Criterion for Anvil Cloud. Preprints, *12th Conf. on Aviation, Range and Aerospace Meteorology,* Atlanta, GA, Amer. Meteor. Soc., 4 pp. [Available online at: http://ams.confex.com/ams/pdfpapers/100563.pdf]

Dye, J. E., M. G. Bateman, H. J. Christian, E. Defer, C. A. Grainger, W. D. Hall, E. P. Krider, S. A. Lewis, D. M. Mach, F. J. Merceret, and J. C. Willet, and P. T. Willis, 2007: Electric fields, cloud microphysics and reflectivity in anvils of Florida thunderstorms, *J. Geophys. Res*., **112**, D11215, doi10.1029/2006JD007550.

Merceret, F. J., M. McAleenan, T. M. McNamara, J. W. Weems, and W. P. Roeder, 2006: Implementing the VAHIRR Launch Commit Criteria Using Existing Radar Products. Preprints, *12th Conf. on Aviation, Range and Aerospace Meteorology*, Atlanta, GA, Amer. Meteor. Soc., 8 pp. [Available online at: http://ams.confex.com/ams/pdfpapers/98076.pdf]