# 6.5 BOUNDARY LAYER INFLUENCES ON FORECASTING TOXIC CORRIDORS AT THE EASTERN RANGE IN SUPPORT OF SPACE LAUNCH

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## 1. INTRODUCTION

The Air Force's 45th Weather Squadron (45 WS) provides comprehensive operational meteorological services to the Eastern Range (ER) and the Kennedy Space Center (KSC). These services include weather support for resource protection, pre-launch ground processing, and day-of-launch operations by the Department of Defense, National Aeronautics and Space Administration (NASA), and commercial launch customers.

Large vehicles such as the Air Force's Titan IV rocket and NASA's Space Shuttle are boosted by solid rocket motors which exhaust substantial amounts of hydrogen chloride (HCl) gas during a normal launch. The Titan IV also carries more than 400,000 pounds of liquid hypergol propellants, which could be released to the atmosphere in the event of a catastrophic failure. Ground operations involving fuel and oxidizer storage and transfer activities also pose a risk of toxic emissions. To obtain maximum launch availability while ensuring safety of government personnel and the civilian population, the Safety Office of the ER must ingest weather data into physical models, which, in turn, assess the risk to safety of each operation. This paper presents one case illustrating the importance of weather information in that process.

## 2. WEATHER SYSTEMS IN SUPPORT OF SAFETY

Range Safety must assess the safety risk of each operation at the ER. Performing risk assessments by ingesting weather data into safety models allows the Range Safety Office to ensure the safety of government personnel and the civilian population.

For the 45 WS to provide required data to the Safety Office, an extensive suite of instrumentation is deployed throughout the Cape Canaveral Air Force Station (CCAFS)/ KSC area as described by Harms et al. (1998). The ER meteorological instrumentation includes: four independent lightning detection systems, an extensive upper-air system (consisting of radars, balloons, Jimspheres, and rocketsondes), hundreds of boundary layer sensors, two weather radars, and a direct GOES weather satellite receiver and display.

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### *2.1 Upper-Air Systems*

A key system for safety support is the ER upper-air system, described by Wilfong et al. (1996). It is operated and maintained at CCAFS by the Range Technical Services Contractor. The frequency of upper-air observations varies from two or three (transponder) rawinsondes per day (for routine forecasting needs), to a combination of 16 or more rawinsondes and Jimspheres in 24 hours to support a single launch.

### *2.2 Boundary Layer Sensors*

Boundary layer sensing at the ER is important for safety's toxic forecasts. Two systems provide data: a network of 44 meteorological towers with wind, temperature, and dew point sensors at various levels, and a network of five 915 MHz Doppler Radar Wind Profilers (DRWPs) with Radio Acoustic Sounding Systems (RASS). Most towers are 16 to 18 m tall, with sensors at two levels. Three others are 67 m and one is 165 m with sensors at various heights. All report wind, temperature, and dew point, either each minute or every five minutes. The network by 915 MHz DRWPS (Table 1) as described by Lucci, et al. (1998) outputs low-level winds and virtual temperature profiles from 120 m to 3 km every 15 minutes.

**Table 1**
**Profiler Locations**

| Profiler | Name | Site | Comment |
|---|---|---|---|
| 1 | RWP 0001 | CX-17 (South Cape) | Southern Most |
| 2 | RWP 0002 | False Cape | Coastal, North Side of the Cape |
| 3 | RWP 0003 | Kennedy Parkway (Merritt Island) | Intermediate Inland |
| 4 | RWP 0004 | Mosquito Lagoon | Northern Most |
| 5 | RWP 0005 | Tico Airport | Western Most |

### *2.3 Other Systems*

While the ER lightning systems, as described by Harms et al. (1997) may be the most unique of all local weather systems; they do not play a significant role in toxic forecasting. Other weather systems, such as radar and GOES satellite imagery, while not used directly by

Range Safety, do aid in the final determination of the actual toxic forecasts.

## 3. A SAMPLE CASE: FEBRUARY 2001

The models used in forecasting toxic corridors at the ER are explained in detail by Boyd et al. (1999). The two primary models referenced in this case study are REEDM (Rocket Exhaust Effluent Diffusion Model) and ERDAS (Eastern Range Dispersion Assessment System). The REEDM predicts vehicle-specific source term cloud characteristics for both nominal launch and catastrophic failure cases. The ERDAS includes two major software systems, which are run and accessed through a graphical user interface.

During the Titan IV B-41 launch countdown on 27 Feb 01, the 915 MHz Profilers provided valuable data for toxic hazard support. They allowed for the minimization of spatial and temporal forecast uncertainties. They facilitated critical decisions regarding launch viewing from the NASA Causeway, while adding to the safety of viewers.

The Titan-IV B-41 launch was repeatedly rescheduled. In late February 2001, it was scheduled on the twenty-third and then the twenty-fourth before it was finally rescheduled for Tuesday the twenty-seventh. The LRR (Launch Readiness Review) for this final rescheduling was on Monday morning of the twenty-sixth; about 36 hours before launch-time at 1359L. There was a four-hour launch window closing at 1759L.

### *3.1 Planning Support*

The following toxic planning forecast (Table 2) and plume plot (Figure 1) were presented at the B-41 LRR. The toxic forecast is dependent on the weather forecast, particularly winds, surface mixing layer depth, and stability.

The general launch weather forecast is provided by the Launch Weather Officer (LWO), who concentrates on the meteorological factors that can have particular impact on the meteorological launch commit criteria, such as visibility, launch pad winds, and lightning. Extensive coordination is maintained between the LWO and the toxic support analysts.

**Table 2**

| TOXIC PLANNING FORECAST |
|---|
| - Warm, spring-like, mid-afternoon conditions. Light southerly winds |
| - Benign blast and toxic conditions expected at the opening of the window |
| - As temperatures drop late in the afternoon, both blast and toxic results will rise. |
| - Also, at dusk, winds and temperatures can change rapidly, and this factor can also increase blast and toxic results |
| - Benign blast and toxic conditions expected at window opening. Increasingly adverse conditions expected as the close of the window approaches, but unlikely to exceed criteria. |

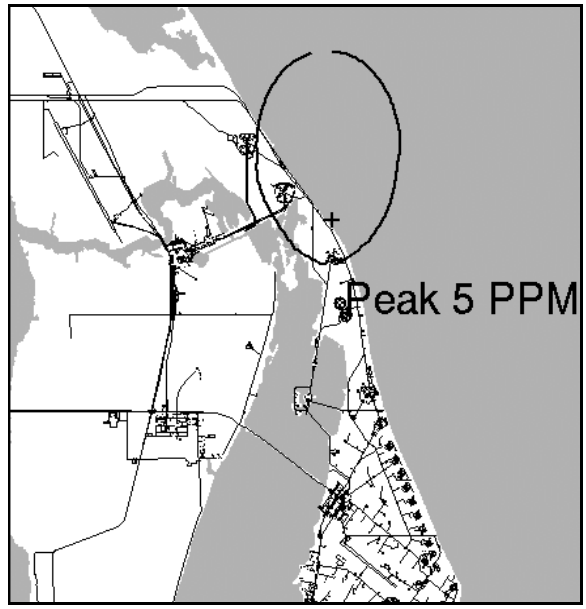


**Figure 1.** The LRR plume forecast for $NO_2$ dispersion (Isopleth is concentrations of 1PPM)

### *3.2 Real-time support*

These predicted conditions materialized during the real-time support efforts on 27 February. The B-41 launch occurred at 1620L about midway through its window from 1359L to 1759L. Launch was delayed from the opening of the window principally by two non-weather issues. The toxic support efforts were initially directed toward evaluation of the conditions for a 1359L launch time, and later (as delays occurred) for 1600L. Launch actually occurred at 1620L.

Real-time support involves: the observation of the real-time weather conditions, an understanding of the weather changes expected to occur, the establishment of the T-zero weather input file, the REEDM run with this weather input, comparison of the REEDM deterministic results with established probabilistic criteria in order to make launch commit recommendations, sequential updates of the T-zero weather, and REEDM predictions as new weather and launch time information become available. The primary REEDM weather inputs during the countdown are rawinsonde files of upper-air data developed from the Meteorological Sounding System (MSS).

Prior to the availability of the 915 MHz DRWPs, upper air data in the boundary layer was provided strictly by MSS balloons (rawinsondes). The balloon data sets are available at approximately hourly intervals in the late count (last four hours). The balloons are released at the CCAFS Weather Station and are tracked by the MSS tracker sited at the same location. Therefore, MSS late-count data has an hourly temporal granularity and provides no indication of spatial variability, since all data is accumulated at the CCAFS Weather Station, located about 6.5 miles from the Titan launch complex (LC-40).

### *3.3 Meteorological Conditions*

ERDAS displays of wind data from the four operational profilers taken at different times are shown in Figures 2 and 3. Four panels are shown in each of these figures. The four panels present wind data for the four profilers in ascending numerical sequence (RWP0001, RWP0002, RWP0003, and RWP0004 from left to right). Within each panel, wind data are displayed for a decreasing sequence of Zulu-times (15-min steps) indicated along the bottom axis; and at ascending altitudes starting at about 130 meters or 400 feet (at 101-meter gates). Wind speed is shown by color-coding (color blocks below the horizontal axis) and wind direction by the orientation of the tail of the barb in a zero-degrees-north-clockwise-positive coordinate system. This is a very convenient ERDAS display for assessing changing wind conditions. The most current update is shown next to the vertical axis, and spatial variations can be readily noted by a comparison of panels.

Figure 2 is the DRWP display at 1603Z (or 1103L) on 27 February. It depicts data from the four DRWPS in operation in 15-minute intervals (from right to left). (Note: In both Figures 2 and 3 (to follow), there are different start times for different profilers, but each has at *least the last six* 15-minute periods listed in the caption). As indicated in the earlier toxic planning forecast for the Titan B-41 LRR presented on 26 February, there was a shallow layer of easterly winds up to about 1000 meters, with southwesterly and then westerly winds at higher altitudes. The two coastal profilers, RWP0001 and RWP0002, showed a rather distinct break at about 1000 meters between the easterly surface layer and the higher-altitude westerlies. The break was much less distinct at the more inland sites, RWP0003 and RWP0004.

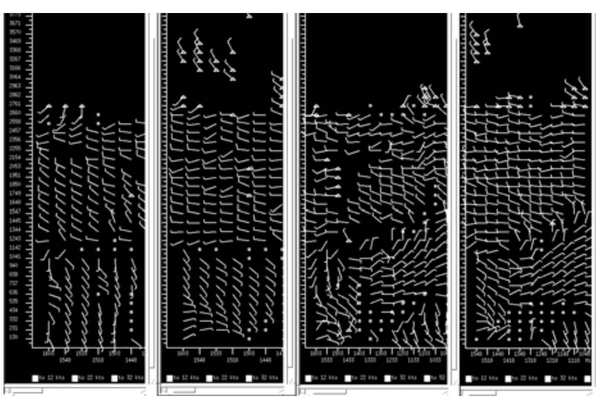

**Figure 2**. 27 Feb 01, 1603Z, 915 MHz DRWPs 01-04 with data for 1448Z-1603Z

RWP0001 is the southernmost profiler and is situated south of the tip of the Cape. In Figure 2 the RWP0001 winds at 1603Z were from the south and southeast in the 1000-meter-thick surface layer, which directed the REEDM plume. The RWP0002 winds were slightly northeasterly at the surface, before becoming more southeasterly with altitude. The inland profiles, RWP0003 and RWP0004, were more ragged and variable, primarily because of increased surface heating effects. With these observations, the rawinsonde file (W3, 1517Z) was modified to predict a mixing layer with southeasterly winds. This forecast produced a REEDM plume plot towards the northwest for a T-zero at the opening of the window at 1857Z (1357L).

The visible satellite image at 1745Z (1245L) showed scattered cumulus over the Florida peninsula, with clear skies over the Atlantic Ocean to the south for about fifty miles from the coastline, and low clouds over the Atlantic Ocean to the north of the Cape. These low clouds and fog east of Volusia County formed overnight from the outflow of showers off the tip of the Cape. The overnight showers moved out to sea from the Cape southward, but left a low cloud deck over the ocean waters to the north. As the CCAFS and KSC surface temperatures rose through the morning hours of the twenty-seventh, these low clouds moved onshore to the southwest to mitigate the rising surface temperatures. These low clouds moving in from the northeast help explain the RWP0004 northeasterly surface winds, seen in Figure 2.

The temperatures dropped overnight and then rose during the day until they dropped between 1300L and 1500L (normally a time of daylight heating). The explanation for this drop is the intrusion of the fog and low cloud deck near Complex 40. From 1500L to 1700L, the cloud deck thinned and the temperatures once again climbed with late afternoon heating.

At 1803Z (1303L) (not shown), the three southern most profilers (RWP0001, 0002, and 0003) indicated a shallow mixing layer with more uniform easterly and southeasterly winds. However, the northern profiler (RWP0004) showed quite northeasterly surface winds. As explained previously, this northeasterly layer was due to the intrusion at Mosquito Lagoon of the offshore low cloud and fog bank that developed over the ocean east of Volusia County to the north of Complex 40. At this point during toxic support activities, it was apparent that the T-zero would be delayed. The count was in an indefinite hold while problems with the ground support equipment for the IMU (Inertial Measurement Unit) were resolved. For toxic modeling purposes, an estimated launch time of 1600L was chosen, and a forecast of the wind conditions for that time was made, using the applicable rawinsonde file (W6, 1817Z) and profiler data. That resulted in the plume forecast towards the southwest.

As seen in Figure 3, at 2003Z (1503L), the three southernmost profilers (RWP0001, 0002, and 0003) showed somewhat more easterly winds. However, the northernmost profiler (RWP0004) still showed slightly more northeasterly surface winds, becoming more easterly with altitude. At this point, the main launch processing issues had been resolved and the count was proceeding toward a launch time of 1620L. Considering this new T-zero and the Figure 3 observations, the W8 (2017Z) rawinsonde file was modified to produce the

REEDM plume plot shown in Figure 4. This figure is the deterministic REEDM prediction for a T-zero at 2120Z (1620L). Results showed a predicted plume heading towards 258 degrees from true north, with a peak concentration of $NO_2$ of 3 ppm at a distance 10 km from LC-40. The displayed isopleth is for a concentration of 1 ppm of $NO_2$, originating 5 km from LC-40 and continuing out to a distance of 21 km from the launch pad.

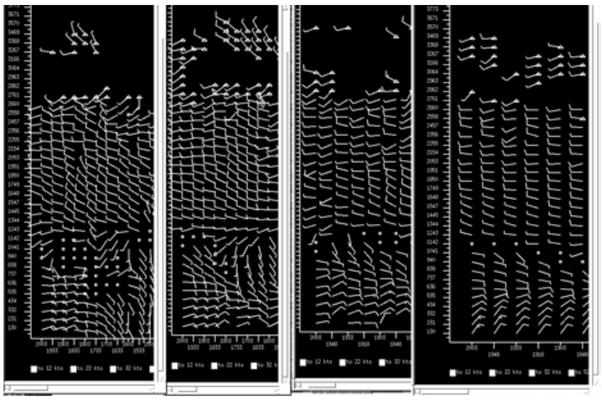

**Figure 3**. 27 Feb 01, 2003Z, 915 MHz DRWPs 01-04 with data for 1848Z-2003Z

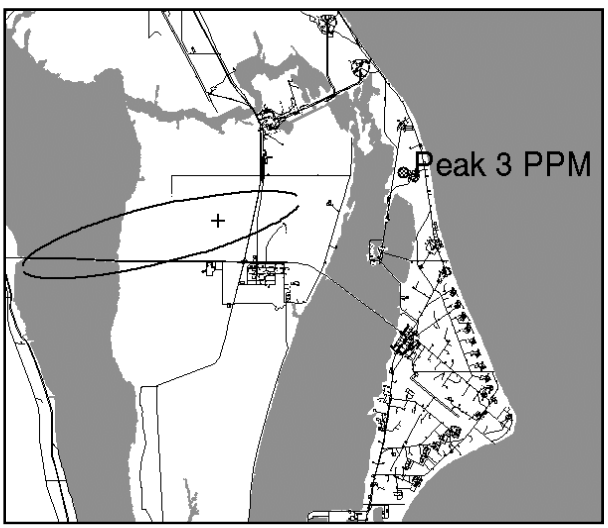


**Figure 4**. REEDM Plume Plot of $NO_2$ using the W8 (2017Z) modified data for T-zero at 1620L

## 4. CONCLUSION

The availability of the 915 MHz profilers during the Titan-IV B-41 launch operations allowed for a better understanding of the changing meteorological conditions. The winds between one and four thousand feet directed the REEDM plume. Without the profilers, identifying the spatial and temporal variations within this layer would have been more difficult. Changing meteorological conditions over the long window could not have been resolved to the granularity required for ingest into physics models. The early-count toxic risk predictions toward the northwest would likely have persisted. The actual risks to the southwest and finally to the west would not have been discerned if the winds had been measured only with the MSS. The toxic risks would have been incorrectly assessed.

The impact of the intruding low clouds and fog on the mixing layer wind profile might have been noticed, but without the profiler display, an assessment of its changing impact over time would have been more difficult.

At approximately T-minus-two-and-a-half-hours in the launch countdown, various emergency response personnel and a Point of Contact for visitors/launch viewers call the Toxic Hazard and Blast Control Center to get the toxic risk assessment for the launch, and to determine if their location has the potential to be in the downwind toxic corridor in the event of a catastrophic launch abort. For this particular launch, the profilers allowed avoidance of unneeded evacuations and relocations.

The bottom line is, use of the 915 MHz DRWPs allowed for increased launch opportunity without decreasing launch safety.

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