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# THE IMPLEMENTATION AND EVALUATION OF THE EMERGENCY RESPONSE DOSE ASSESSMENT SYSTEM (ERDAS) AT CAPE CANAVERAL AIR STATION/KENNEDY SPACE CENTER

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## 1. INTRODUCTION

NASA and the Air Force at Kennedy Space Center/Cape Canaveral Air Station (KSC/CCAS) are attempting to upgrade and improve their capabilities for emergency response dispersion modeling and mesoscale meteorological forecasting. Their goal is to improve short range forecasts (up to 24 hours) for phenomena such as thunderstorms and sea breezes and to more accurately predict toxic diffusion concentrations in case of hazardous spills. To assist NASA and the Air Force in achieving this goal, the Applied Meteorology Unit (AMU) has been evaluating the Emergency Response Dose Assessment System (ERDAS).

The AMU's purpose is to evaluate selected new technologies and transition those which are ready into operational use by forecasters providing weather support to Shuttle, military, and commercial space flight operations (Ernst and Merceret 1995). The AMU also devises techniques to use existing technologies more effectively, and advises on matters relating to technology acquisition.

ERDAS is a prototype software and hardware system configured to produce routine mesoscale meteorological forecasts and enhanced dispersion estimates on an operational basis for the KSC/CCAS region. ERDAS includes two major software systems which is run and accessed through a graphical user interface. The first software system is the Regional Atmospheric Modeling System (RAMS), a three-dimensional, multiple nested grid prognostic mesoscale model. The second software system is the Hybrid Particle and Concentration Transport (HYPACT) model, a pollutant trajectory and concentration model. ERDAS also runs the Rocket Exhaust Effluent Diffusion Model (REEDM).

Mission Research Corporation/ASTER developed ERDAS for the Air Force for the purpose of providing emergency response guidance to operations at KSC/CCAS in case of an accidental hazardous material release or an aborted vehicle launch. The ERDAS development occurred during the period 1989 to 1994. under Phase I and II Small Business Innovative Research contracts. ERDAS was delivered to the Air Force's Range Operations Control Center (ROCC) in March 1994. The AMU was tasked with keeping ERDAS running and with evaluating ERDAS during the period March 1994 to December 1995.

Before safety personnel and weather forecasters accept ERDAS as an operational emergency response system, they must determine its value, accuracy and reliability. In partial fulfillment of this requirement, the AMU is evaluating ERDAS in a near-operational environment to determine if and how it should be transitioned to an operational environment. The evaluation of ERDAS has included:

- Evaluation of the sea breeze predictions
- Comparison of launch plume location and concentration predictions.
- Case study of a toxic release.
- Evaluation of model sensitivity to varying input parameters.
- Evaluation of the user interface.
- Assessment of ERDAS's operational capabilities.

This paper describes the system, the model evaluation, the process of transitioning ERDAS from a research project to an operational system, and also presents the results of the launch case studies.

## 2. ERDAS DESCRIPTION

ERDAS is described in Tremback et al. 1994. A brief description of the different components of ERDAS and its configuration are presented in the following sections. ERDAS runs on an IBM RS 6000 Model 550 workstation with 64 Mb of memory and 2.8 Gb of disk storage.

### *2.1 RAMS*

At the core of ERDAS is RAMS which was developed by Colorado State University and MRC/ASTER. RAMS produces the wind and temperature fields which drive the ERDAS diffusion models. Summaries of RAMS features and recent meteorological applications can be found in Pielke et al. (1992). It is used by many users worldwide in numerous research and operational applications.

To reduce computational runtimes in ERDAS, RAMS was configured with a 3 km inner mesh size and with the explicit cloud microphysics modules turned off. Previous thunderstorm forecasting experiments at KSC showed that a "dry" prognostic model demonstrated skill at predicting the initiation of sea breeze storms during the upcoming day. A 24-hour forecast with this version of RAMS requires approximately nine hours to complete on the RS 6000

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Model 550. The grid configuration for RAMS is a 60 km mesh covering the southeastern United States, a 15 km grid covering most of the Florida peninsula, and a 3 km mesh covering a 110 x 110 km region around KSC/CCAS.

RAMS is initialized twice daily at the standard data times of 0000 UTC and 1200 UTC. Fixed data inputs into RAMS include topography, U. S. Geological Survey-provided land use/land characteristics, and climatological sea surface temperatures. Variable input meteorological data include Nested Grid Model forecast data, National Weather Service rawinsonde and surface data, buoy data, and KSC/CCAS mesonetwork tower data. Model initialization is performed using the RAMS isentropic analysis package.

### 2.2 *Diffusion Models HYPACT and REEDM*

The primary model used for computing dispersion estimates is HYPACT. HYPACT is the advanced Lagrangian particle dispersion model in ERDAS. Dispersion in the Lagrangian mode of HYPACT is simulated by tracking a large set of particles. Subsequent positions of each particle are computed from the relation:

$$X[t+\Delta t] = X[t] + [u + u'] \Delta t$$

$$Y[t+\Delta t] = Y[t] + [v + v'] \Delta t$$

$$Z[t+\Delta t] = Z[t] + [w + w' + w_p] \Delta t$$

where u, v and w are the resolvable scale wind components which are derived from RAMS or the hybrid (RAMS/tower observations) wind field, and u', v', and w' are the random subgrid turbulent wind components deduced from RAMS. The $w_p$ term is the terminal velocity resulting from external forces such as gravitational settling.

REEDM predicts plume rise and downwind concentrations resulting from nominal or aborted launches. In ERDAS, REEDM produces the source term which is used by HYPACT to predict plume dispersion and resulting downwind concentrations.

For modeling launch scenarios, HYPACT obtains the source term data (release rate) from the REEDM launch plume data. HYPACT then diffuses the plume using the RAMS-predicted wind fields and potential temperature fields to advect and disperse the particles vertically and horizontally downwind from the source.

HYPACT can modes any number of sources which are specified anywhere in the domain and configured as point, line, area, or volume sources. The emissions from these sources can be instantaneous, intermittent, or continuous and the pollutants can be treated as gases or aerosols. The primary release scenarios which ERDAS models are:

- "Cold spills" of toxic chemicals at launch pads and storage facilities, in which evaporation takes place from pools. Using both small or large numbers of particles, HYPACT produces plumes which are viewed on a map background and then calculates detailed concentrations and dosage estimates.
- Exhaust ground clouds from nominal launches of Titan, Atlas, Delta, and Space Shuttle vehicles. REEDM and HYPACT simulate dispersion of the ground cloud and exhaust plume gases and aerosols.
- Launch vehicle abort clouds. REEDM and HYPACT predict the dispersion for gases and aerosols from debris clouds from a launch vehicle abort.

### 2.3 *Graphical User Interface*

ERDAS is driven from a single graphical user interface (GUI) menu. From this mouse-driven menu, the operator can view the results of the RAMS forecasts. Horizontal and vertical cross-section plots of winds, temperature, moisture, etc. are drawn using NCAR Graphics at the ground surface or at elevated levels for all of the available forecast times. The operator can display the southeast U.S., the Florida peninsula, or the CCAS/KSC area. A mouse-driven arbitrary zoom feature allows the operator to examine closely any local area. On the smaller scales, a high resolution map shows details such as roads and buildings.

If an accidental release occurs, an operator can click on a button and a menu is displayed which controls the dispersion estimates. The operator enters the data on chemical type, release rate, spill amount, location, etc. or chooses a pre-programmed accident scenario with predefined data. The operator chooses which model to run (HYPACT or REEDM) and whether to use forecast meteorology or an objective combination of the forecast and observed meteorology. The dispersion estimates are computed and the operator displays the results.

## 3. EVALUATION OF ERDAS

The AMU focused the evaluation of ERDAS on wind predictions, launch plume diffusion, and hazardous spill diffusion. The evaluation showed that ERDAS handled all of the situations very well but that deficiencies exist that need to be addressed before the system becomes a certified operational system.

### 3.1 *Wind Predictions*

Dispersion models require accurate wind data to produce accurate concentration predictions. Therefore, the evaluation of RAMS focused on the accuracy of its predicted wind speed and wind direction. RAMS predictions were compared to the observed hourly wind speeds and directions from several towers and surface observation sites in the Cape Canaveral area.

This analysis compares the wind data collected at the 4-meter level of Tower 110 with the RAMS wind data from the lowest grid height of 11 meters interpolated to the Tower 110 location. Tower 110 is located between Launch Complexes 40 and 41, approximately 1 km west of the coastline. The example analysis period presented in this report is the seven-day period 15-21 July 1994.

To determine the effect of clouds and precipitation on the RAMS predictions, we produced graphs of hourly observed total sky cover and observed weather (thunder, rain, rain shower, and/or thunderstorm) from the Shuttle Landing Facility. Graphs with this data are included in Figure 1 which shows observed and predicted wind speed and wind direction for a representative seven-day period.

The primary goals of comparing the observed and predicted winds were to determine:

- How well RAMS predicted the sea breeze with regard to its timing and location,
- What effect did cloudy skies and thunderstorms have on RAMS predictions, and
- How well did RAMS predict the diurnal variability of wind speed.

The typical sea breeze regime on Florida's east coast is characterized by an early morning, westerly, off-shore component wind (1200 UTC to approximately 1800 UTC) that switches to an easterly, on-shore component wind during late morning or early afternoon (approximately 1600 UTC to 2000 UTC). Of the seven days shown in Figure 1, RAMS predicted a morning westerly component wind that switched to an east wind on six of the days. Of these six days, Tower 110 observed a westerly wind that switched to an east wind on five of the days. On 15 July 1994, the observed wind was easterly through the morning hours. RAMS consistently predicted a morning westerly wind for only one hour before switching the winds to easterly as shown on the wind direction graphs as gray spikes at 1300 or 1400 UTC on 15-19 July. On these days, the pressure gradient was relatively weak, and the model was most likely detecting the early morning land breeze sometimes referred to as a drainage flow.

Even though RAMS did a good job predicting the occurrence of the sea breeze for these seven days, it predicted the switch from westerly to easterly flow earlier than it occurred on all but one of the five days that it correctly predicted the sea breeze occurrence. Table 1 presents the times of the predicted and observed sea breeze passage at Tower 110.

Table 1. Time of sea breeze passage at Tower 110 for 15-21 July 1994.

| Date | RAMS | Observed | Difference: Predicted–Observed |
|---|---|---|---|
| 15 July 94 | 1500 UTC | Continuous easterly winds | - |
| 16 July 94 | 1400 UTC | 1600 UTC | -2 hours |
| 17 July 94 | 1400 UTC | 1600 UTC | -2 hours |
| 18 July 94 | 1400 UTC | 1500 UTC | -1 hours |
| 19 July 94 | 1400 UTC | 1700 UTC | -3 hours |
| 20 July 94 | No sea breeze predicted | No sea breeze observed | - |
| 21 July 94 | 1500 UTC | 1500 UTC | 0 hours |

In general, the graph comparing wind directions for the seven day period indicated that the wind directions from RAMS agree reasonably well with the observed wind directions except on 19 and 20 July. The graph of the sky cover and weather events at the bottom of

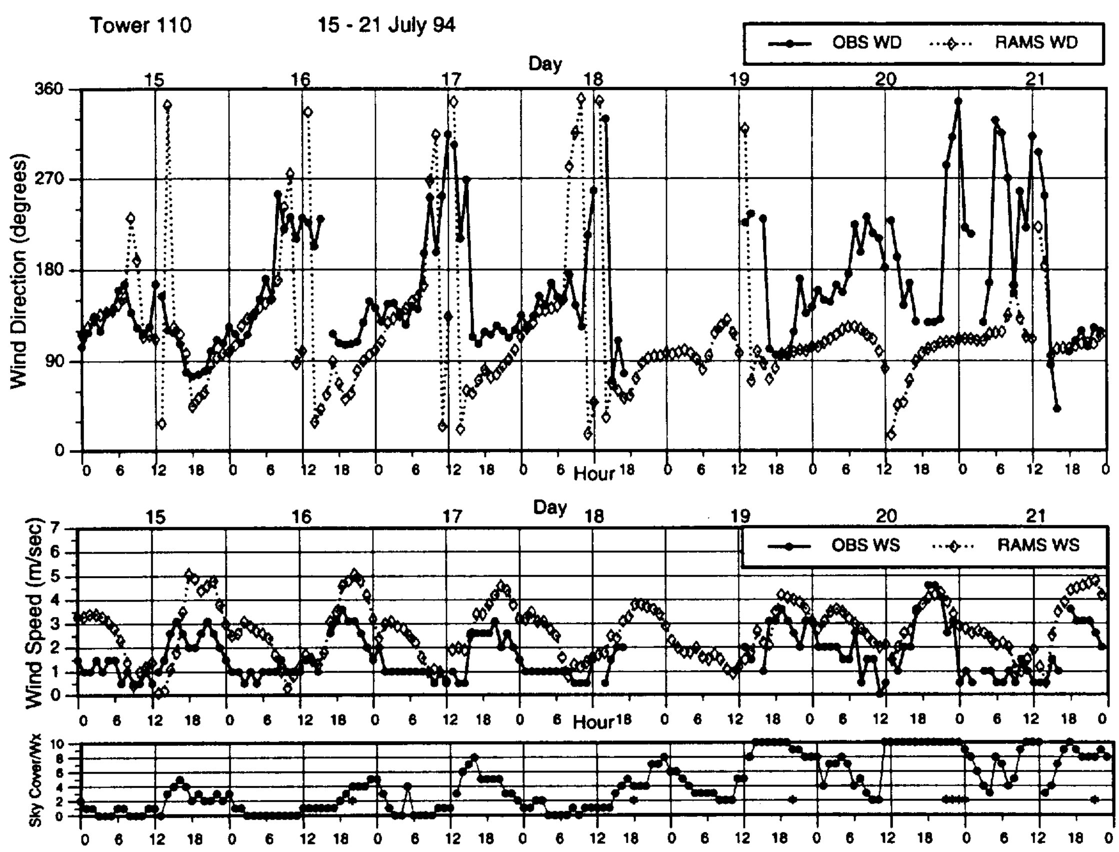


Figure 1. Graphs comparing the winds observed at Tower 110 (black) and predicted by RAMS (gray) for 15-21 July 1994. The top graph shows wind direction (degrees), the middle graph shows wind speed (ms$^{-1}$), and the bottom graph shows observed sky cover in tenths (black circles) and observed weather (black asterisks) at the Shuttle Landing Facility. RAMS data were produced by daily RAMS runs which were initialized at 1200 UTC and which ran for 24 hours.

Figure 1 shows that on 19 and 20 July there was significant cloud cover through the morning hours. The other five days in the analysis period had minimal sky cover during the morning hours.

RAMS accurately predicted the wind direction on days that were not cloudy during the morning hours but was unable to predict wind direction during the cloudy conditions of 19 and 20 July. This result is not surprising since the model is configured to run in the "dry mode" meaning the microphysics module in RAMS that generates clouds and precipitation is turned off to reduce the model runtime. Therefore, the model was not expected to perform well during these cloudy conditions and the results of this analysis confirm this.

### 3.2 *Launch Plume Location Analysis*

This evaluation consisted of comparing ERDAS diffusion model data with launch plume data collected for the Titan IV Launch on 03 May 1994. The Titan IV rocket was launched from Launch Complex 41 (LC-41) at CCAS at 1555 UTC on 03 May 1994. RAMS, REEDM and HYPACT were used to model the transport and diffusion of the exhaust plume and to compare the modeled plume data with observed data collected by Aerospace Corporation's plume imaging cameras. The following is a discussion of the modeling analyses of this launch.

#### 3.2.1 *RAMS Analyses*

The RAMS simulation starting at 1200 UTC on 03 May was used for this analyses. At 1600 UTC, near the time of the launch, RAMS predicted the surface winds at a height of 10.6 m to be from approximately 110° and the winds aloft at a height of 1212 m to be from approximately 150°.

To assess the accuracy of the RAMS wind predictions on the morning of 03 May, RAMS data were compared with data measured at Tower 110, located less than 2 km from LC-41. The winds at the lowest two tower levels (3.6 m and 16.4 m) and the winds in the lowest RAMS layer (10.6 m) for 1500 UTC to 1700 UTC are compared in Table 2. For these three times, the data show that the RAMS wind directions at 10.6 m were more easterly than the observed southeasterly winds at 3.6 m and 16.4 m at Tower 110. The RAMS average wind direction was 87° while the average observed wind directions were 122° at 3.6 m and 132° at 16.4 m. The RAMS wind speeds were slightly stronger than the observed wind speeds at both tower levels. RAMS average wind speeds were 5.3 m $s^{-1}$ while the observed wind speeds averaged 3.6 m $s^{-1}$ at 3.6 m and 4.4 m $s^{-1}$ at 16.4 m.

Table 2. Observed wind data at Tower 110 during the period 1500 UTC to 1700 UTC.

| | Observed 3.6 m | | Observed 16.4 m | | RAMS 10.6 m | |
|---|---|---|---|---|---|---|
| Time (GMT) | Wind direction (degrees) | Wind speed (m $s^{-1}$) | Wind direction (degrees) | Wind speed (m $s^{-1}$) | Wind direction (degrees) | Wind speed (m $s^{-1}$) |
| 1500 | 134 | 3.6 | 142 | 4.6 | 106 | 4.3 |
| 1600 | 111 | 3.6 | 127 | 4.1 | 79 | 5.7 |
| 1700 | 121 | 3.6 | 128 | 4.6 | 77 | 5.9 |

#### 3.2.2 *ERDAS Diffusion Analyses*

ERDAS uses REEDM to predict the initial source term for the Titan IV launch plume. REEDM generates the source term by taking data stored for each launch vehicle and for each material emitted during a launch and computing the total amount of material released. REEDM then distributes the material into different vertical layers. For the launch analysis presented here, hydrogen chloride (HCl) was selected because it is a chemical routinely modeled by Range Safety during pre-launch operations.

REEDM calculated the cloud stabilization height at 930 meters. The cloud stabilization height is defined as the height of the center of the cloud at the point the cloud temperature approaches the ambient temperature or the cloud buoyancy approaches zero (Bjorklund 1990). HYPACT plume predictions

To determine how well ERDAS modeled the launch plume, the REEDM/HYPACT predictions were compared with observations made by Aerospace Corporation's plume imaging cameras (Aerospace 1995). Aerospace Corp. is collecting measurements of Titan IV launch clouds using visible and infrared cameras as part of a project to validate models such as REEDM. Data from the 3 May 1994 Titan IV launch were obtained from Heidner (1994).

Figure 2 shows this plume centerline on a map of CCAS. Figure 2 shows how the observed plume moved initially to the west with the low-level easterly winds and then moved north as it rose upward reaching the level of the southerly winds at approximately 1200 m.

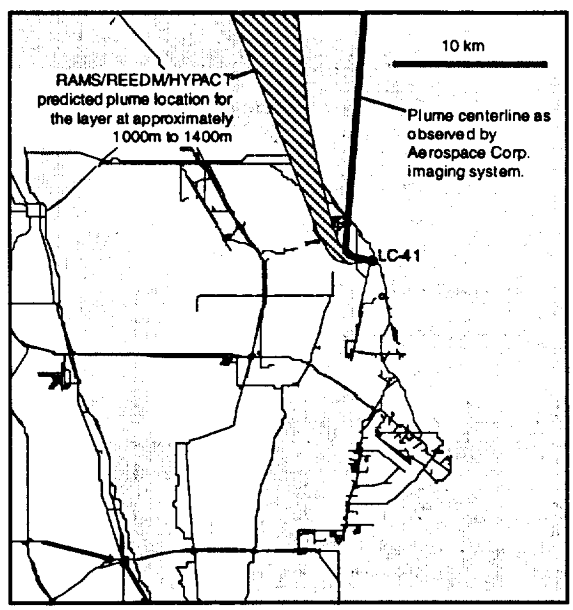


Figure 2. Centerline trajectories of observed and modeled (REEDM/HYPACT) plume for Titan IV launch on 3 May 1994.

For this Titan IV launch, HYPACT moved the lowest part of the plume (at a height of approximately 400 m) to the west in response to the low-level easterly flow. HYPACT moved the upper part of the plume (at a height of approximately 1300 m) to the north-northwest with the south-southeasterly flow aloft.

To compare the REEDM/HYPACT modeled plume location to the observed location, HYPACT's plume for the layer 1000 to 1500 meters was used for the comparison since this layer matched the height of the observed plume. Figure 2 shows the paths of the observed and REEDM/HYPACT modeled plumes. The HYPACT-predicted plume followed a very similar trajectory to the observed plume but HYPACT moved it more to the west than observed. HYPACT predicted the northward movement beginning at 15 minutes after launch as it moved the plume in a north-northwesterly direction. The observed plume began moving north after approximately 5 minutes.

The analyses of this Titan IV launch case study indicate that the RAMS/REEDM/HYPACT modeling system has promising potential for modeling launch exhaust plumes but that some improvements are needed.

### 3.3 *Toxic Spill Simulation*

The RAMS and HYPACT models in ERDAS were used to simulate a release of toxic gas from Launch Complex 41 (LC-41) at CCAS. LC-41 is located on a narrow strip of land (approximately 1 km wide) between the Atlantic Ocean and the Banana River. A detailed description of this toxic release scenario is provided in Evans et al. (1996). Results showed that the diffusion predictions are sensitive to the 3 km x 3 km size grid mesh for the complex water and land boundaries in the KSC/CCAS area. In RAMS, each grid square is assigned a percent land value and a land use category. These assignments significantly affect the RAMS predictions of vertical motions near each square. The simulation showed that the grid resolution over the LC-41 area is currently too coarse to accurately resolve upward vertical motions due to heating of the narrow strip of land. Therefore, adjustments were made to the percent land values which produced better RAMS/HYPACT predictions of the movement of the toxic cloud compared to observed winds. Predictions for future simulations could be improved even more by reducing the grid size to represent the land and water boundaries.

This simulation showed that the RAMS/HYPACT models can produce a representative, three-dimensional depiction of a toxic plume.

## 4.0 SUMMARY

ERDAS is a system which combines the mesoscale meteorological prediction model RAMS with the diffusion models REEDM and HYPACT. Operators use a graphical user interface to run the models for emergency response and toxic hazard planning at CCAS/KSC.

The Applied Meteorology Unit has been evaluating the ERDAS meteorological and diffusion models and obtained the following results:

- RAMS adequately predicts the occurrence of the daily sea breeze during non-cloudy conditions for several cases.
- RAMS shows a tendency to predict the sea breeze to occur slightly earlier and to move it further inland than observed. The sea breeze predictions could most likely be improved by better parameterizing the soil moisture and/or sea surface temperatures.
- The HYPACT/REEDM/RAMS models accurately predict launch plume locations when RAMS winds are accurate and when the correct plume layer is modeled.
- HYPACT does not adequately handle plume buoyancy for heated plumes since all plumes are presently treated as passive tracers.

Enhancements should be incorporated into the ERDAS as it moves toward being a fully operational system and as computer workstations continue to increase in power and decrease in cost. These enhancements include the following:

- Activate RAMS moisture physics.
- Use finer RAMS grid resolution.
- Add RAMS input parameters (e.g. soil moisture, radar, and/or satellite data).
- Automate data quality control.
- Implement four-dimensional data assimilation.
- Modify HYPACT plume rise and deposition physics.
- Add cumulative dosage calculations in HYPACT.

## 5.0 ACKNOWLEDGMENTS

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