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ARAC's Radiological Support of the Cassini Launch

R.L. Baskett
J.C. Pace

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Ronald L. Baskett and John C. Pace
Atmospheric Sciences Division
Lawrence Livermore National Laboratory
Livermore, CA 94551
(925) 423-6731; rbaskett@llnl.gov

Abstract

The Atmospheric Release Advisory Capability (ARAC) program at the Lawrence Livermore National Laboratory (LLNL) was the U.S. Department of Energy atmospheric modeling resource used for the contingency of potential radiological releases during the launch of the Cassini mission. Having the ARAC system up and running was one of the launch criteria during the countdown. The ARAC Center at LLNL forecasted detailed weather conditions and delivered consequence assessments for potential accident scenarios to NASA before and during launch operations. A key aspect of ARAC's support was to acquire a variety of meteorological data for use in both forecast and real-time model calculations. ARAC acquired electronically two types of real-time observed meteorological data: 1) the set of on-site tower and profiler data via the Cape Canaveral Air Station (CCAS) Meteorological Interactive Data Display System (MIDDS), and 2) routine regional airport observations delivered to the ARAC Center from the Air Force Weather Agency. We also used two forecasted data sources: 1) the U.S. Air Force 45th Weather Squadron at CCAS forecasted soundings for launch time, and 2) the Navy Operational Regional Atmospheric Prediction System (NORAPS) prognostic model which ARAC ran over the Cape. The NORAPS runs produced detailed 24-hr forecasts of 3-D wind fields. ARAC used default radiological accident source terms involving the potential destruction of Cassini's Radioisotope Thermoelectric Generators (RTGs) during 3 phases: 1) before the launch, 2) during the first 5 sec after ignition, and 3) from 5 to 143 sec after ignition. ARAC successfully developed and delivered dose and deposition plots at 24 hours, 3 hours, and 30 minutes before each of the launch windows.

Introduction

The Cassini mission, conducted by the National Aeronautics and Space Administration (NASA) to study Saturn, has radioactive material on board the spacecraft to supply heat and electrical power. Although the risk of a release of radioactive material during the launch was very small, federal plans call for the Department of Energy (DOE) to provide emergency response support during the launch of any NASA mission involving radioactive materials.

The radioactive material used for Cassini is Plutonium-238. Heat is supplied by 129 Radioisotope Heater Units (RHUs), each containing 2.56 g of ^{238}Pu, and electrical power is supplied by three Radioisotope Thermoelectric Generators (RTGs), containing a total of 32.7 kg of ^{238}Pu. The RHUs and RTGs are designed to withstand almost any catastrophic event, so even in the event of most accident scenarios, no nuclear material would have been released. In the rare cases when a release was postulated to occur, the total amount of released ^{238}Pu was predicted to be between 0.56 g and 360.14 g, depending on the type of event.

DOE assigned the task of emergency response dispersion modeling during the Cassini launch to the Atmospheric Release Advisory Capability (ARAC) at the Lawrence Livermore National Laboratory (LLNL). The role of ARAC was to provide pre-launch guidance about where hazardous material would have gone if released, and in the event of an accident to provide refined calculations to help determine the magnitude of the release. This paper describes how ARAC carried out this mission.

ARAC Modeling System

The ARAC system (Figure 1) uses topographical and meteorological data to generate a time-varying series of three-dimensional mass-adjusted wind fields, which are used to drive a Lagrangian particle dispersion model (Sullivan et al. 1993). The three-dimensional dispersion model accounts for the effects of spatial and temporal variation of mean wind and turbulence, gravitational settling, dry and wet deposition, and initial plume buoyancy and momentum.

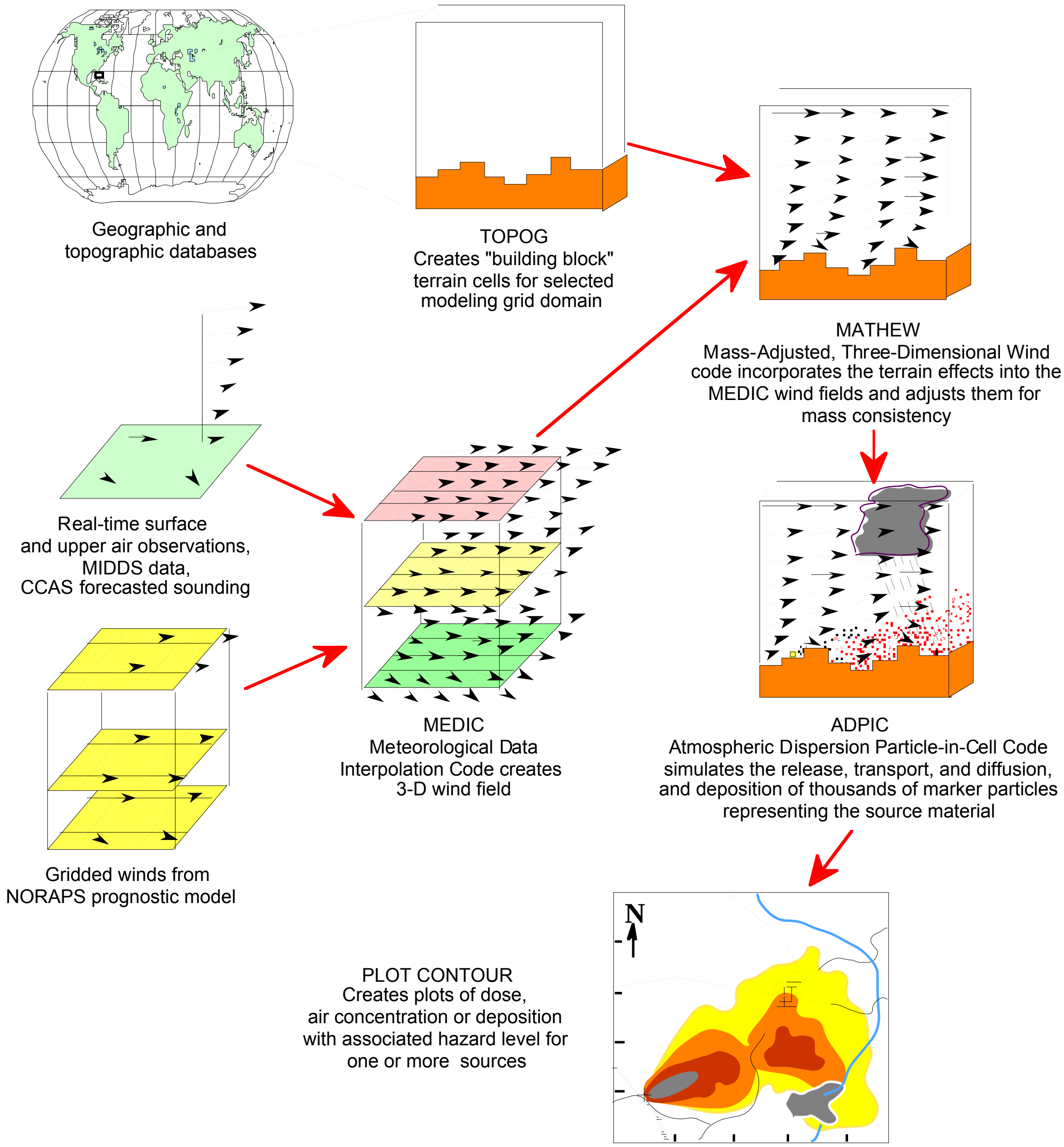

Figure 1. ARAC Emergency Response Modeling System

ARAC meteorologists use horizontal and vertical cross-sections through the plume along with other displays to study and evaluate the structure of the plume, in order to decide whether the models are working optimally. A thorough understanding of the 3-D wind pattern is critical to accurate dispersion modeling. If the model is not simulating the flow conditions correctly, an ARAC meteorologist adjusts inputs to create the expected results. The model results are only as good as the inputs, model physics, and the judgment of the user.

The accuracy of the ARAC models has been well defined based on many controlled field tracer studies, when the source term is well known and the meteorological conditions are well represented (Foster and Dickerson 1990). ARAC's system allows use of multiple sources of meteorological data (met data), and generally the more met data, the better the result.

Modeling Considerations

We did not perform the simulation of the explosive cloud rise that would occur during an accident involving a rocket. Instead, we used the results of previous NASA and DOE studies which predicted the configuration of the stabilized cloud following the dissipation of the immediate heat and buoyancy effects, and the distribution of the radioactive material in the cloud. Because the source terms were well-specified, our primary challenge was to determine the complex wind patterns that can occur around the Cape. We used four met data sources for its Cassini calculations – two forecasted and two real-time. One key source was forecasted vertical wind profiles generated by the U.S. Air Force's 45th Weather Squadron (45 WS) at Cape Canaveral Air Station (CCAS). These proved to be remarkably accurate. The second source of forecasted data came from our recent implentation of the Navy Operational Regional Atmospheric Prediction System (NORAPS). NORAPS is a weather forecast model developed by the Navy Research Laboratory, and operated at the Fleet Numerical Meteorology and Oceanography Center. NORAPS provides high-resolution, time-varying forecasted gridded wind data. These data were ideal for initializing our 3-D diagnostic wind field model. To use NORAPS for Cassini, we accelerated the operational implementation effort of NORAPS at LLNL to meet the Cassini schedule.

The primary source of real-time observations was from the over 40 multi-level meteorological towers, rawinsonde soundings, a 50 MHz profiler, and five 915 MHz profilers. Collected automatically by the CCAS Meteorological Interactive Data Display System (MIDDS), these data were transferred to an ARAC Site Workstation deployed to KSC. The ARAC Site Workstation software also allowed our meteorologist to quality control the data before using them in the models. Supplemental regional surface and upper air observations were also available from airports in the region. These are routinely delivered to the ARAC Center from the Air Force Weather Agency. We employed new software tools to automatically retrieve and store, and manually visualize and edit all the met data before using it to initialize the wind field.

Launch Support

NASA procedures required ARAC to be available and operational in order for the launch to proceed. All model calculations were done at the ARAC Center in Livermore, California. ARAC assessment meteorologists ran NORAPS, evaluated met data obtained from MIDDS, generated products, and coordinated with the deployed personnel. In addition, we deployed four ARAC staff and three ARAC computer systems to Florida. On-site personnel assisted in interpretation of the model results and acted as interfaces to the staff at LLNL, describing current conditions and channeling requests for support.

ARAC deployed to two separate facilities – the Radiological Control Center (RADCC) on KSC and the Advance Launch Support Group (ALSG) located in an armory in Cocoa Beach. Two meteorologists worked in the RADCC, using two ARAC Site Workstation Systems (SWSs). The SWS collects meteorological data, electronically transfers accident release information from the site to the ARAC Center, and receives model products delivered from the ARAC Center. The RADCC supported the Range Operations Control Center, where NASA directed operations. A third meteorologist, with a portable SWS, was deployed to the ALSG. The ALSG was the center of operations to coordinate any off-site consequences of an actual release. A fourth ARAC staff, a computer technician, set up the equipment and resolved any problems.

Communications is a critical component of a multi-agency response. ARAC coordinated with 45th Weather Squadron to access to MIDDS data and to obtain the forecasted soundings. In addition, the Air Force detailed a weather forecaster to work alongside the ARAC personnel in the RADCC, assisting in interpretation of local weather conditions. ARAC’s support from the 45 WS was excellent.

The MIDDS data retrieval and all communications between the ARAC Center in Livermore and the deployed personnel were done over dedicated communications circuits provided by DOE's Remote Sensing Laboratory (RSL). We also used telephone circuits and modems as a backup system. The three ARAC computer systems deployed to Florida were configured to operate with all our available communications options, and to provide the capability to view, use, and edit the MIDDS data. ARAC worked with communications personnel from NASA/KSC as well as RSL to design, configure and test the system used for launch support.

ARAC also coordinated with the 45th Space Wing Safety Office and its supporting contractor (ACTA, Inc.), which operate a dispersion model (Rocket Exhaust Effluent Diffusion Model, or REEDM), used before every launch at CCAS/KSC to predict the behavior of the clouds of toxic chemicals which result from all launches. Although ARAC did not model the toxic cloud from Cassini, the similarity between the ARAC and ACTA/Safety missions led to cooperation and improved capabilities. ARAC and ACTA cooperated on a post-event evaluation of the toxic cloud resulting from the explosion of a Delta-II rocket at CCAS on 17 January 1997 (Pace et al 1998).

ARAC Model Products for Cassini

Previous NASA and DOE safety analyses produced three categories of potential release scenarios. For the launch support, ARAC modeled one representative scenario for each category. These three categories pertained to releases before the launch, during the first 5 sec after ignition, and from 5 to 143 sec after ignition. (Beyond 143 sec after ignition, the spacecraft would have fallen into the ocean, and no release of nuclear material was possible resulting from an impact on water.) For each scenario, ARAC created tailored inputs for its dispersion model, taking into account the size distribution of the released particles, which is extremely important in predicting the associated health effects, and the predicted vertical and horizontal distributions of released material.

ARAC generated 50-year committed effective dose equivalent (CEDE), total ground deposition, and instantaneous air concentration plots at ground level, all valid at 30 min intervals out to 6 hr after a simulated release at the beginning of each day's launch window. In addition, ARAC generated plots showing predicted conditions at various levels above the ground at 30 min intervals. These plots were used to plan flights for airborne sampling of the plume. (Note that the launch windows were 140 min long; the actual time of a launch and therefore of any release could have been different than the time used in ARAC's forecast calculations.)

The only plots ARAC sent to NASA were a single CEDE plot and a single deposition plot (Table 1) for each of the 3 release scenarios, each valid 6 hr after a simulated release at the beginning of each day's launch window. ARAC generated these 6 plots at 3 times – 24 hr, 3 hr, and 30 min – before each launch window, and sent them to NASA using a Geographical Information System operated by RSL. This gave NASA just the basic pre-launch plots they needed to prepare in case an accident occurred. Initial plots were used to pre-deploy field measurement teams, who would have sampled the air and ground to define the radioactive cloud had there been an a release.

Table 1. Initial ARAC Plot Types

PLOT TYPE	PLOT DEFINITION	PLOT USE	CONTOUR VALUE	CONTOUR DESCRIPTION
50-year Cumulative Effective Dose Equivalent (CEDE)	The inhalation dose an individual would have received outdoors at ground level from cloud passage	Vector field measurement teams, Estimate initial exposure	>5.0 rem >1.0 rem > 0.1 rem >0.05 rem	EPA early phase PAG (upper limit) for sheltering EPA early phase PAG (lower limit) for sheltering 10% of EPA early phase PAG
Total Ground Deposition	The activity of the material deposited on the ground after plume passage	Vector field measurement teams	10.0 $\mu Ci/m^2$ 2.0 $\mu Ci/m^2$ 1.0 $\mu Ci/m^2$ 0.2 $\mu Ci/m^2$ 0.05 $\mu Ci/m^2$	(~FIDLER detection limit)

ARAC also generated considerably more plots which were not sent to NASA, but were sent to the deployed ARAC personnel in case they were needed. If an accident had occurred, there would have been no time to create those plots; but they would have been needed immediately.

This dual approach provided NASA with just the appropriate information for pre-launch considerations, as well as allowed for complete preparation for potential accident response activities.

In the event of an accident, ARAC would have immediately generated a new set of plots based on the actual time of the release, using the latest available meteorological data. Then, as field measurement data were delivered to the ARAC Center via the RSL GIS, we would have begun generating refined plots to improve the modeled representation of the plume, and to estimate the actual source term. Using the same tool developed for model evaluation studies, we display measurement data over the model prediction. We also calculate ratios of observed versus modeled concentrations to estimate the magnitude of the actual release.

Summary

Preparations for emergency response support to NASA's Cassini mission were extensive. While one hopes such an effort is never actually needed, careful planning, testing, and integration of ARAC's complex 3-D radiological dispersion model tool proved to be a timely and effective analysis capability for initially locating the plume from a release in the event of an accident. The ARAC contribution was a key element of the overall NASA-DOE emergency response team.

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