APPENDIX B

DECEMBER 15, 1997

THE AIR FORCE TECHNICAL APPLICATIONS CENTER (AFTAC) ATMOSPHERIC MODELING DOCUMENTATION

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE

07 JAN 1998

HQ USAF/XOI
1480 Air Force Pentagon
Washington DC 20330-1480

Mr. Charles Battaglia
Staff Director, Senate Committee on Veterans' Affairs
Washington DC 20510-6375

Dear Mr. Battaglia

Attached is the Second AFTAC Report on Atmospheric Modeling of the 10 Mar 91 Chemical Warfare Agent Release at the Khamisiyah (Iraq) Munitions Pit. While the AFTAC results are not meteorologically inconsistent with previous Office of the Special Assistant for Gulf War Illnesses (OSAGWI) modeling efforts, the results do indicate some additional areas that may have been exposed to at least Low Level Exposure dosages from the Khamisiyah plume. Therefore, we recommend that the selected dosage footprints identified in the AFTAC study be fused with the dosage footprints from the OSAGWI efforts.

If you have any questions concerning this report please have your staff contact Major Randy Tritt, AF/XOIRY, at (703) 695-1358.

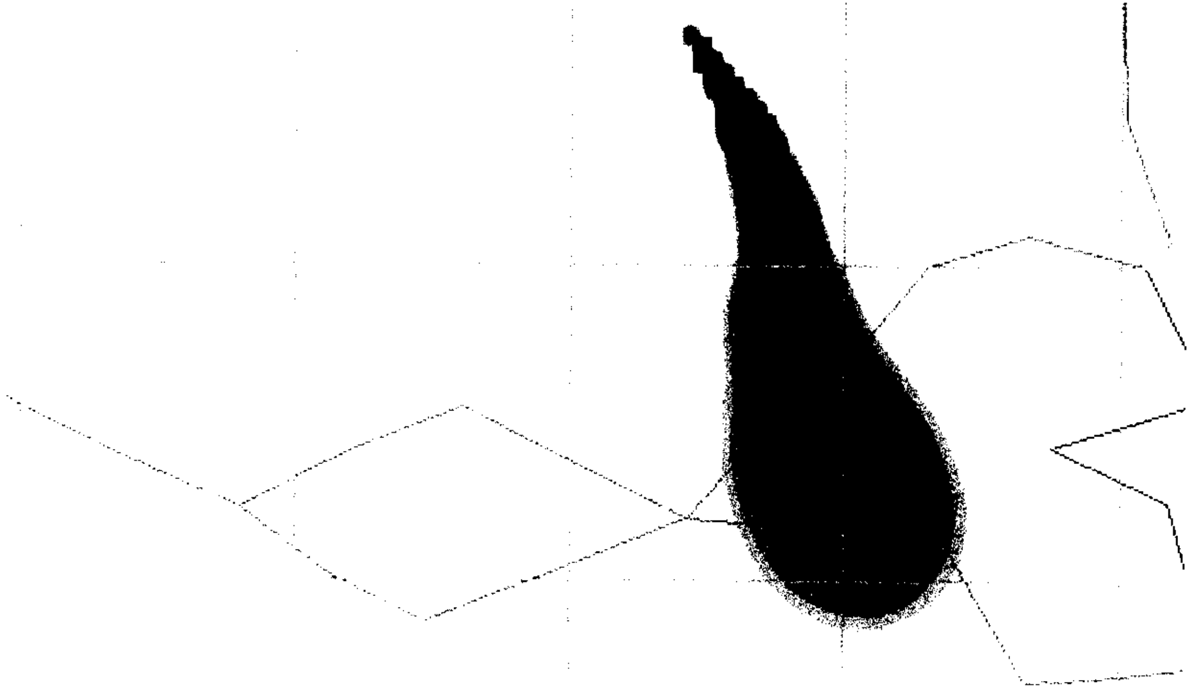
Sincerely

KENNETH K. DUMM, Col, USAF
Deputy Director of Intelligence, Surveillance,
and Reconnaissance
DCS, Air and Space Operations

Attachment: Second AFTAC Report

cc: Dr. Bernard Rostker, OSAGWI

The Air Force Technical Applications Center (AFTAC) Report on Atmospheric Modeling of the 10 Mar 91 Chemical Warfare (CW) Agent Release at the Khamisiyah (Iraq) Munitions Pit



15 December 1997

EXECUTIVE SUMMARY

In order to obtain a better understanding of the technical issues involved in the demolition of chemical warfare (CW) agents in the Iraqi Khamisiyah munitions pit, the Senate Committee on Veterans Affairs requested that the Air Force Technical Applications Center (AFTAC) apply their expertise to the problem and complete an analysis of the event. This report completes the original AFTAC analysis provided to the Office of the Special Assistant for Gulf War Illnesses (OSAGWI).

AFTAC meteorologists used four models from their suite of atmospheric models to complete this analysis. Two of the models, the Short-range Layered Atmospheric Model (SLAM) and the Global Atmospheric Multi-layered Transport model (GAMUT), are transport and diffusion models. The third model, the Regional Atmospheric Modeling System (RAMS), is a prognostic meteorological model and the fourth model is a research and development (R&D) atmospheric chemistry model.

The source term was based on the 15-minute resolution release rate data developed by the Edgewood Research, Development and Engineering Center (ERDEC), CIA, and SAIC from a field test at Dugway Proving Grounds (See Appendix 4, page 4-10).

A quality controlled data set was developed by blending data retrieved from AFTAC's Weather System (AWES) global weather data base, the Naval Research Laboratory archive, and data provided by the Science Applications International Corporation (SAIC). In addition, a set of global analyses from the National Center for Atmospheric Research (NCAR)/National Center for Environmental Prediction (NCEP) reanalysis project (Kalnay, 1996) was used as a supplemental source of coarse data.

The RAMS model did a very good job predicting high-resolution meteorological data fields. The resulting SLAM 24 hour dosage areas depicted for SLAM runs using observed data and SLAM runs using RAMS data (Appendix 4, page 4-1 through 4-6) are similar to the dosage footprints published in the 4 Sep 97 DoD/CIA report titled "Modeling the Chemical Warfare Agent Release at the Khamisiyah Pit". However, AFTAC modeling results indicate additional areas of exposure to significant dosages from the Khamisiyah plume within Iraq. While there are obvious differences compared to the previous DoD/CIA sponsored modeling efforts, this is expected when different models are applied. The application of our R&D atmospheric chemistry model to the Sarin and Cyclosarin dosage areas of Low Level Exposure and 1st Noticeable Effects yielded smaller areas of potential exposure (See Appendix 6, pages 6-8 through 6-37).

While the AFTAC analysis is not meteorologically inconsistent with the previous OSAGWI modeling efforts, the results do indicate some additional areas of Low Level Exposure dosages not included in the DoD/CIA report. We recommend these results be used to supplement modeling work already completed by OSAGWI.

1 Introduction

AFTAC was tasked to model the CW agent effluent plume, which resulted from the 10 Mar 91 destruction of the Khamisiyah munitions pit in Iraq. The RAMS meteorological model and the transport and diffusion model SLAM were used by AFTAC meteorologists to evaluate the Khamisiyah event. Another AFTAC transport and diffusion model, GAMUT, was used to determine mixing layer depths in the area of interest. In addition, an R&D atmospheric chemistry model was used to model the deposition and degradation of the effluent plume that consisted of Sarin and Cyclosarin. This report summarizes the methodology applied and the results of this modeling effort.

2 Why We Need a Meteorological Model

Three key parameters must be determined to enable any meteorological analysis of the Khamisiyah plume; the depth of the transport layer, the wind direction in the transport layer, and the wind speed in the transport layer.

Weather data in Iraq have historically been relatively sparse but, as a result of Desert Storm, surface and upper air observation data in Iraq during this period were virtually non-existent. This lack of data makes determination of the speed and direction of the plume transport particularly difficult. An apparent area of diffluent wind flow (indicated by the available surface observation data in the region) to the south of Khamisiyah during this period further complicates the transport and diffusion analysis of the Khamisiyah plume.

A sound meteorological analysis of the transport and diffusion of the Khamisiyah plume is dependent upon the availability of high-resolution meteorological data in the vicinity of plume transport and diffusion. These data are necessary to determine key parameters and resolve important meteorological features such as the area of diffluent winds mentioned above. In this case, the only way to obtain high-resolution meteorological data in the area of concern is to use a prognostic meteorological model. And in order to generate a sound meteorological model run, a good weather data set must first be assembled. The scarcity of observation data in Iraq and the surrounding countries make development of the best possible weather data set a necessity.

3 Data Preparation

The first and most important step in atmospheric modeling is the preparation of the data set to be used by the models. AFTAC meteorologists wanted to use the same data set used previously by DoD modelers, but were unable to acquire an exact copy of that data set. So we started from scratch and evaluated all the available weather data in an effort to assemble the best possible data set.

Raw weather data for this analysis was extracted from several sources. The primary source was the AFTAC Weather System (AWES) quality controlled archive of global surface, upper air, and gridded weather data. These data are routinely obtained from Air Force Global Weather Central (AFGWC) and the Air Force Combat Climatology Center (AFCCC) and archived in AWES. A second important data source was the archive at the Naval Research

Laboratory at Monterey. Additionally, the Science Applications International Corporation (SAIC) also provided us with some key observation data. A significant amount of time was spent examining the quality of these weather data. This was an important preliminary step in modeling the effects of the weather during the Khamisiyah event.

Surface observations at both synoptic (3 hour intervals) and hourly intervals, as well as upper-air observations at six and 12-hour intervals, were retrieved from the AWES database. Surface and upper-air (both land and ship) observations were obtained from the Navy's operational database. The Navy data included both unclassified and declassified sources. SAIC provided special land surface observations taken by USAF and Special Forces close to the Khamisiyah area near the time of the event.

Extreme care was taken in blending the Navy and AWES data. The quality of the AWES data was significantly better because it had been through several iterations of quality control at AFGWC, AFCCC, and AFTAC. Only those Navy observations that did not appear in the AFTAC database and met quality check criteria were retained. As a result, most of the final data set consisted of observations retrieved from AWES. The most significant contribution from the Navy data was a large number of ship observations in the Persian Gulf and delayed observations from Saudi Arabia and Iran.

Several difficulties arose in comparing the AWES and Navy data sets. AWES station locations are accurate to hundredths of a degree in latitude and longitude; but positions in the Navy data set are truncated to a tenth of a degree. Where possible, the Navy station locations were updated with positions from AWES. To further compound this problem, it was not unusual to find different World Meteorological Organization (WMO) station identifiers for the same station between the two data sets. Where unclassified and declassified observations conflicted, the declassified observation was kept. Where Navy and AWES observations conflicted, the AWES observation was kept.

During the blending process, corrections were applied to surface observations with known errors. Many of these errors were of a frequency and/or magnitude that would have strongly effected modeling results. For example, several stations in the area of Khamisiyah listed repeated reports, incorrect elevations, or gross errors in wind speeds, temperatures, and dewpoints.

No quality control procedures had been originally applied to the Navy upper-air data. Many soundings had only mandatory levels and were frequently missing heights. In many soundings obvious errors were found, such as repeated levels with conflicting wind observations. It was not uncommon to find an AWES sounding at the same time and location as a Navy sounding, but with additional levels. For this reason, only a small number of Navy soundings in the vicinity of Khamisiyah were retained. These soundings had sufficient height, wind, and temperature information to be useful to the models. The rest were discarded.

To improve the integrity of the data set, all observations surrounding Khamisiyah for several hundred kilometers near the time of the event were plotted for an intensive manual examination. In addition, gross error checks for wind shear and a hydrostatic atmosphere were applied to all of the soundings before they were input to the SLAM and RAMS models.

A set of global analyses from the National Center for Atmospheric Research (NCAR)/National Center for Environmental Prediction (NCEP) reanalysis project (Kalnay, 1996) was a good additional source of coarse data that was used to complete our blended data set.

Pages 1-1 through 1-3 in Appendix 1 depict the increase in surface and upper air observations achieved from this process. The stations shaded in yellow are additional data points not in AWES that were retrieved. Note that several surface stations were added to the AFTAC data set, but only one upper air reporting station was added.

4 Technical Description of the Meteorological Model Run

The Regional Atmospheric Modeling System (RAMS, Pielke, et al., 1992) was the meteorological model used by AFTAC meteorologists to produce dense three-dimensional forecast fields of mass and winds to simulate the Khamisiyah plume. The model configuration and some of the model options utilized for this case study are described in this section. Our goal was to use RAMS to produce accurate high resolution forecast fields over the region of interest. Accordingly, we configured the model to run with four grids as described in Table 1 and depicted on page 5-1 of Appendix 5. The grids utilized a telescoping nesting configuration (i.e., grid 4 is within grid 3, which is within grid 2, which is within grid 1).

Table 1. RAMS Model Grid Configuration

Grid number	#x points	#y points	#z points	Horizontal (Km)	Initial delta-z (m)
1	32	32	28	80	50
2	34	34	28	20	50
3	42	42	33	5	15
4	42	42	28	1.25	15

Grid numbers 1 and 2 utilized the same vertical configuration, employing 28 vertical levels with an initial spacing of 50 meters stretching to 1200 meters at the top near 16 kilometers. The third grid utilized the vertical nested grid scheme (Walko, et al. 1995) which allowed an initial spacing of 15 meters, gradually expanding to a spacing of 1200 meters near 10 kilometers and continuing up to the model top near 16 kilometers. The vertical structure of the fourth grid was identical to the third except that this grid extended only to approximately 10 kilometers instead of up to the model top at 16 kilometers. Communication between the nested grids was accomplished using the RAMS' two-way interactive nesting scheme described by Clark and Farley (1984) and Clark and Hall (1991).

As stated above, the RAMS grid scheme was set up with an 80-kilometer resolution domain grid and three additional nested grids. The innermost grid was set to 1.25-kilometer resolution to try to resolve early movement of the plume. We were unable to resolve the swamp near the source with the 1.25-kilometer grid. We did not consider the additional computer time that would be necessary to resolve the swamp with a finer resolution grid a good use of our time.

The next nested grid was a 5-kilometer grid necessary to provide high-resolution wind fields in southern Iraq. The last nested grid was a 20-kilometer resolution grid that covered the remainder of the area of interest within the model domain. Although RAMS can be configured with much finer resolution grids, it was not done in this case because current computer limitations at AFTAC would dictate run times exceeding several weeks. AFTAC has programmed installation of computer resources by Feb 98 that will provide a capability to process high-resolution model runs in just hours rather than weeks.

The cumulus parameterization activated on grids 1-3 is a modification of the Kuo (1974) scheme described by Molinari (1985). The full microphysics package available in the model was utilized; parameterization of all rain and ice microphysical species available in the model was activated.

Long and short wave radiation was parameterized using the scheme developed by Chen and Cotton (1983).

RAMS allows the user to input some spatially varying data sets into the model for the purposes of defining the lower boundary. Topographical data were specified at 10 arc minute resolution (approximately 18.5 km) on the outer two grids, while on the inner two grids 9 arc second resolution (approximately 300 m) topography data derived from the National Imagery and Mapping Agency's (NIMA) Digital Terrain Elevation Data (DTED) source were used. Climatological sea surface temperatures specified at 10 arc minutes defined the water temperatures where appropriate, and land percentage data specified at 10 arc minutes resolution defined the land/sea interface. Careful checking of these climatological sea surface temperatures versus the available ship observations in the available data indicated this sea surface temperature data set was approximately 2 degrees Kelvin too warm in the northern Persian Gulf region. Accordingly, the model sea surface temperature fields in these regions were decreased by 2 degrees Kelvin.

Meteorological data are input to the model using the RAMS isentropic analysis package (ISAN), (Tremback, 1990). This package reads the gridded, surface, and upper-air observations as described in earlier sections of this report. Each of these data types are blended to produce data sets at 12 hourly intervals (i.e., at 0000 and 1200 UTC) to provide initial and lateral boundary conditions. Gross error checks, hydrostatic, and wind shear criteria quality control were applied to these data prior to ingestion by ISAN.

To control error growth, four dimensional data assimilation (4DDA, Stauffer and Seaman, 1990) was used on grids 1 and 2 using the ISAN produced 12 hourly analyses of the u and v wind components, potential temperature, and water vapor mixing ratio. The nudging time-scale used over the majority of the model domain was relatively weak 3 hours; a stronger time-scale (approximately 25 minutes) was used along the lateral boundaries of grid 1. It should be pointed out that we are nudging the model toward the large-scale meso-alpha scale features contained in the meteorological observations; we are allowing the model physics to drive the smaller scale features associated with the transport and diffusion of the effluent.

RAMS was executed for 120 hours, starting at 0000 UTC 9 March 91. The start time was chosen to allow the model approximately 36 hours to "spin-up" prior to the time of the explosion. Model output files were written at hourly intervals. These hourly forecasts of wind and mass were then input to SLAM to simulate the transport and diffusion of the effluent.

5 Technical Description of Transport and Diffusion Model Runs

AFTAC's primary transport and diffusion model, SLAM, was run several times using all available data types, including RAMS output data, as input to determine a plausible solution. The 15-minute resolution release rate table (Appendix 4, page 4-10) was developed by the CIA, Edgewood Research, Development and Engineering Center (ERDEC), and SAIC from a field test at Dugway Proving Grounds. These data were used as the source term in the SLAM runs. The source term is explained in detail in the DoD/CIA report. Trajectories were generated using a 48-hour duration.

Several SLAM runs were necessary to develop a series of trajectories and concentration displays for evaluation. The following combinations of data were used to make the SLAM runs: Surface data only; Upper-Air data only; Surface and/or Upper-Air data; Surface and/or Upper-Air and/or Gridded reanalysis data; and RAMS data only (SLAM/RAMS). Gridded reanalysis data were used heavily with the surface and/or upper air and/or gridded data (SLAM/OBS) run as input to SLAM in areas that lacked dense surface weather observation data.

5.1 SLAM Runs With Multiple Data Types

In the SLAM runs where multiple data types were used, SLAM used all data types that were available. The gridded reanalysis data are not considered (weighted) equally in SLAM, but are down-weighted with respect to the surface and upper-air data to interpolate the trajectory transport wind and mixing depth. Based on our experience with SLAM, the PIMIX method was used to calculate the mixing depth in SLAM and was used for both daytime and nighttime calculations.

The mixing depth daytime default value for SLAM was set at 1500 meters and the nighttime default value was set at 100 meters. Default values are used by SLAM when the model has insufficient data to calculate a mixing depth.

The maximum allowed value for a *calculated* mixing depth was set at 3000 meters and the minimum allowed *calculated* mixing depth was set at 100 meters. It is sometimes necessary to cap the SLAM calculated mixing depth because the model has difficulty resolving the mixing depth from soundings that do not include enough levels, or include only data from mandatory levels.

Stability was computed from surface data. The stack height and sampler heights were set at zero.

The puff size was limited to a 3-sigma growth. New puffs were released at 15-minute intervals and the model time step interval was also set to 15 minutes.

Gridded concentrations were calculated on a 0.04-degree X 0.04-degree grid from 27 to 32 degrees north latitude and 43 to 51 degrees east longitude (25,000 grid points).

The transport and diffusion results of the SLAM/OBS run are depicted in Appendix 3, page 3-1 through 3-21. These results are also provided in an animated format on the CD-ROM that accompanies this report.

5.2 SLAM Model Run Using RAMS Data

AFTAC's global transport and diffusion model, GAMUT, has a capability to calculate mixing depths from gridded data. Because of the lack of observed upper air sounding data in Iraq, and based on a thorough review of the RAMS data, AFTAC meteorologists decided to use the gridded reanalysis fields with GAMUT to obtain calculated mixing depths for the region. The resulting mixing depths that were manually set in SLAM for the RAMS data run were 2500 meters for daytime and 200 meters for nighttime. A discussion of the rationale for this procedure is presented in section 8.3 of this report.

SLAM settings for the RAMS data runs were otherwise the same as those stated in paragraph 5.1 above.

The transport and diffusion results of the SLAM model run with RAMS data are depicted in Appendix 5, page 5-177 through 5-197. These results are also provided in an animated format on the CD-ROM that accompanies this report.

6 Atmospheric Chemistry Model Runs

Since no atmospheric chemistry is applied in SLAM, it provides a conservative estimate of dosage footprints. The analysis of the Khamisiyah plume is the first application of AFTAC's atmospheric chemistry model in an attempt to refine the SLAM output and account for possible deposition and atmospheric degradation. The refined dosage predictions from this atmospheric chemistry model yield smaller dosage footprints than SLAM in virtually every case. This R&D model generated logical and reasonable results for the deposition and degradation of Sarin and Cyclosarin within the Khamisiyah plume.

The results of the atmospheric chemistry modeling study indicate two significant influences on the downwind fate of Sarin and Cyclosarin. First, the deposition of Sarin should be considered an important loss process. The type of land use over which the plume passed impacted the loss of Sarin due to deposition to some extent. Based on the current deposition parameters, Cyclosarin concentrations were not as affected by deposition as Sarin, although there remains some influence. The other significant influence on the downwind fate of Sarin and Cyclosarin is the ambient conditions through which the plume passes. These model runs were conducted using a two-order magnitude range of ambient NO_x levels. Results suggest that chemical transformation can play a significant role in decreasing the concentrations of Sarin and Cyclosarin at higher NO_x concentrations.

An in-depth discussion of the atmospheric chemistry model run is contained in Appendix 6, pages 6-1 through 6-7. Pages 6-8 through 6-37 in Appendix 6 depict minimum affect dosages for Sarin and Cyclosarin when atmospheric chemistry and deposition are considered for the two SLAM runs presented in this report.

7 Calculation of Dosage

SLAM dosage results are graphically depicted on charts in Appendix 4 on pages 4-1 *through 4-3 for the SLAM/OBS data. The dosage results for the SLAM/RAMS data are* located in Appendix 4 on pages 4-4 through 4-6. The release rate used for the SLAM model was in kg/hr. Model concentrations are depicted as hourly average concentrations in $kg/m^3 \times 10^{-12}$. The hourly concentrations are summed over a 24-hour period (0000 - 2359 UTC) to produce a daily total concentration. Daily dosages (in mg min m^{-3}) are calculated by multiplying the daily total concentrations (χ) by

$$\chi \times 10^{-12}\ \{kg/m^3\}hr \times 10^6\ \{mg/kg\} \times 60\ \{min/hr\} = \chi \times 6 \times 10^{-5}\ \{mg\ min/m^3\}$$

The dosage plots that result from the application of the atmospheric chemistry model are located on pages 6-8 through 6-37 in Appendix 6. The release rate used for the Atmospheric Chemistry model was in g/hr. Model concentrations are reported as hourly average concentrations in $moles/m^3$. The hourly concentrations are summed over a 24-hour period (0000 - 2359 UTC) to produce a daily total concentration. Daily dosages (in mg min m^{-3}) are calculated by multiplying the daily total concentrations (χ) by

$$\chi\ \{moles/m^3\}hr \times MW\ \{g/mole\} \times 10^3\ \{mg/g\} \times 60\ \{min/hr\} = \chi \times 6 \times 10^4\ \{mg\ min/m^3\}$$

8 Evaluation of Model Results

The SLAM/OBS model runs are distinctively different than the SLAM/RAMS model runs. If we could assume the RAMS data fields are correct we could discard the SLAM/OBS run as a viable solution. Conversely, we could discard the SLAM/RAMS run if the SLAM/OBS runs used a dense network of surface and upper air observations. In this case, we can do neither. The RAMS forecast data fields compare very well to the available observed data and gridded reanalysis data. At the same time the results of the SLAM/OBS model runs are actually based on real meteorological data, albeit sparse, and cannot be ignored without good reason. An evaluation of this modeling exercise dictates some comparisons are made of both the results and the workings of SLAM/OBS versus SLAM/RAMS.

Although we supplemented the observed surface and upper air data with gridded reanalysis data in the region for the SLAM/OBS run, those data may be too coarse to resolve mesoscale wind flow in the region. The reanalysis data grid points were interpolated from the same sparse observed surface and upper air data currently available. In fact, the analysts may have had less data available to them than we do at present. Therefore, we believe that perturbations in the wind flow that effected the transport of the Khamisiyah plume were surely smoothed out by the analysts that developed the gridded reanalysis data set. This also effects the SLAM/RAMS run because the reanalysis data were also used to nudge the RAMS model run.

8.1 Evaluation of RAMS Run

AFTAC meteorologists conducted an extensive evaluation of the RAMS predicted meteorological data fields and found them to be very good. Our evaluation included a thorough comparison of RAMS data fields to the available surface and upper air observations and the gridded reanalysis data within the model domain. The RAMS data compare very well in almost every case. RAMS soundings were plotted on Skew-T's along with the observed sounding for the same location and time. The sounding profiles compared very favorably. In one of the poorer comparison examples, at the Saudi Arabian Hafar Al-Batin airport, observed winds below 850mb were northerly at 10 knots at 11 Mar 0000Z. However, the RAMS winds in the same layer were generally northeast at 5 knots or less for the same time. We did not consider this a significant discrepancy since the Airport was located in a very weak high-pressure area where surface winds were variable and the predicted sounding data fit the synoptic situation very well. Even though this is one example where the RAMS data did not seem to match the observed data very well, the sounding was still fairly good. However, this discrepancy is in large part responsible for significant differences between the SLAM/OBS run and the SLAM/RAMS run.

We also conducted a thorough comparison review of the RAMS predicted surface, 925mb, and 850mb wind and temperature fields to the observed and gridded reanalysis data. In all cases, RAMS data compared very well to the observed and gridded reanalysis data. In several instances RAMS appears to do a better job handling data fields over areas of complex terrain than does the gridded reanalysis data.

Pages 5-2 through 5-5 of Appendix 5 are Skew-T's plots of RAMS forecast soundings and the observed sounding data at the Hafar Al-Batin Airport in Saudi Arabia.

Pages 2-1 through 2-41 of Appendix 2 are surface and upper air charts from observed observations and gridded reanalysis data that depict the weather patterns of 10-13 mar 91. Charts are included in Appendix 2 that were created from both gridded and observation data.

Pages 5-6 through 5-101 contain large scale sets of charts for every 3 hours starting 10 Mar 91 at 0000Z and ending 13 Mar 91 at 2100Z. Each set contains three charts; a plot of observed surface observations; RAMS forecast surface temperatures, and RAMS forecast surface wind streamlines.

Pages 5-102 through 5-136 contain finer scale sets of charts for every hour starting 10 Mar 91 at 1200Z and ending 10 Mar 91 at 1800Z. Each set contains five charts; a plot of observed surface observations, RAMS forecast surface temperatures, RAMS forecast surface wind streamlines, and even finer scale charts of the RAMS forecast temperature and surface wind streamlines.

Pages 5-107 through 5-176 contain large scale sets of charts for every 12 hours starting 10 Mar 91 at 0000Z and ending 13 Mar 91 at 1200Z. Each set contains five charts; a plot of observed 850mb wind observations; RAMS forecast 850mb temperatures; RAMS forecast 850mb wind streamlines; RAMS forecast 925mb temperatures; and RAMS forecast 925mb wind streamlines.

8.2 Evaluation of SLAM Runs With Multiple Data Types

AFTAC meteorologists consider the dosage footprints that result from the SLAM/OBS run (Appendix 4, page 4-1 through 4-3) to be the best of the SLAM runs using multiple data types. Our years of experience with SLAM have taught us that the more complete the data set is with SLAM, the better the results. Although the gridded reanalysis data is coarse, it still provides quality data in areas of sparse meteorological observations.

The SLAM/OBS model run grew the plume faster than SLAM/RAMS during the first day. Therefore, the plume mixed through a deeper layer than the SLAM/RAMS model run. In addition, strong vertical sheer was present in the surface based inversion layer below 900mb. If the plume from the Khamisiyah munitions pit did mix through a layer equally as deep on the first day, then it surely was carried away to the east by the stronger westerly flow above 900mb. The SLAM/OBS run also brings the influence of the westerlies to a lower altitude than the SLAM/RAMS run and forces trajectories to the east. Since we cannot positively determine the height the plume actually mixed to on day 1, we cannot ignore the more easterly position of the primary SLAM/OBS footprint or the additional SLAM/OBS footprint over the Persian Gulf (Appendix 4, page 4-2).

8.3 Evaluation of SLAM Runs Using RAMS Data

In our initial SLAM run with RAMS data, SLAM did poorly calculating mixing depths. SLAM picked up on very minor "kinks" in the RAMS sounding profiles and interpreted them as the top of the surface based inversion layer. This caused SLAM to calculate an inversion layer that was too low and as a result the plume stayed too close to the ground. In order to correct the problem we used our long-range transport and diffusion model GAMUT to calculate mixing depths from the gridded data fields. This technique yielded much better estimations of the mixing depth, which we rounded off and hard-wired into SLAM for the SLAM/RAMS data run.

The low-level (below 925mb) RAMS forecast wind speeds were very weak compared to some observations in the area in some cases. Because of this, the Khamisiyah plume did not grow as fast the first night or mix as high vertically in the SLAM/RAMS run compared to the SLAM/OBS run. The fact that the plume stayed lower and that the low level RAMS forecast winds were lighter than the available observed winds in the region kept the plume very low and slow. This situation is also a distinct possibility and the resulting dosage footprints (Appendix 4, page 4-4 through 4-6) cannot be ignored as a possible correct solution.

The resulting plume transport and diffusion from the SLAM/RAMS run is depicted in Appendix 5, pages 5-177 through 5-197. Dosage footprints for this same run are depicted in Appendix 4, pages 4-4 through 4-6.

In an effort to determine what effect a change in stability would have on our Low Level Exposure area, we made one SLAM run with RAMS data where the stability was increased by one category (more unstable) for only one hour (1500Z 11 Mar 91). The results depicted in Appendix 4, page 4-8 yielded a smaller dosage footprint. We include these data for information only to demonstrate the sensitivity of ground based dosages to stability categories.

Appendix 2, pages 2-42 and through 2-48 contains Skew-T plots of upper air observations that also depict stability indices and calculated Mixing heights for the three SLAM techniques; PIMIX, Richardson Number, and POTEMP.

8.4 Evaluation of the Atmospheric Chemistry Model Runs

These model data are provided for information purposes only, as their scientific value is yet to be tested and evaluated (See separate report in Appendix 6).

9 Conclusions/Recommendations

Both the SLAM/OBS model run and the SLAM/RAMS model run provide sound meteorological solutions for the Khamisiyah plume analysis. Although it is beyond the capability of current modeling technology to quantify key meteorological parameters with 100% accuracy, the dosage footprints of CW agents derived from both of these SLAM model runs (Appendix 4, pages 4-1 through 4-6) are meteorologically consistent.

The AFTAC atmospheric chemistry model is still an R&D model and many assumptions had to be made to produce the model run for the Khamisiyah event. However, the model generated logical and reasonable results for the deposition and degradation of Sarin and Cyclosarin within the Khamisiyah plume. These modeling results (Appendix 6) indicate the SLAM dosage footprints for each of the three days are probably smaller than the footprints depicted in this report or in the 4 Sep 97 DoD/CIA report titled "Modeling the Chemical Warfare Agent Release at the Khamisiyah Pit".

The AFTAC analysis is meteorologically consistent with the previous OSAGWI modeling efforts. However, our results do indicate some additional areas may have been exposed to at least Low Level Exposure dosages from the Khamisiyah plume. We recommend that the dosage footprints from the RAMS/SLAM modeling depicted in Appendix 4, pages 4-1 through 4-6 be added to the dosage footprints depicted in the 4 Sep 97 DoD/CIA report.

References

1. Chen, S., and W.R. Cotton, 1988: The sensitivity of a simulated extratropical mesoscale convective system to longwave radiation and ice-phase microphysics. J. Atmos.Sci., 45, 3897-3910.

2. Clark, T.L., and R.D. Farley, 1984: Severe downslope windstorm calculations in two and three spatial dimensions using an anelastic interactive grid nesting: A possible mechanism for gustiness. J. Atmos. Sci., 41, 329-350.

3. Clark, T.L., and W.D. Hall, 1991: Multi-domain simulations of the time dependent Navier-Stokes equations: Benchmark error analysis of some nesting procedures. J. Comput. Phys., 92, 456-481.

4. Kuo, H.L., 1974: Further studies of the parameterization of the influence of cumulus convection on large scale flow. J. Atmos. Sci., 31, 1232-1240.

5. Molinari, J., 1985: A general form of Kuo's cumulus parameterization scheme. Mon. Wea. Rev.,113, 1411-1416.

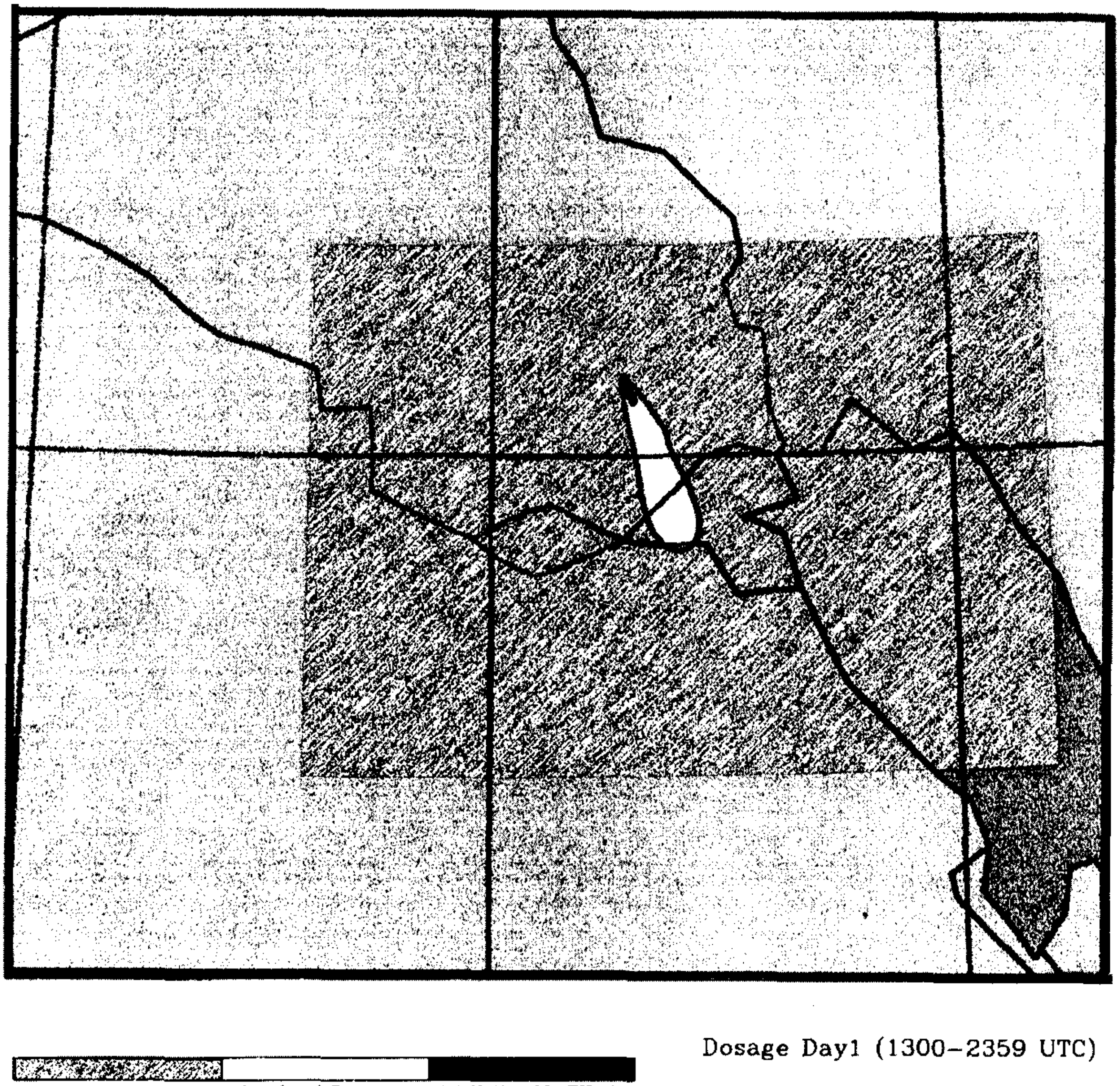
6. Pielke, R.A., and Co-authors, 1992: A comprehensive meteorological modeling system-RAMS. Meteor. Atmos. Phys., 49, 69-91.

7. Stauffer, D.R., and N.L. Seaman, 1990: Use of four-dimensional data assimilation in a limited area mesoscale model. Part I: Experiments with synoptic scale data. Mon. Wea. Rev., 118, 1250-1272.

8. Tremback, C.J., 1990: Numerical simulation of a mesoscale convective complex: Model development and numerical results. Ph. D. dissertation, Atmos. Sci. Paper No. 465, Colorado State University, 247 pp.

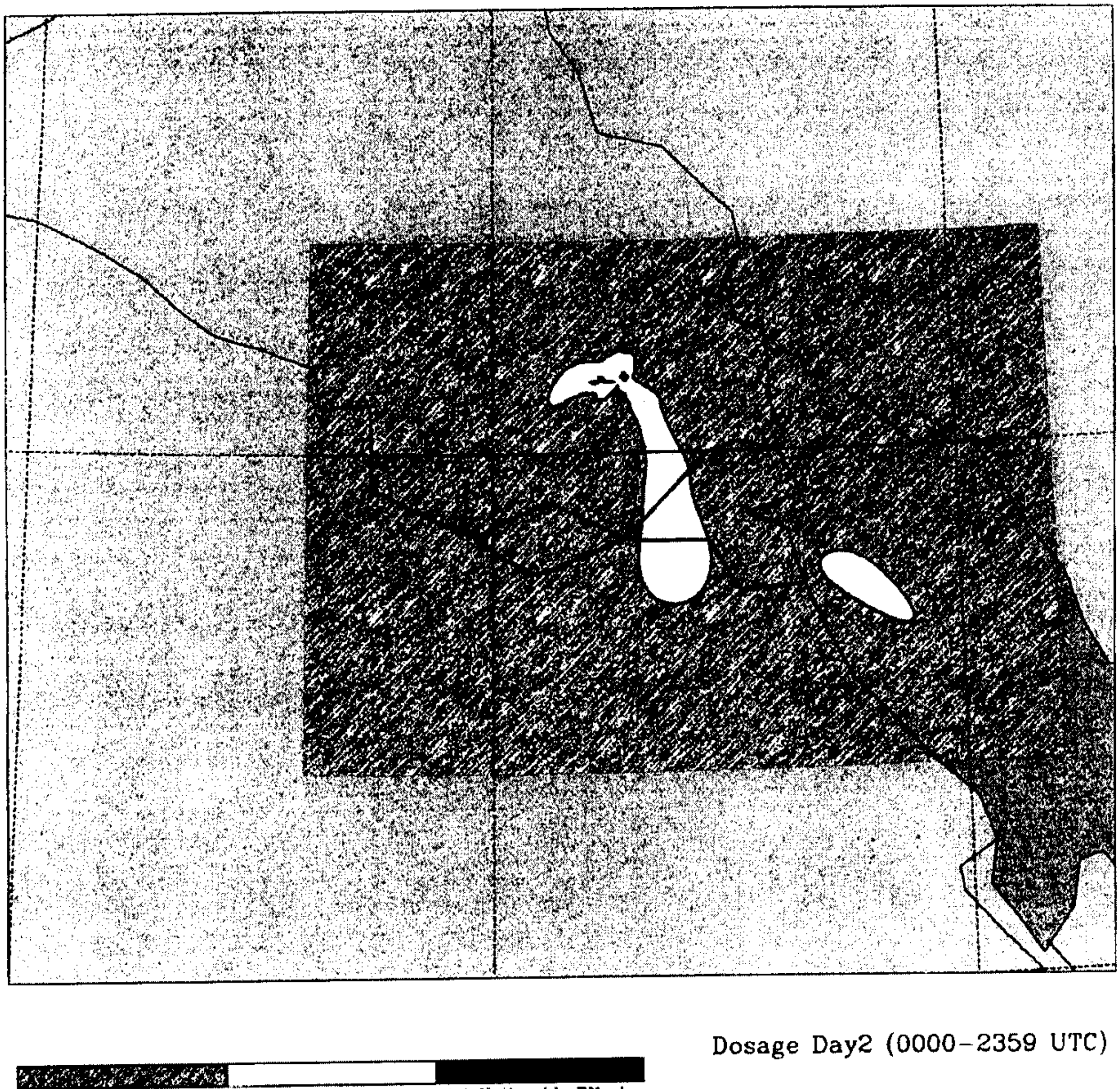
9. Walko, R.L., C.J. Tremback, R.A. Pielke, and W.R. Cotton, 1995: An interactive nesting algorithm for stretched grids and variable nesting ratios. J. Appl. Meteor., 34, 994-999.

10. Kalnay, E., and Co-authors, 1996: The NCEP/NCAR 40-year reanalysis project. Bulletin of the American Meteorological Society, 77, 437-471.



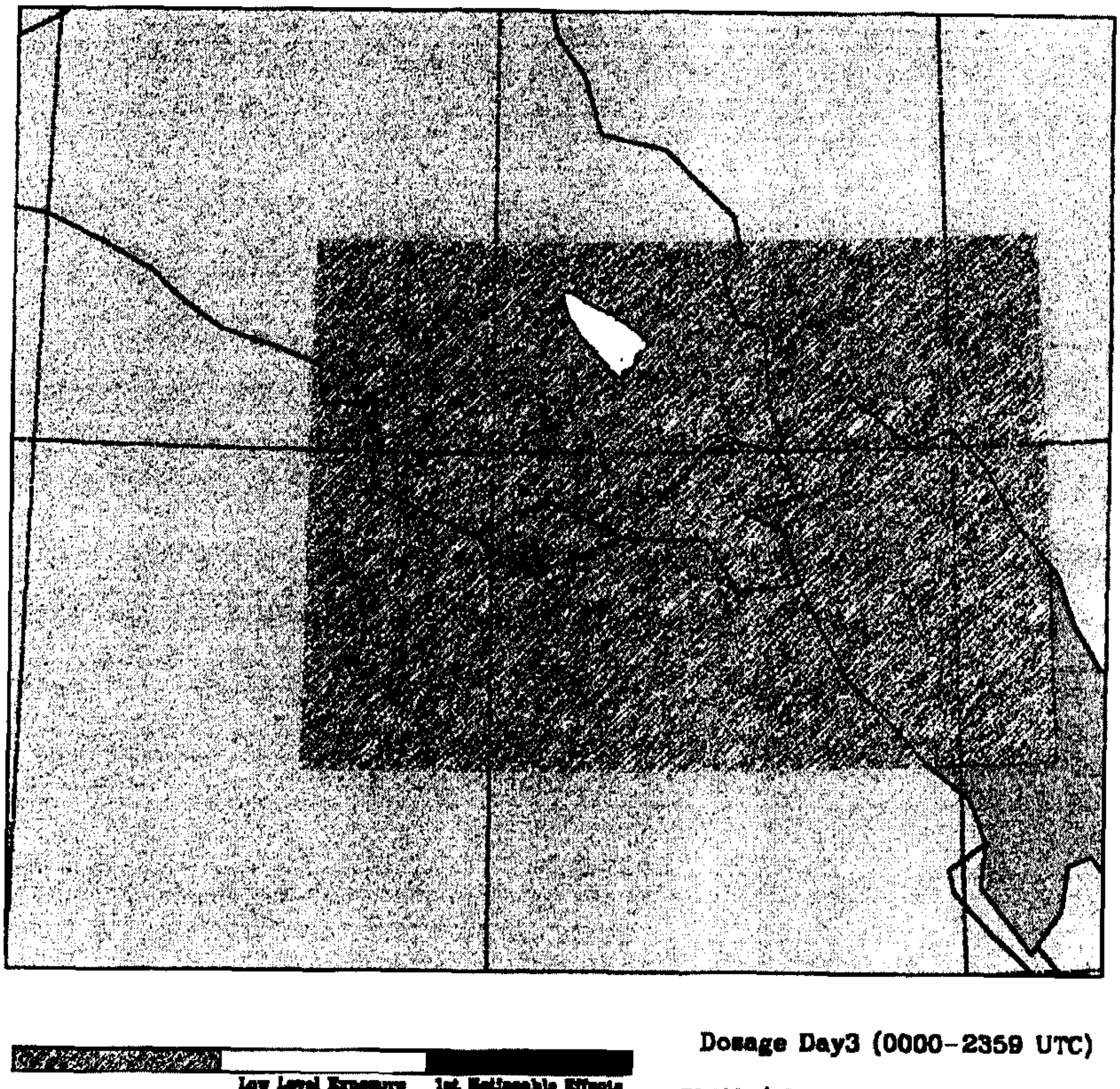
Dosage Day1 (1300-2359 UTC)

SLAM / Surface,Upper-Air,Reanal



Dosage Day2 (0000-2359 UTC)

SLAM / Surface,Upper-Air,Reanal



Dosage Day3 (0000-2359 UTC)

SLAM / Surface,Upper-Air,Reanal