# NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

# THESIS

## USING RAPID ENVIRONMENTAL ASSESSMENT TO IMPROVE THE HAZARD PREDICTION AND ASSESSMENT CAPABILITY FOR WEAPONS OF MASS DESTRUCTION

by

Victor B. Ross III

December 2003

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Submitted in partial fulfillment of the
requirements for the degree of

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# ABSTRACT

The Oceanographer of the Navy is responsible for the environmental data portion of the “4-D cube”. This is a new concept that creates a Virtual Natural Environment that must be capable of rapid environmental updates. This research investigates using in situ atmospheric measurements to improve the performance of the Navy mesoscale model, Coupled Ocean-Atmosphere Mesoscale Prediction System. These enhanced, operational model forecasts are used to supply atmospheric forcing to a dispersion model, the Hazard Prediction and Assessment Capability, and the outcome is evaluated to determine the impact of the additional data.

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# I. INTRODUCTION

## A. BACKGROUND

The Oceanographer of the Navy's Operational Concept, which defines the role of the Meteorology and Oceanography (METOC) community, revises many of the METOC operational roles within the United States Navy. One of the new roles defined in the document is "the ability to determine the impact of Weapons of Mass Destruction (WMD) and Weapons of Mass Effect (WME)" (Oceanographer of the Navy, 2002). This role is to be fulfilled by using a number of new METOC tools. In order to use these tools, new data formats and computer applications are being created to allow for the implementation of Rapid Environmental Assessment (REA).

REA is the application of continuous observations and data assimilation to short-range forecasting. The normal environmental assimilation interval of 6 to 12 hours is not rapid enough for most military applications. Extended time intervals negate much of the data collected since it is superceded by later data points. This lack of rapid data collection and assimilation prevents many applications from receiving the information to more correctly represent the constantly changing atmospheric and oceanic conditions.

One of the initial requirements to accomplish REA is the creation of the "4D Cube". The 4D cube is defined as "a virtual entity of geospatially referenced data, information and knowledge used to support interoperable nodes/systems" (Oceanographer of the Navy, 2002). The knowledge base that will house the 4D cube called the Virtual Natural Environment (VNE). Integration of real-time atmospheric information into the VNE is the key to the REA process, and should allow for more accurate forecasting of the impact of WMD/WME.

In order to create the VNE, the Navy’s Coupled Ocean-Atmosphere Mesoscale Prediction System – On Scene (COAMPS™-OS) is used. This allows for the finest-resolution model information to be integrated with accredited decision making tools like the Joint Effects Model (JEM, 2003). The output from JEM can then be used by the METOC officer to provide the on-scene expertise regarding METOC factors influencing agent dispersion.

## B. THESIS APPROACH

This thesis focuses on the implementation of REA used in the process of determining the impact of WMD/WME. Specific global locations are identified weekly by Joint military commands as possible targets for strikes with WMD/WME. Targets for the thesis were reviewed based upon current weather patterns, available classified observational data, and available initial model conditions.

Current weather patterns are chosen so that there are changing conditions in the area selected. Criteria for selection include, but are not limited to: frontal passages, boundary-layer instability, and local circulations such as land/sea breeze. Areas of stable, slowly changing atmospheric conditions would probably be less likely to show benefit from the REA process.

Classified observational data are required to show the true impact of the REA process. Since the models receive real-time unclassified observational information, true REA impact cannot be measured without the inclusion of additional observations. Areas with higher numbers of observations or upper-air observations are given preference since this will increase the model’s available data set with which to perform the REA.

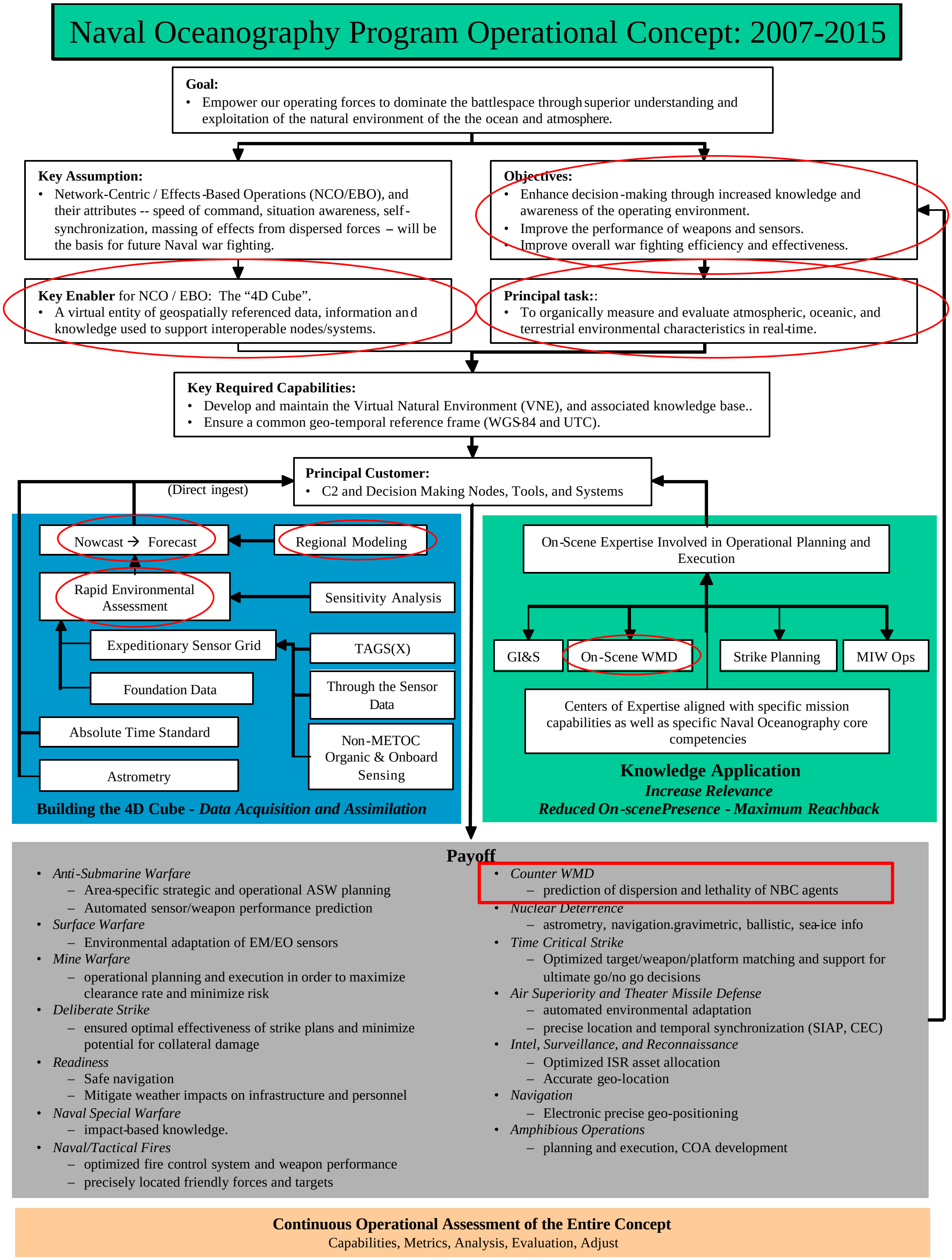
Initial boundary conditions are very important to the REA process. Improper boundary conditions can cause the REA process to significantly degrade the forecast. This can be due to poor choice of grid choice resolution or large differences in the terrain resolutions. These conditions can make a large difference in the final outcome of the REA process.

In order to look at the impact of the REA process, COAMPS™-OS is run in a real real-time configuration. This allows for constant updating of the forecast information for the designated areas. At selected times a WMD/WME event is simulated. A dispersion model data set is prepared at the time of the event as the baseline data set. A concurrent thesis effort in Computer Science has developed a real-time data support capability for JEM (Ross, 2003). All available classified and additional unclassified observational data are collected and assimilated into the COAMPS™-OS data stream. The model is run again with the new data, and a second dispersion model data set is prepared from the completed run. The data sets are each used to initialize the dispersion model, and outputs are compared.

## C. EXPECTED RESULTS

The increased resolution of the model combined with the REA information should give a more accurate representation of the atmospheric conditions to be supplied to the dispersion model. If there are changing weather patterns, the model should produce a better dispersion plume with the enhanced data from the REA process. In more stable or slowly changing conditions, the REA process will probably not produce a noticeable change to the dispersion plume. No matter which situation is encountered, the output from the REA process should still produce the best input for use in the dispersion model. This comparison of REA and non-REA HPAC dispersion forecasts will also investigate the sensitivity of HPAC to model fields.

The complete REA process is an integral part of the N096 Operational Concept (Figure 1), and will allow for better decision making ability in the operating environment. It will also create a more accurate prediction system with which to provide source inputs for both weapons and sensors. Finally, it will provide the increased resolution needed to support the counter WMD/WME efforts.



Naval Oceanography Program Operational Concept: 2007-2015

**Goal:**
- Empower our operating forces to dominate the battlespace through superior understanding and exploitation of the natural environment of the the ocean and atmosphere.

**Key Assumption:**
- Network-Centric / Effects-Based Operations (NCO/EBO), and their attributes -- speed of command, situation awareness, self-synchronization, massing of effects from dispersed forces – will be the basis for future Naval war fighting.

**Objectives:**
- Enhance decision-making through increased knowledge and awareness of the operating environment.
- Improve the performance of weapons and sensors.
- Improve overall war fighting efficiency and effectiveness.

**Key Enabler** for NCO / EBO: The “4D Cube”.
- A virtual entity of geospatially referenced data, information and knowledge used to support interoperable nodes/systems.

**Principal task::**
- To organically measure and evaluate atmospheric, oceanic, and terrestrial environmental characteristics in real-time.

**Key Required Capabilities:**
- Develop and maintain the Virtual Natural Environment (VNE), and associated knowledge base..
- Ensure a common geo-temporal reference frame (WGS-84 and UTC).

**Principal Customer:**
- C2 and Decision Making Nodes, Tools, and Systems

**Payoff**
- *Anti-Submarine Warfare*
  - Area-specific strategic and operational ASW planning
  - Automated sensor/weapon performance prediction
- *Surface Warfare*
  - Environmental adaptation of EM/EO sensors
- *Mine Warfare*
  - operational planning and execution in order to maximize clearance rate and minimize risk
- *Deliberate Strike*
  - ensured optimal effectiveness of strike plans and minimize potential for collateral damage
- *Readiness*
  - Safe navigation
  - Mitigate weather impacts on infrastructure and personnel
- *Naval Special Warfare*
  - impact-based knowledge.
- *Naval/Tactical Fires*
  - optimized fire control system and weapon performance
  - precisely located friendly forces and targets
- *Counter WMD*
  - prediction of dispersion and lethality of NBC agents
- *Nuclear Deterrence*
  - astrometry, navigation.gravimetric, ballistic, sea-ice info
- *Time Critical Strike*
  - Optimized target/weapon/platform matching and support for ultimate go/no go decisions
- *Air Superiority and Theater Missile Defense*
  - automated environmental adaptation
  - precise location and temporal synchronization (SIAP, CEC)
- *Intel, Surveillance, and Reconnaissance*
  - Optimized ISR asset allocation
  - Accurate geo-location
- *Navigation*
  - Electronic precise geo-positioning
- *Amphibious Operations*
  - planning and execution, COA development

**Continuous Operational Assessment of the Entire Concept**
Capabilities, Metrics, Analysis, Evaluation, Adjust

Figure 1. N096 Operational Concept (After Oceanographer of the Navy, 2002)

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# II. MESOSCALE AND DISPERSION MODELING

## A. MESOSCALE MODELING

This thesis will use three major categories of models, hydrostatic global models, non-hydrostatic mesoscale models, and microscale dispersion models. Within DOD the most prevalent mesoscale models are the Coupled Ocean/Atmosphere Mesoscale Prediction System (Hodur, 1997) and the Fifth-Generation National Center for Atmospheric Research / Penn State Mesoscale Model (Anthes, 1978). The COAMPS™-OS forecast area is bounded by a larger model field, typically Navy Operational Global Atmospheric Prediction System (NOGAPS), and boundary conditions need to be scrutinized before accepting the area. In order to attempt to improve on the current inner nest of COAMPS™-OS, this thesis will add non traditional observational data. This will illustrate the REA process that is described by the new operational Concept of Operations.

The REA process should be important for effective use of mesoscale models in the dispersion modeling process. All models have time delays created by the actual running time of the model. Atmospheric conditions are constantly changing, and those changes are frequently more important in areas where DOD forces are operating. Units are usually deployed in areas of denied data availability or coastal areas where atmospheric conditions change rapidly. Without local observational information the models may not have enough information to properly resolve local mesoscale circulations. COAMPS™-OS performs an analysis every 6 or 12 hours on all nests using previously forecast fields at the first guess field. This procedure incorporates new data for each assimilation time and then restarts the assimilation in an attempt to minimize error growth over time (Johnson-Winegar, 2003).

COAMPS™-OS has a number of advantages over just using observations or an analysis that could positively affect the dispersion models. One focuses on the determination of the planetary boundary layer (PBL). COAMPS™-OS uses a fine vertical resolution and the 2.5 PBL model (Mellor and Yamada, 1974) to specify the PBL. This allows the model to better detect phenomena missed by other models such as sharp variations in topography, land-and-sea breeze circulations, and local contrasts in physical properties (Johnson-Winegar, 2003).

In order to meet the time constraints to satisfy REA requirements, the current COAMPS™-OS used at NPS can run double-nested spherical models in a .27° and .09° resolution. This allows both nests, 31x31 grid points, to be modeled in approximately 80 minutes. The output from the run, 0 - 24hr forecast, can then be used to initialize the dispersion model.

## B. DISPERSION MODELING

Atmospheric transport and diffusion modeling has been conducted for decades, but evaluation methods have varied over the years starting with linear least-squares analyses and progressing to the use of bootstrap techniques (OFCM, 2002). The Office of the Federal Coordinator for Meteorological Services and Supporting Research specifically cites many areas for research and concern for the number of dispersion models being used operationally by government agencies. The current estimates show that while there are only a few approaches for dispersion modeling there are over 140 modeling systems. Of those modeling systems, 29 are used operationally by different government agencies (OFCM, 2002).

There are currently three primary modeling systems used in the Department of Defense (DOD): the Hazard Prediction and Assessment Capability (HPAC), the Emergency Management Information System (D2PUFF), and the U.S. Navy’s Chemical/Biological Agent Vapor, Liquid, and Solid Tracking model (VLSTRACK). To simplify this confusing situation, Space and Warfare Command (SPAWAR) has been tasked to create JEM. This model is created by combining the best parts of the three primary models into a single modeling system. When completed, it will replace all other operational dispersion modeling systems used by DOD services. The final JEM implementation will handle the following scenarios: counterforce, passive defense, accident, incident, high altitude releases, urban Nuclear, Biological, and Chemical (NBC) environments, building interiors, and human performance degradation (Integrated Chemical and Biological Defense Research, Development and Acquisition Plan, 2003).

Much of the suggested OFCM research will need to be performed to make JEM and other future models more reliable. These areas include: source characterization, urban dispersion, PBL, coastal influences, deposition rates, re-suspension, and complex terrain. This thesis looks at an area with complex terrain and coastal influences, and incorporates them into the REA cycle for inclusion in the dispersion modeling process. This is important since meteorological input into dispersion modeling is still an area in need of extensive research. Both the input parameters for dispersion modeling and the uncertainties associated with the parameters need to be defined and understood by the end users of JEM.

# III. GENERAL DISCUSSION AND PROCEDURES

## A. ADDITIONAL MODELING CONCERNS

Remote military operations often occur in data-sparse areas, and the data being collected is not always included in the models run at remote locations. This is a function of both time and communications capabilities. Placing the modeling capability with the larger remote units will allow for inclusion of remote data as well as allowing for mission completion when communications are not available. In this thesis, that capability is created with a single Linux based Personal Computer (PC) running both COAMPS™-OS and TEDServices.

Another capability under utilized in the military is the access to non-standard observations. These observations can be from any number of military sensors or personnel. Many of these observations are classified, and never make it into the data streams used in modeling. For this thesis, the addition of profiler data is being included. This data supplements lower-level atmospheric measurements. Many experts question the need for balloon measurements of the atmosphere above the surface. Profilers can supplement this data set with measurements typically reaching up to approximately 700 millibars. Since the profilers operate continuously, there is also a better chance that they will capture phenomena that could be missed by the balloon soundings. The inclusion of the profiler data, and ship surface observations when available will give the atmospheric model more data to resolve the coastal phenomena. This is listed by all the experts as one of the key concerns for furthering dispersion modeling (OFCM, 2002). While this thesis attempts to address this concern, there are a large number of other military observations that could assist in this area as well. The ability to rapidly assess the current environment, and modify a forecast to better represent the current environment is critical for dispersion modeling.

## B. LOCATION AND DATA SELECTION

This thesis implements the REA over the San Diego, CA area. This area was chosen after several other possibilities. Athens, Greece was considered because of the planning for the Olympic Games in 2004, but due to other obligations, there are not many naval units in the area to provide the extra data needed to test the REA concept. The second choice was Washington, D.C., implementing REA using the DCNet currently under development. This is a mesoscale observation network being created by the National Oceanic and Atmospheric Administration. This area could not be used effectively since COAMPS™-OS ignores surface wind measurements over land. The final choice of San Diego, CA was chosen since there are typically naval units in the area, and there is a network of atmospheric profilers in the area. Neither of these data sources is currently included in COAMPS™-OS modeling. The ship surface observations will assimilate surface wind, temperature, and pressure since the observations are over the ocean where surface-wind observations are included. The profilers along the coast will add lower-level upper-air data to the data assimilation.

Surface data from ships is collected using a combination of data sources including Fleet Numerical Meteorology and Oceanography Center (FNMOC), METCAST, and the METOC center in San Diego. Since there is no single source location to retrieve all secret-level observations, multiple channels have to be used. These observations are particularly important since they represent the observations that would be collected directly by the military units in the area of a suspected WMD/WME attack. Preferably, there would also upper-air soundings from balloon launches aboard United States Navy (USN) ships, but the database ingest routine was not functioning correctly and these data were not included.

The profiler data could be made available in remote areas. The data used in this thesis are available in 15 or 60 minute data sets. In order to allow for inclusion in COAMPS™-OS without rewriting the assimilation routines, the profiler data must be represented at the standard atmospheric levels used for upper-air soundings. Although this does not give the best possible resolution provided by the profilers, it does give more frequently available data than is provided from the twice daily upper-air soundings.

## C. DATA INGEST

The previous two hours of data is collected from the unclassified profiler web site every hour. This data is then processed into standard levels by a program provided by the Navy Research Laboratory – Monterey (NRL-Monterey). The processed files are then transferred to the classified network for inclusion in the Single Tactical Environment

Data Server (Single TEDS). This data flow was mandated by the fact that TEDServices cannot pull observational data or use observations for atmospheric modeling. The data flow of the thesis configuration is shown in Figure 2.

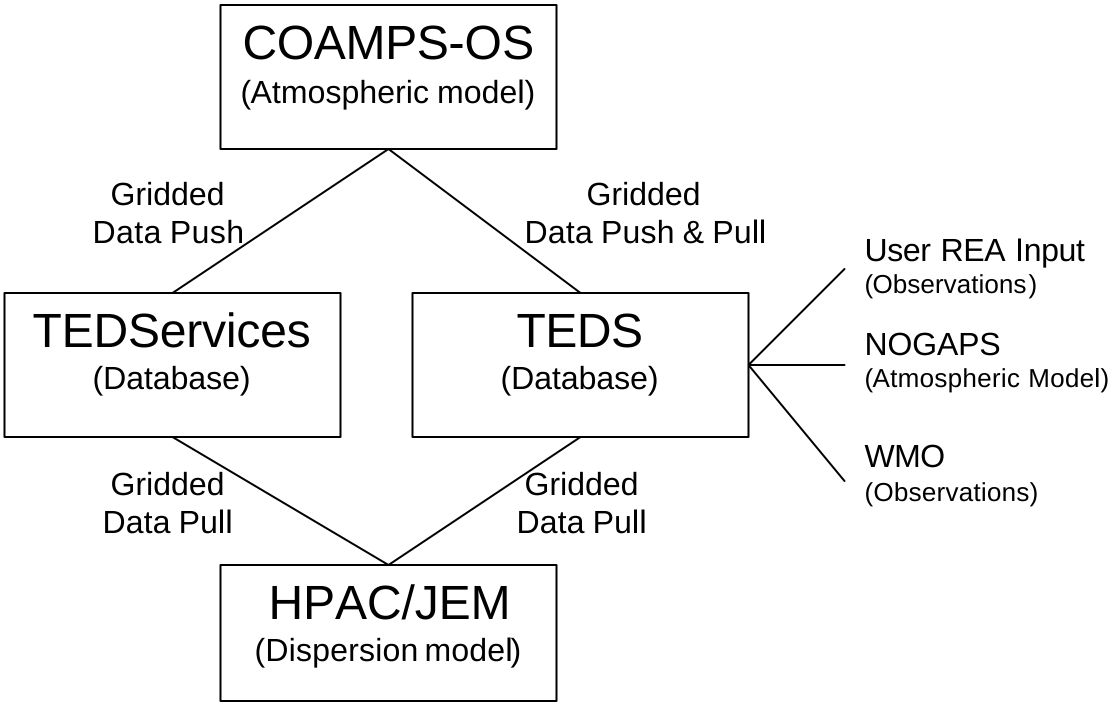


Figure 2. Thesis Data Flow

Atmospheric observations are collected from the classified network from any available source. This can include emails from the regional center in San Diego, or access to the master TEDS at FNMOC using METCAST. Each of these observations is then added to the model database using a Web-based interface.

## D. ATMOSPHERIC MODEL DATA FLOW

In order to perform the successful REA, the Single TEDS database at FNMOC is used as the primary data source for COAMPS™-OS. TEDS holds not only the atmospheric observations, but also the NOGAPS and COAMPS™-OS boundary conditions. These data are used to initialize the atmospheric model on a continuous 6-hour assimilation schedule. Output from COAMPS™-OS is then stored back to TEDS as well as TEDServices. All of these data are computed in spherical coordinates since TEDServices cannot convert from Lambert-Conformal to spherical coordinates. The grids output are then made available to the dispersion modeling systems from both TEDS and TEDServices.

## E. DISPERSION MODEL DATA FLOW

Upon completion of the atmospheric model, the data is submitted to both TEDS and TEDServices for storage and dissemination. Of the data created from the atmospheric model, only a small sub-set is used by the dispersion model. The required two and three dimensional fields needed from the atmospheric model are listed in Table 1 (Defense Threat Reduction Agency, 2003). Using the Java/Web-based page, the data file can be retrieved from the Single TEDS stored at FNMOC. This data retrieval for an area of 0.5° x 0.5° including a 24-hour forecast divided in hourly segments requires between 15 and 40 minutes. This does include network latency associated with the data being stored at FNMOC. Using the results from the Computer Science thesis (Ross, 2003), the equivalent data file can be retrieved from TEDServices in approximately one to two minutes. This retrieval has a minimal latency issue since the data is on the same network. Each of the independent data files can then be used to provide boundary conditions for the dispersion model.

| **3D** | **2D** |
|---|---|
| U_WIND<br>W_WIND<br>V_WIND<br>PHI<br>POTENTIAL_TEMPERATURE<br>WATER_VAPOR_MIXING_RATIO | TERRAIN_HEIGHT |

Table 1. Dispersion Parameters

## F. WMD AND REA SIMULATION

Overall operational simulation is accomplished by having a COAMPS™-OS area running continuously over the operating area. This area is automatically run every 12 hours for a 24-hour forecast period. Each model run uses the previous COAMPS™-OS, NOGAPS and available observations to initialize the new model run. At selected times, a place is selected to be the site of a WMD/WME. At the time of the simulated WMD/WME, dispersion data sets are pulled from both TEDS and TEDServices. All available observations from both unclassified and classified sources are then added to TEDS, and the observational data is reacquired for assimilation in the initialization. The atmospheric model is rerun using the new observational data, and the resulting data is again pulled from both TEDS and TEDServices for analysis.

## G. VERIFICATION DATA

To best identify how well the dispersion model depicts the simulated WMD/WME event, the site is located near one of the profiler locations. The profiler graphics are collected every 24 hours so that a comparison can be made between the graphic produced by the WMD/WME model and the continuous graphics produced by the wind profilers.

# IV. RESULTS

## A. INTRODUCTION

The process of allowing the model to run in an automated 12-hour cycle and then running an REA forecast did pose a number of problems. Since the initial conditions for the automated runs cannot be affected by the extra data, they had to be saved until after the initial model run. The process of then adding and extracting that many observations at a single time was not always possible. There were three instances when the data could not be added and extracted before the next automated model run was started. Then for the REA run, the additional profiler and classified surface data were added to the saved TEDS data and new analysis and COAMPS™-OS forecasts were prepared. At the conclusion of each model run, both the automated and the REA, the data had to be inserted back to the respective databases.

The location chosen to run the experiment was Coronado, California region. Although there were other areas considered, Coronado offered the best options for including real-time operational data. Since COAMPS™-OS does not use surface wind observations over land, the option of using the Washington D. C. mesonet of surface observing stations was not an option. As shown in Figure 3, the southern California area has a number of atmospheric profilers to provide low-level upper-air observations as well as occasional ships providing off-shore observations that can be used. Coronado also was specifically was chosen because there is both a profiler and upper-air sounding site nearby, it is a military base, and a likely WMD/WME target.

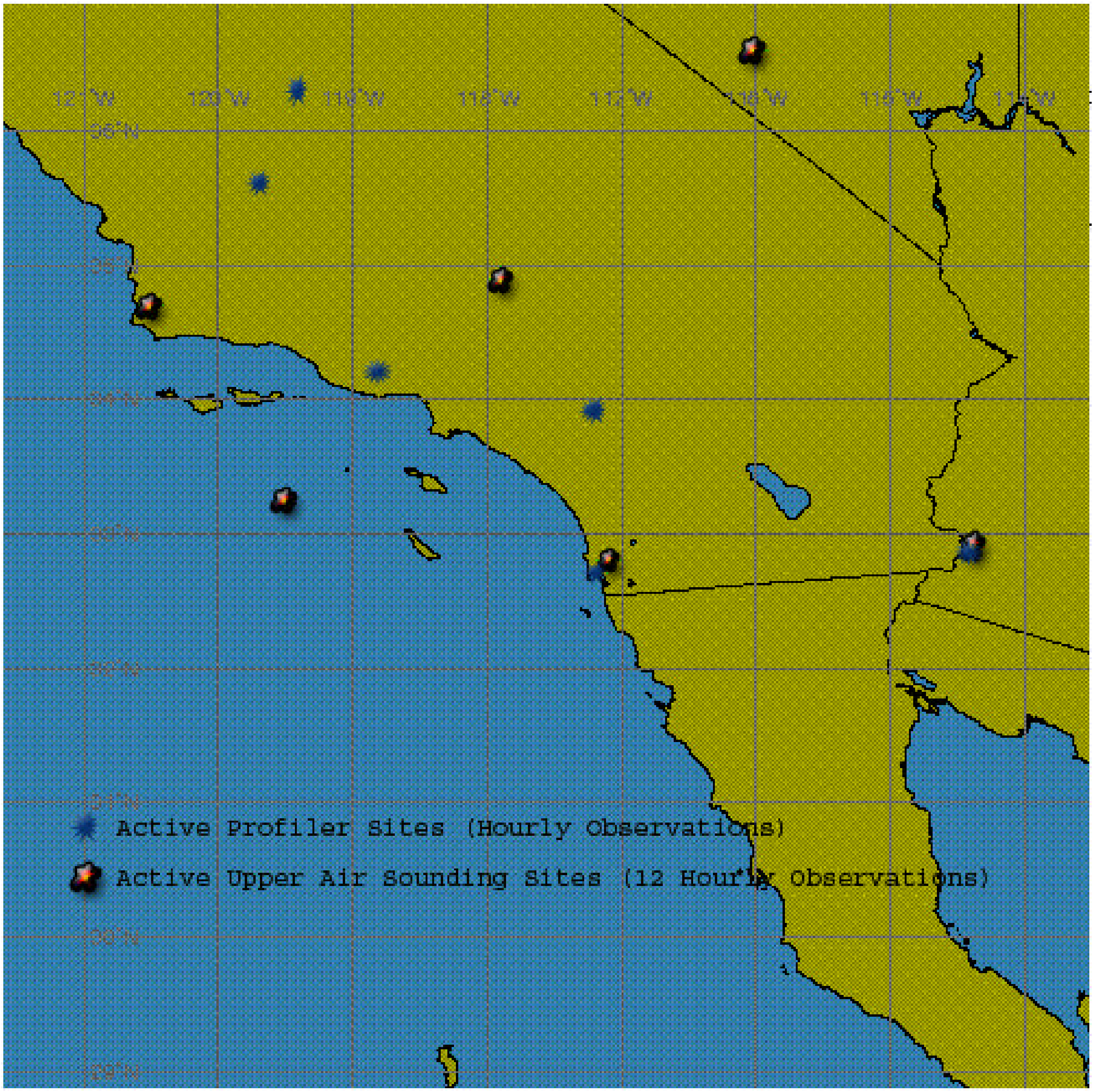


Figure 3. Profiler and Sounding Locations

The parameters for running COAMPS™-OS and HPAC were static throughout the thesis. The parameters for COAMPS™-OS are presented in Appendix A. The parameters for HPAC are presented in Appendix B.

## B. SYNOPTIC OVERVIEW

The period from Nov 11, 2003 to Nov 21, 2003 was selected to test the COAMPS™-OS and JEM/HPAC systems and evaluate the REA runs. At the start of the period in the upper levels, there was a short wave trough over central California extending south west into the eastern Pacific. Over the next 24 hours, a cut-off low forms just off southern California as shown in Figure 4. The low deepens slightly before lifting out by 00Z on Nov 13, 2003. This leaves a predominant west to east flow over southern California until a new short wave moves into the area around 00Z on Nov 15, 2003. By 00Z on Nov 16, 2003 the short wave extends from west of Baja, Mexico over the San Diego, CA area. High pressure moves in and dominates the area by 00Z on Nov 17, 2003. The ridge extends from the Pacific Northwest through central California leaving the San Diego area downstream of the ridge axis. The ridge moves onshore by 00Z on Nov 18, 2003, and is centered over San Diego by 12Z on Nov 19. Near the end of the period split flow develops over the area showing a short wave in the Pacific Northwest and a new low forming near 30°N and 145°W. Light westerly flow continues over the Southern California area during this period.

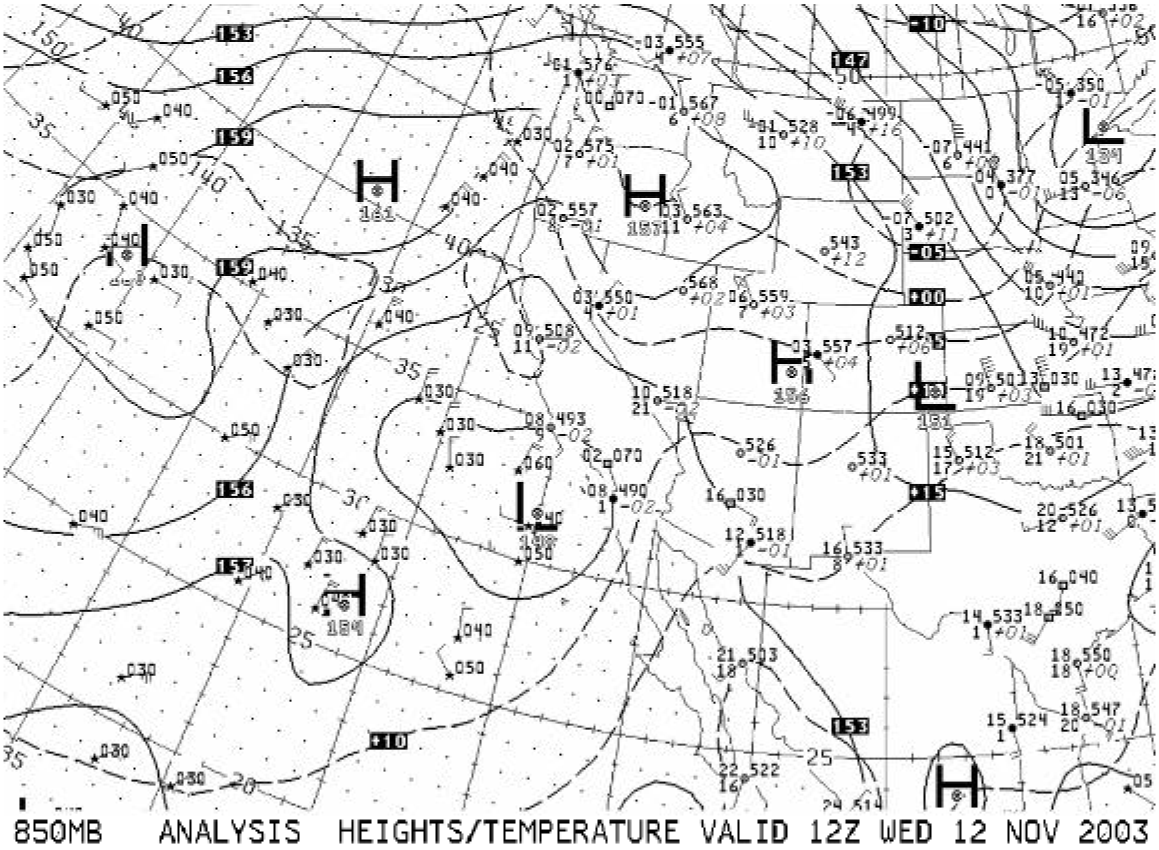


Figure 4. 12 Nov 2003, 12Z 850 mb Analysis

## C. MESOSCALE CHANGES

The primary purpose of the thesis is to study how REA can affect the mesoscale modeling and subsequently the dispersion modeling. The operational wind data are primarily from NOGAPS, satellite and upper-air soundings. This thesis also studies the impact of adding the atmospheric profilers in California. These profilers can provide the same type of upper-air data as a balloon sounding, but continuously. There were anywhere from 4 to 10 profiler soundings added in the inner nest and 8 to 19 profilers soundings added in the outer nest during the data test period. An example of these stations is shown in

Figures 5 and 6. There was also occasional data added from United States Navy (USN) ships off the coast of California.

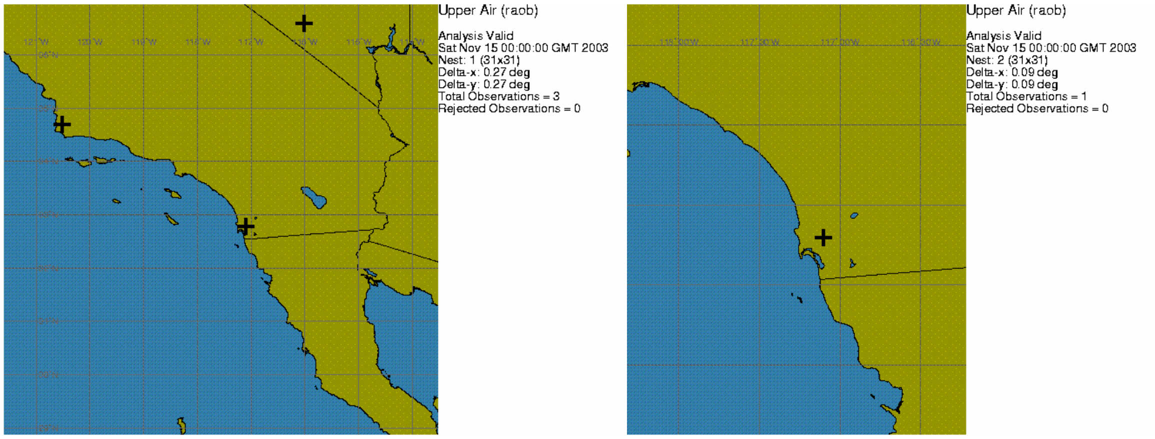


Figure 5. Upper-air Soundings – Both Nests

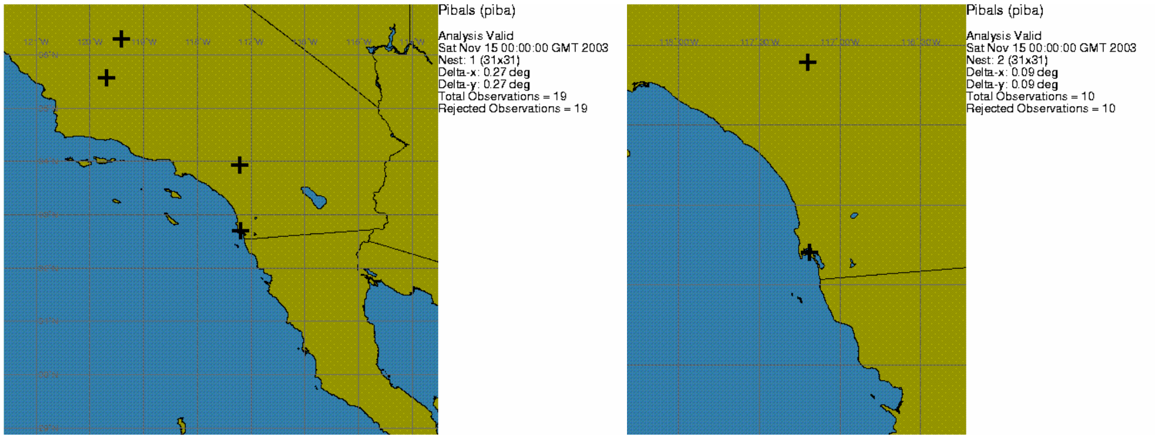


Figure 6. Profiler Soundings – Both Nests

The addition of the profilers did create noticeable changes in the all REA COAMPS™-OS output. Of the 17 model runs, 5 were considered to have had a significant impact from the REA process. Each of these data sets was analyzed to see if the REA process added value. All five instances showed improvement from the model runs without the additional REA data. One of the more drastic changes after adding the additional data is shown in Figure 7. This instance was used as the time for a simulated WMD/WME to determine how modified parameters from the mesoscale model would affect the outcome of the dispersion model. As a comparison, another case is presented when the REA fields did not seem much different from the original fields. This data is shown in Figure 8. This instance was also used as the time for a simulated WMD/WME as well. Of the 17 total model runs listed in Appendix C, 5 appeared to have a large enough departure of the forecast to warrant further scrutiny. Each of these is listed below by date and time of the model run.

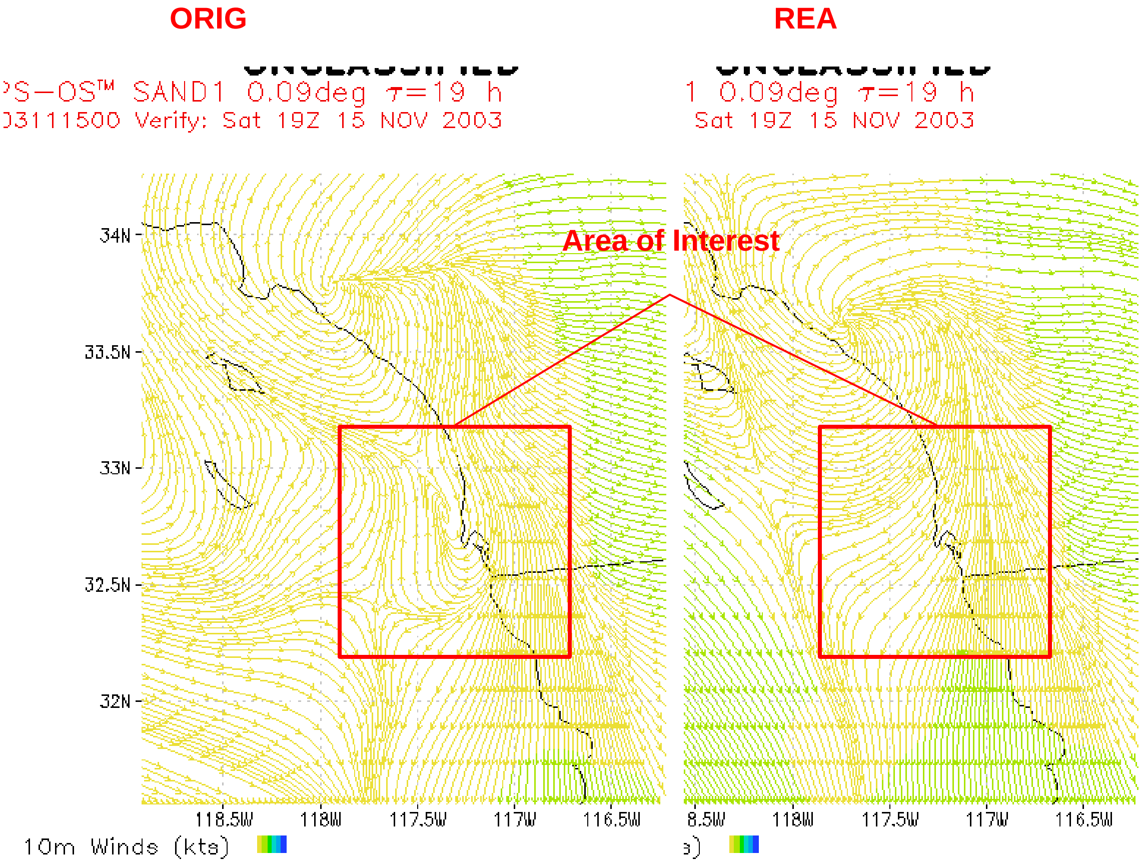


Figure 7. COAMPS™-OS Before and After REA - 2003111500

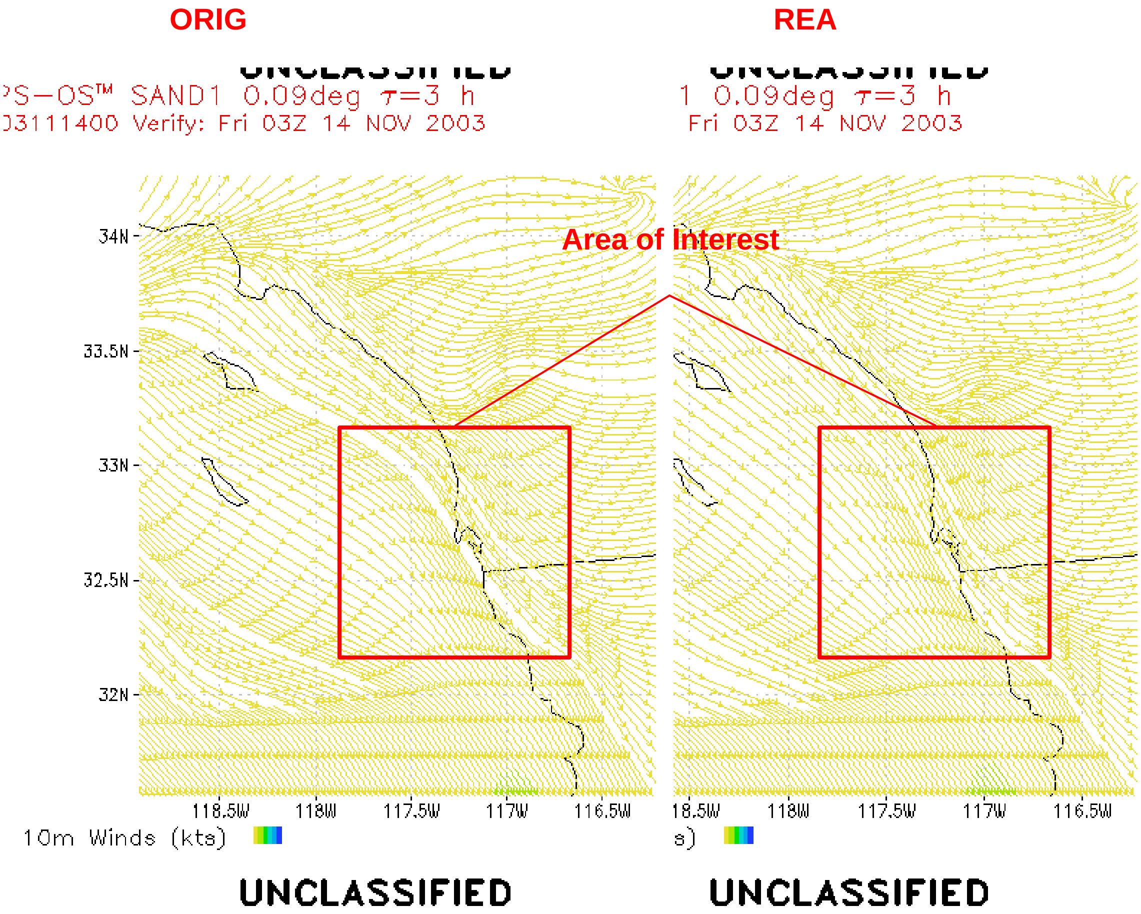
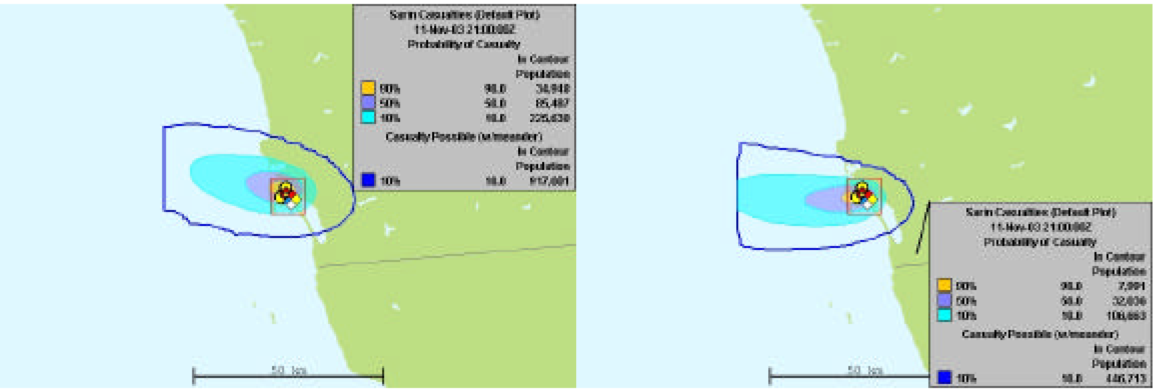


Figure 8. COAMPS™-OS Before and After REA – 2003111400

### 1. November 11 2003, 12Z Model Run

There is a low confluence over the Coronado area at the start of the WMD time and a continuing onshore low-level flow throughout the incident. The levels above 925 mb show a directional change from onshore to offshore during the incident. This wind shift is directly related to the movement of the low-level vortex shown in Figure 4. When comparing the winds from the pre and post REA model runs against the profiler wind data at 850 mb, 925 mb, and 10 m. The REA model run was clearly more representative of the actual atmosphere. The fact that the REA model run picked up on the easterly flow earlier than the original model run is clearly shown in Figure 9. More details are given in Appendix F.



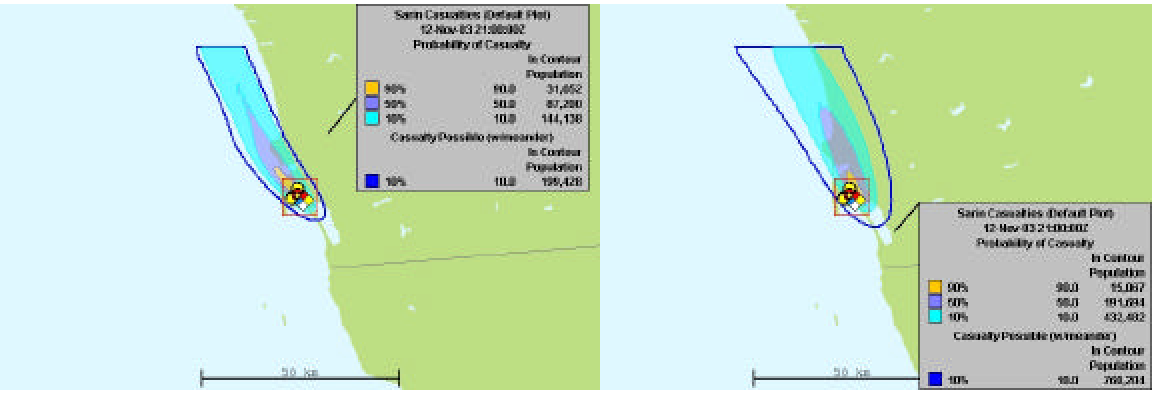
TEDServices before REA

TEDServices after REA

Figure 9. Dispersion Model Outcome – 2003111112 Model Run / 2003111117 WMD

### 2. November 12 2003, 12Z Model Run

There is low-level confluence over the CA / Mexico border at the start of the WMD time with northerly flow over Coronado. This progresses to a confluence line over Coronado as the run continues with an onshore flow and confluence line inland by the end of the WMD. When comparing the pre and post REA conditions, the REA model run was clearly more representative of the actual atmosphere. In this instance, the REA model run picked up on the onshore flow earlier than the original model run. This is seen in Figure 10. More details are given in Appendix F.

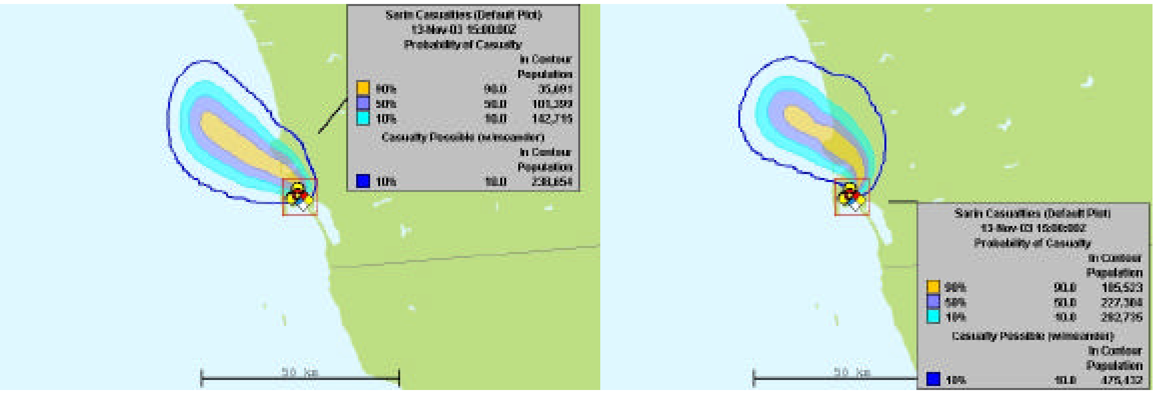


TEDServices before REA TEDServices after REA

Figure 10. Dispersion Model Outcome – 2003111212 Model Run / 2003111217 WMD

### 3. November 13 2003, 00Z Model Run

Onshore flow and a confluence ridge to the south move offshore throughout the run and create offshore flow. The REA run keeps a southerly wind longer and keeps the confluence area over land longer. When comparing the pre and post REA conditions, the REA model run was clearly more representative of the actual atmosphere. In this instance, the REA model run picked up on the onshore flow earlier than the original model run. This is seen in Figure 11. More details are given in Appendix F.

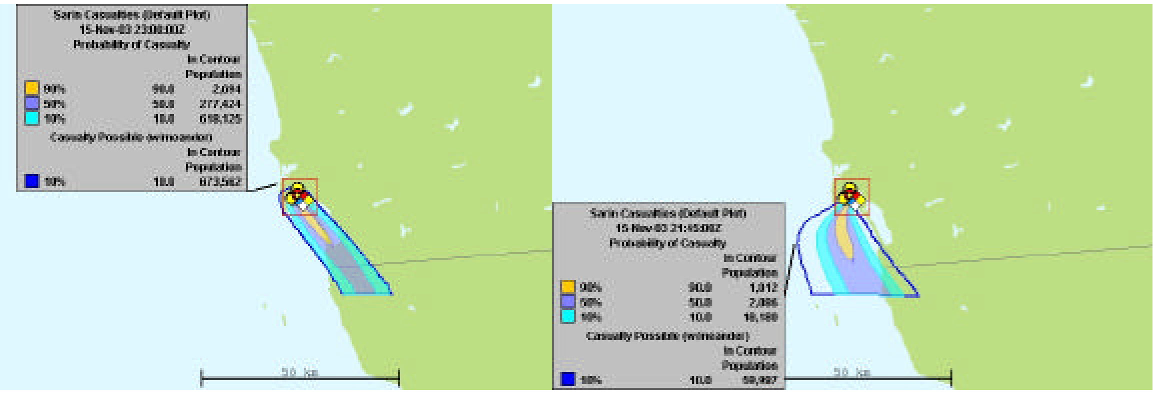


TEDServices before REA TEDServices after REA

Figure 11. Dispersion Model Outcome – 2003111300 Model Run / 2003111311 WMD

### 4. November 15 2003, 00Z Model Run

Northerly flow creates an offshore flow at WMD time that becomes an offshore flow throughout the WMD time. The REA run shows an earlier offshore flow from the north which pushes most of the contaminant offshore earlier. When comparing the pre and post REA conditions, the REA model run was slightly more representative of the actual atmosphere. This REA case actually picked up on an offshore flow that was not present in the original model run. This shows a large impact in Figure 12. More details are given in Appendix F.



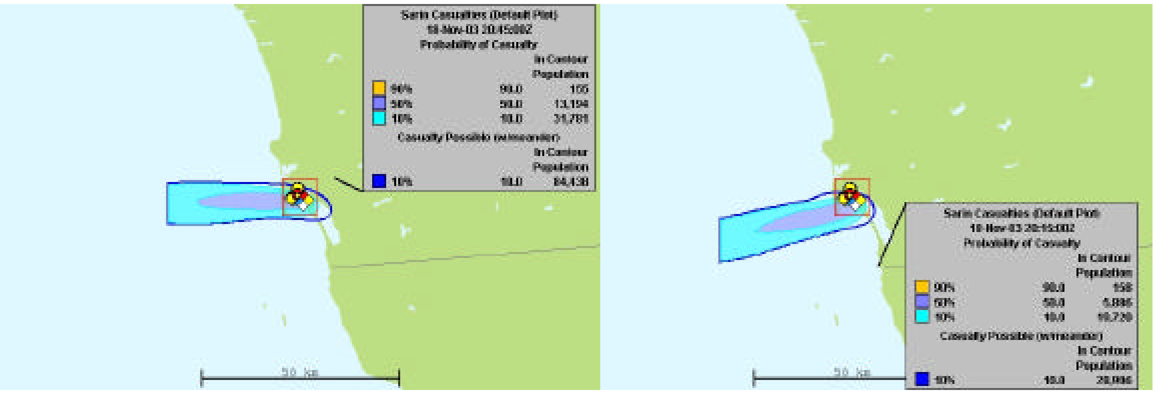
TEDServices before REA TEDServices after REA

Figure 12. Dispersion Model Outcome – 2003111500 Model Run / 2003111519 WMD

### 5. November 18 2003, 00Z Model Run

Onshore flow creates a confluence line east of Coronado at low levels with upper-level off shore flow. The REA run shows a more northerly wind moving the plume more to the south over the dispersion run. When comparing the pre and post REA conditions, the REA model run was slightly more representative of the actual atmosphere.

This REA run shows a northerly flow that was not present in the original run. This is shown in Figure 13. More details are given in Appendix F.

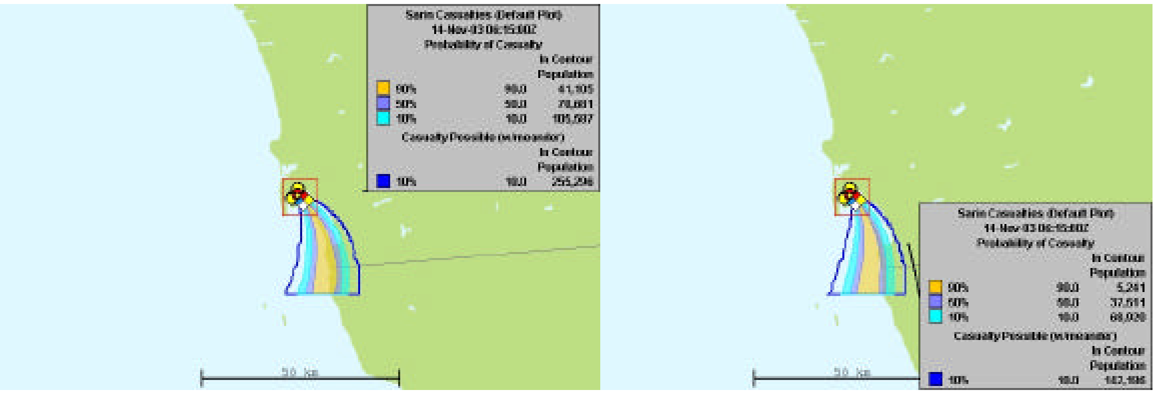


TEDServices before REA TEDServices after REA

Figure 13. Dispersion Model Outcome – 2003111800 Model Run / 20031817 WMD

### 6. November 14, 2003, 00Z Model Run

As shown in Figures 9 - 13, there is some expected variability in how much effect the REA process has on the outcome of the mesoscale model. Figure 9 shows one of the instances when there was little effect on the dispersion outcome.



TEDServices before REA TEDServices after REA

Figure 14. Dispersion Model Outcome – 2003111400 Model Run / 2003111403 WMD

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# V. CONCLUSIONS AND FURTHER RESEARCH

## A. CONCLUSIONS

The use of profiler and ship observations did have an impact on the mesoscale modeling effort using COAMPS™-OS. This implementation of REA is possible for deployed units, and would give the opportunity to incorporate many more data sources than current operational procedures allow. Although there were a number of issues attempting to get all of the software to perform correctly on the same computer system, the integration of the systems is possible to allow for a single machine to be deployed for mesoscale and dispersion modeling data.

The inclusion of profiler and ship observations did make a difference in the mesoscale and dispersion modeling forecasts. This difference was most noticeable when there was a short wave trough or cut-off low in the area of the forecast. For this thesis, the times when these phenomena were in the area, the forecasts were never negatively impacted. They were, in three of the five cases, significantly positively impacted.

As a forward deployed REA capability, TEDServices and COAMPS™-OS should be set up to allow independent operation without have to access TEDS. This is very important in the timeliness of the forecast during times when communications are limited to the deployed unit.

## B. FURTHER RESEARCH

Continued work should be done to incorporate all available data into COAMPS™-OS. Since our forces typically operate in data-deprived areas, any data that is available from local sources would be well utilized by the atmospheric and dispersion models. These data sources include: mobile upper-air soundings, non-standard surface observations, unmanned air vehicles, aircraft reports, and profilers. In order to assimilate this data as quickly as possible, COAMPS™-OS should have the option to do data assimilation at one-hour intervals. This could allow a deployed asset the ability to run the model with six-hour intervals, and always have the best available boundary conditions and observations.

Other future research initiatives should examine how well the JEM and HPAC forecasts match the atmospheric conditions. This should include a look a how dependent each of the dispersion models is on the forecast wind speeds. MEDOC format requires four decimal places, but is there noticeable depreciation in the forecast if the winds are truncated with fewer decimal places? This and future research support the development of a robust REA capability to support DOD everywhere on the globe.

# APPENDIX A – COAMPS™-OS SETTINGS

## COAMPS™-OS MODEL SETTINGS

Map Projection: Spherical
Mesh 1 Center Lat (°): 32.909 N
Mesh 1 Center Lon (°): 117.568 W
Data Assimilation Interval: 6 hours
Sigma Output: 1 hour
Nowcast: Off

| **Mesh** | **1** | **2** |
|---|---|---|
| Size | 31x31 | 31x31 |
| Spacing | 0.27° | 0.09° |
| Offset | 0x0 | 11x11 |
| Tau Times | 0-24 | 0-24 |
| Analyzed | Yes | Yes |
| Output | All parameters & heights | All parameters & heights |

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# APPENDIX B – HPAC MODEL SETTINGS

| | | |
|---|---|---|
| SITE OF WMD: | **32.7101 N** | **117.202 W** |
| Munition Type: | **500 kg Bomb** | |
| Agent: | **GB (Sarin)** | |
| Mass: | **100 kg** | |
| Release Mass: | **80 kg** | |
| Height Above Ground: | **2 m** | |
| Horizontal Uncertainty: | **0** | |
| Vertical Uncertainty: | **0** | |
| Spread: | **400m** | |
| Initial Size: | **12 m** | |
| Dissemination Efficiency: | **100%** | |
| Agent Purity: | **100%** | |
| Vapor Fraction: | **40%** | |
| Liquid Fraction: | **40%** | |
| MMD: | **500µm** | |
| Sigma D: | **2** | |
| Number: | **32** | |

**WEATHER CHARACTERISTICS**

| | |
|---|---|
| Boundary Layer Method: | **Operational** |
| Large Scale Variability Method: | **Operational** |
| Surface Moisture: | **Normal** |
| Surface Type: | **Cultivated** |
| Cloud Cover: | **Clear** |
| Precipitation: | **None** |
| Terrain | **OFF** |
| Land Cover | **OFF** |

**SIGMA LEVELS USED**

| | |
|---|---|
| 1100 | 9425 |
| 750 | 8675 |
| 500 | 7800 |
| 330 | 6800 |
| 215 | 5800 |
| 140 | 4800 |
| 90 | 3900 |
| 55 | 3100 |
| 30 | 2300 |
| 10 | 1600 |

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# APPENDIX C – DATA RUNS

Both the time of the model run and the time of the WMD are in the first column. The numbers of observations in the inner and outer nests are listed in the table below. The REA value is a subjective measurement looking at the dispersion plumes and their departure from each other. The scale ranges from 1 (completely overlapping) to 10 (not overlapping). The final column looks at the reason why the WMD time was chosen.

| DTG<br>WMD | OBSERVATIONS | | | | | | | | REA | 10 M STREAMLINE REASON |
|---|---|---|---|---|---|---|---|---|---|---|
| | Upper Air | | Sat Wind | | Surface | | Profiler | | | |
| | OUT | IN | OUT | IN | OUT | IN | OUT | IN | | |
| 11/11/03–00Z<br>11/11/03-08Z | 3 | 1 | 51 | 8 | 70 | 32 | 9 | 4 | 5 | ON/OFF SHORE FLOW |
| 11/11/03-12Z<br>11/11/03-17Z | 4 | 1 | 48 | 12 | 63 | 30 | 8 | 4 | 6 | CONFLUENCE |
| 11/12/03-00Z<br>11/12/03-17Z | 3 | 1 | 79 | 17 | 68 | 31 | 19 | 9 | 3 | DIFLUENCE TO N.W. |
| 11/12/03-12Z<br>11/12/03-17Z | 4 | 1 | 76 | 5 | 67 | 31 | 8 | 4 | 8 | CONFLUENCE TO S. |
| 11/13/03-00Z<br>11/13/03-11Z | 3 | 1 | 98 | 12 | 79 | 32 | 18 | 9 | 6 | CONFLUENCE |
| 11/13/03-12Z<br>11/13/03-20Z | 4 | 1 | 40 | 40 | 69 | 31 | 16 | 8 | 2 | DIFLUENCE |
| 11/14/03-00Z<br>11/14/03-03Z | 3 | 1 | 53 | 3 | 70 | 33 | 10 | 4 | 1 | ON/OFF SHORE FLOW |
| 11/15/03-00Z<br>11/15/03-19Z | 3 | 1 | 63 | 5 | 72 | 34 | 19 | 10 | 9 | ON/OFF SHORE FLOW |
| 11/16/03-12Z<br>11/16/03-16Z | 2 | 2 | 77 | 12 | 71 | 31 | 8 | 4 | 2 | DIFLUENCE |
| 11/17/03-00Z<br>11/17/03-03Z | 3 | 1 | 74 | 5 | 72 | 32 | 4 | 2 | 1 | CONFLUENCE TO W. |
| 11/17/03-12Z<br>11/17/03-21Z | 4 | 1 | 61 | 6 | 68 | 30 | 21 | 8 | 1 | ONSHORE FLOW |

|  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| 11/18/03-00Z<br>11/18/03-17Z | 3 | 1 | 108 | 10 | 70 | 32 | 20 | 8 | 6 | CONFLUENCE TO E. |
| 11/18/03-12Z<br>11/18/03-17Z | 0 | 0 | 14 | 14 | 10 | 2 | 27 | 10 | 1 | CONFLUENCE TO E. |
| 11/19/03-00Z<br>11/19/03-18Z | 3 | 1 | 23 | 23 | 81 | 33 | 17 | 6 | 1 | CONFLUENCE TO E. |
| 11/19/03-12Z<br>11/19/03-18Z | 3 | 1 | 50 | 4 | 70 | 30 | 19 | 8 | 1 | CONFLUENCE TO E. |
| 11/20/03-00Z<br>11/20/03-05Z | 3 | 1 | 133 | 27 | 83 | 33 | 15 | 6 | 1 | CONFLUENCE TO E. |
| 11/20/03-12Z<br>11/20/03-17Z | 3 | 1 | 75 | 11 | 68 | 31 | 25 | 10 | 3 | CONFLUENCE |

# APPENDIX D – PROBLEMS ENCOUNTERED

| Problem | Issue | Fixed? |
|---|---|---|
| COAMPS™-OS / TEDS X & Y Destagger | The grids were not being destaggered in the X or Y direction. This creates large errors in the dispersion model | Y |
| COAMPS™-OS / TEDS / HPAC Interface | The HPAC retrieval routine was pulling the wrong nest from the database, and interpolating the data down the the inner nest resolution. This creates large errors in the dispersion model. | Y |
| TEDServices / Z Destagger | The grids were not being destaggered in the Z direction correctly. The 0m sigma level was not being dropped. This creates errors in the dispersion model. | Y |
| TEDServices - COAMPS™-OS Integration | TEDServices and COAMPS™-OS both use Apache and Tomcat software, and had to be integrated | Y |
| Mobile Upper-air Observation Ingest | Mobile Upper-air profiles cannot be successfully ingest for use by COAMPS™-OS | N |
| WMO Grid IDs Needed in TEDServices | Grids need specification showing the WMO grid number. | N |
| TEDServices Grid Extraction | You need to be able to specify classification, projection, and grid spacing | N |

Table 2. Problems Encountered

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# APPENDIX E – DATA TRANSFER

TEDS and TEDServices deal with multiple data runs in different methods. TEDS keeps the original data, and the new data. The HPAC retrieval from TEDS typically returned the same data as the automated model run. Occasionally there were different values, but there is no consistency in that process. TEDServices replaces the older data with a newer data set if they cover the same geographic area and time. For this thesis, the data used in HPAC was the TEDS automated model run, TEDServices automated model run, and the TEDServices REA model run.

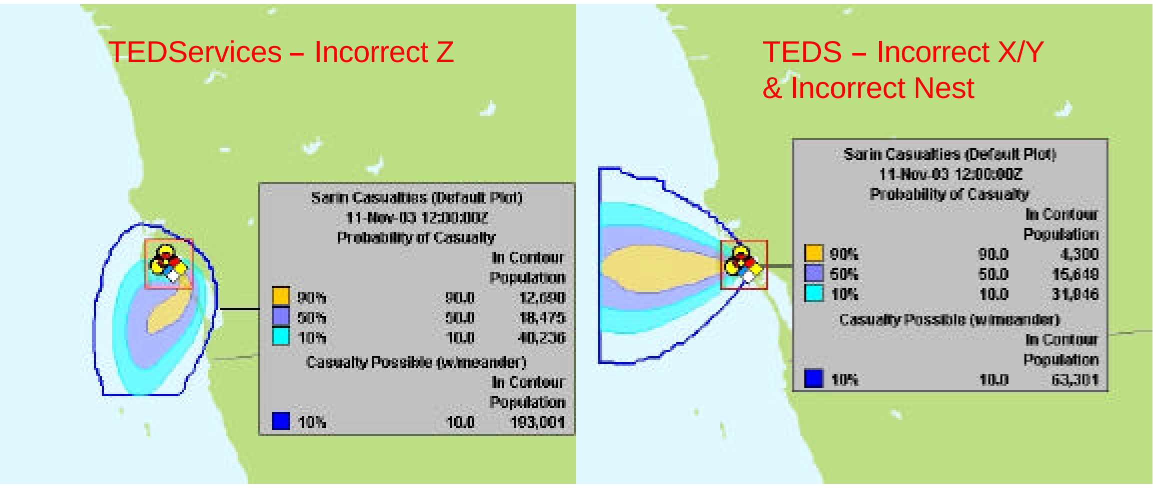
Using both databases in the WMD/WME modeling runs allows the display of how data storage and transmission can affect the final outcome of the dispersion model. Each data source was given the same geographic criteria for data retrieval, but did not return the same geographic area. The differences, as interpreted by HPAC, shown in Table 4 are created because TEDS starts at the requested point and returns interpolated values based on the requested grid spacing while TEDServices returns the closest points on the grid.

| Data Store | **North** | **South** | **East** | **West** |
|---|---|---|---|---|
| Request | 33.00°N | 32.50°N | 117.00°W | 117.50°W |
| TEDS | 32.95°N | 32.50°N | 117.05°W | 117.50°W |
| TEDServices | 33.09°N | 32.46°N | 116.67°W | 117.74°W |

Table 3. Geographic Data Coordinates

This causes the TEDServices file to be significantly larger when retrieved from the data server. The data from TEDS is approximately 1.4 MB while TEDServices is 2.5 MB. Although the TEDServices data file is much larger, it is stored on the same system as the model. This allows for much faster download times. Using the idea that an REA reaction to a WMD/WME event should take less than an hour, the data transfer time from the remote database can make the process unfeasible. After using the first average of 45 minutes for the actual REA model to run, there is only 15 minutes to run the dispersion model. This is possible with the locally run TEDServices with retrieval times at an average of less than 1.5 minutes, but might not be possible over the wide area network with TEDS and average retrieval times over 20 minutes.

Another important issue with COAMPS™-OS data deals with the fact that COAMPS™-OS has independent grids in the x, y and z directions. In order to present the data from COAMPS™-OS at a single geographic grids point, the database must receive or create the corrected values to correspond to this single location. During initial development of this thesis there were errors found in both data transmission to TEDS and storage in TEDServices. The data being stored in TEDS was not recreated in the x or y directions correctly. The TEDS retrieval routine was also pulling the incorrect nest. In this case it was pulling from the outer nest and interpolating the data down to the resolution of the smaller nest. The data being stored in TEDServices was not being recreated in the z direction correctly. Each of these errors can dramatically affect the outcome of the dispersion modeling process as shown in Figure 15. Both TEDS and TEDServices now store all data correctly.



Sarin Casualties (Default Plot)
11-Nov-03 12:00:00Z
Probability of Casualty

| | | In Contour Population |
|---|---|---|
| 🟨 90% | 90.0 | 12,090 |
| 🟪 50% | 50.0 | 18,475 |
| 🟦 10% | 10.0 | 40,236 |

Casualty Possible (w/meander)

| | | In Contour Population |
|---|---|---|
| 🟦 10% | 10.0 | 193,001 |

Sarin Casualties (Default Plot)
11-Nov-03 12:00:00Z
Probability of Casualty

| | | In Contour Population |
|---|---|---|
| 🟨 90% | 90.0 | 4,300 |
| 🟪 50% | 50.0 | 15,649 |
| 🟦 10% | 10.0 | 31,846 |

Casualty Possible (w/meander)

| | | In Contour Population |
|---|---|---|
| 🟦 10% | 10.0 | 63,301 |

Figure 15. Database Changes

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# APPENDIX F – REA EXAMPLES

To confirm the assistance or detriment of REA data, output graphics from COAMPS™-OS were compared with the Point Loma profiler data within the inner nest. Examples of each of the instances are shown here.

## A. NOVEMBER 11 2003, 12Z MODEL RUN

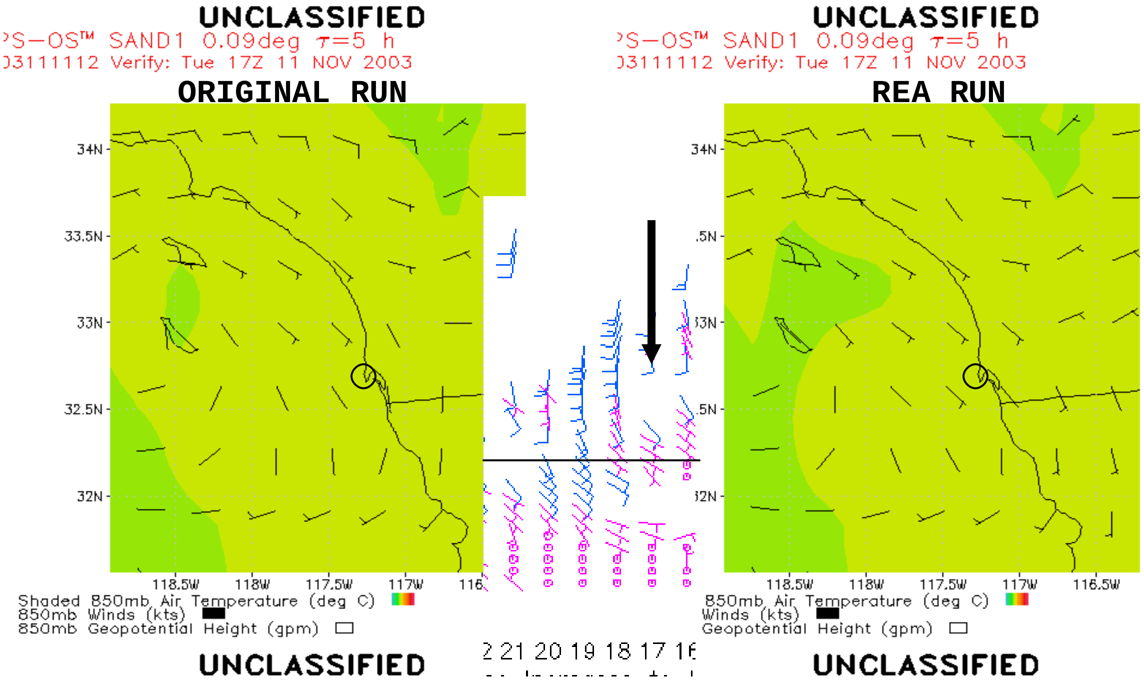

Figure 16. Model Validation : 11 Nov 2003, 17Z

## B. NOVEMBER 12 2003, 12Z MODEL RUN

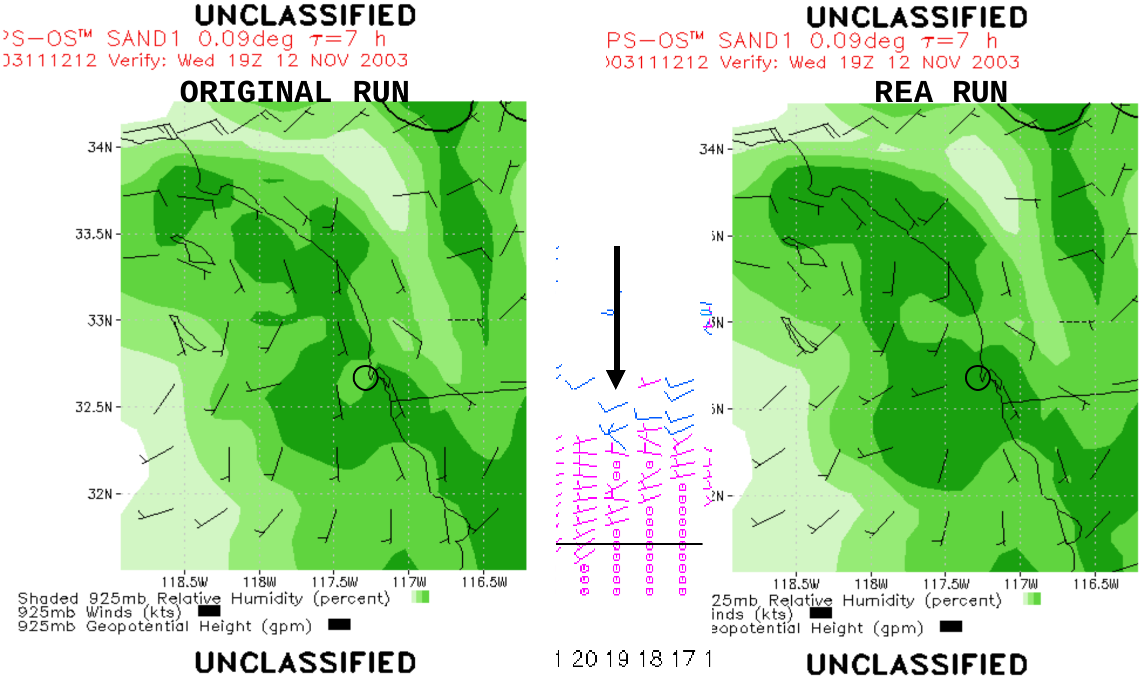

Figure 17. Model Validation : 12 Nov 2003, 19Z

## C. NOVEMBER 13 2003, 00Z MODEL RUN

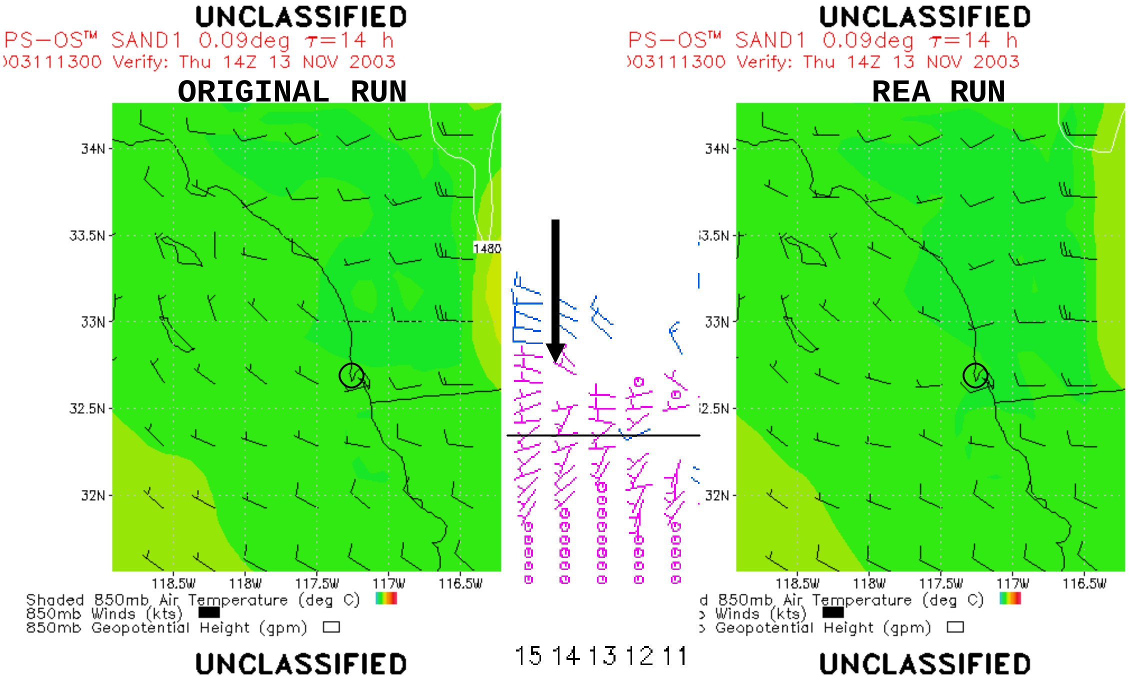

Figure 18. Model Validation : 13 Nov 2003, 14Z

## D. NOVEMBER 15 2003, 00Z MODEL RUN

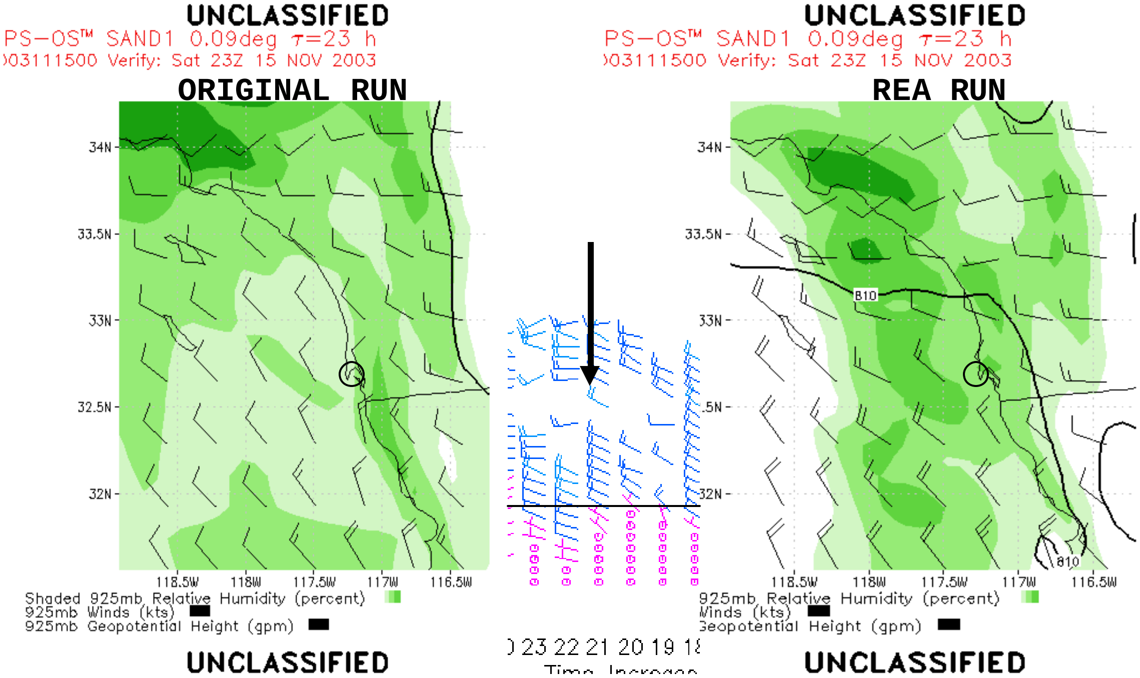

Figure 19. Model Validation : 15 Nov 2003, 23Z

## E. NOVEMBER 18 2003, 00Z MODEL RUN

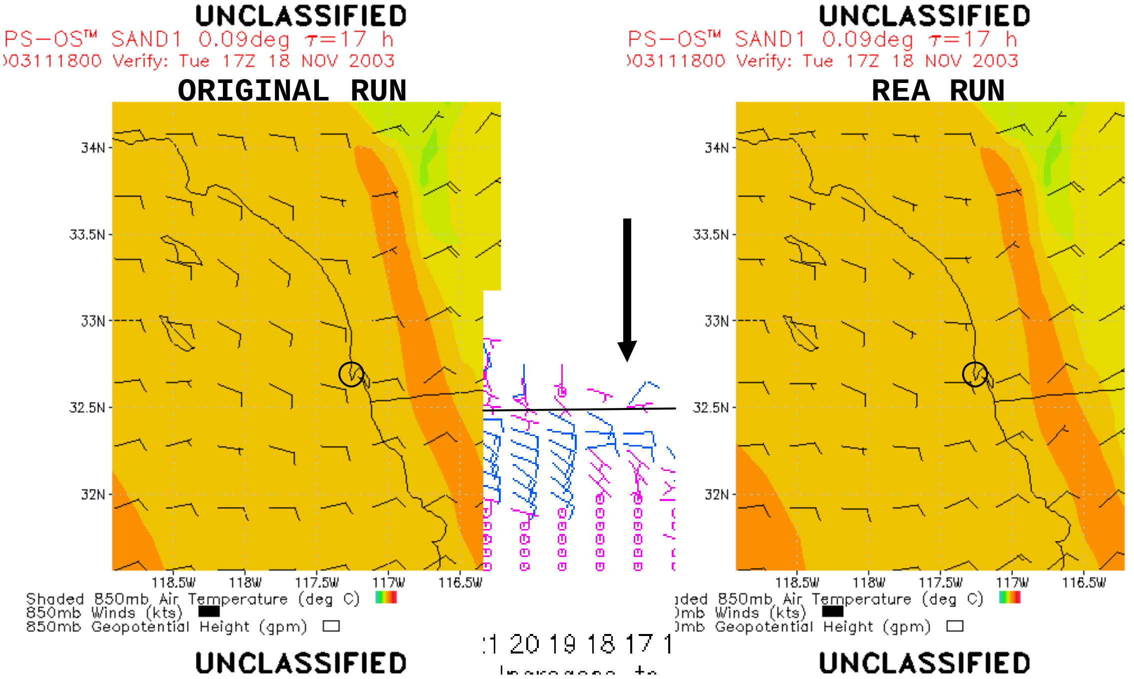

Figure 20. Model Validation : 18 Nov 2003, 17Z

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