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HIGH RESOLUTION MESOSCALE WEATHER DATA IMPROVEMENT TO SPATIAL EFFECTS FOR DOSE-RATE CONTOUR PLOT PREDICTIONS

THESIS

Christopher P. Jones, Major, USA

AFIT/GNE/ENP/07-04

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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AFIT/GNE/ENP/07-04

HIGH RESOLUTION MESOSCALE WEATHER DATA IMPROVEMENT TO SPATIAL EFFECTS FOR DOSE-RATE CONTOUR PLOT PREDICTIONS

THESIS

Presented to the Faculty

Department of Engineering Physics

Graduate School of Engineering and Management

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science (Nuclear Sciences)

Christopher P. Jones, MS

Major, USA

March 2007

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AFIT/GNE/ENP/07-04

HIGH RESOLUTION MESOSCALE WEATHER DATA IMPROVEMENT TO SPATIAL EFFECTS FOR DOSE-RATE CONTOUR PLOT PREDICTIONS

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AFIT/GNE/ENP/07-04

Abstract

Reanalysis weather data is obtained for dates surrounding historical nuclear tests and processed through Regional Atmospheric Modeling System (RAMS) software to produce a high-resolution weather forecast. Output from RAMS is visualized to check for validity and input into Hazard Prediction and Assessment Capability (HPAC) software and modeled predictions are compared to historical observation data. Simulations are conducted using constant high resolution weather and varying terrain resolution. The HPAC prediction is numerically compared to historical observation data. The result of this research culminated in the knowledge that early-time, low-altitude wind data was neglected by HPAC's incorporation of the Defense Land Fallout Interpretive Code (DELFIC) Cloud Rise Module, resulting in HPAC predictions being inaccurate for early fallout deposition.

Acknowledgements

I wish to express my gratitude to my advisor, Lt Col Fiorino, for his continued enthusiasm and guidance throughout the course of this research. I would also like to thank committee members Dr. Charles J. Bridgman and Dr. David W. Gerts for their assistance with technical issues and code debugging. In addition, Kyle Dedrick and Pat Hayes from the Defense Threat Reduction Agency, as well as CAPT Paul Adamson, USAF, were of invaluable assistance in teaching me LINUX and walking me through the set-up of the LINUX based software used in the early stages of the research. MAJ Kevin Pace’s previous research laid the groundwork for this thesis, and I am indebted to him for his clarity and depth of explanation in his thesis.

I thank my family, and especially my wife for their patience and understanding of long hours and my frustration. Without their love, faith, and encouragement, I could not have completed this process. Finally, I would like to thank God for blessing me in all ways. He is my rock and foundation in all I do.

Christopher P. Jones

Table of Contents

Page

List of Figures

Figure Page

Figure Page

Figure Page

Figure Page

List of Tables

Table Page

HIGH RESOLUTION MESOSCALE WEATHER DATA IMPROVEMENT TO SPATIAL EFFECTS FOR DOSE-RATE CONTOUR PLOT PREDICTIONS

I. Introduction

Background

During the period of 1945-1962, nuclear testing was performed at or near the earth's surface to validate weapon design or to study the effects of nuclear weapons under varying physical conditions. The result of this testing was the production of radioactive debris that contained materials that are potentially hazardous to flora, fauna, and the local population that exist both in the immediate area of the tests, and in any location where the debris could be transported by meteorological or blast effects.

The ionizing radiation that is a result of the radioactive byproducts of the weapon is termed fallout. When combined with the debris that is incorporated from the blast into the fireball, or with the saturated water in the atmosphere, the radioactive atoms can settle to the ground in a pattern determined by downwind transport mechanisms. If the blast is at or near the surface, the local fallout is material that settles out from the troposphere, and may persist for hours to a few days, depending on the yield of the weapon, height of burst, and weather patterns. Conversely, if the weapon is detonated at a high enough altitude, such that the fireball does not make contact with the surface, local fallout may be relatively insignificant, and the radioactive atoms will disperse into the stratosphere, resulting in global fallout over a period of weeks to months.

Once the fallout is deposited on the ground or objects, it continues to be a hazard for periods related to the isotope's decay timeline and sequence. High doses of penetrating whole-body radiation can result in the immediate (within hours) death of a subject, while the effect of a moderate or low dose of radiation may result in minor immediate trauma, such as burns, followed by delayed radiation effects such as late-life cancer, genetic mutations, or birth defects. In unpopulated or sparsely populated regions, fallout may still be detrimental to the environment, in that after deposition of the radioactive atoms, it may enter the food chain through various pathways, ultimately becoming a part of the human diet. This indirect ingestion of harmful radioisotopes can result in the same effects described above for moderate or low-dose irradiation due to fallout.

In an effort to protect the population and environment from the hazardous effects of fallout, software programs have been developed to model the expected pattern of fallout from a particular given yield, using prediction of future weather based on historical weather data. The use of an accurate model can supplement or preclude the time- and material- intensive radiological survey of the fallout pattern after a detonation, and give a rough estimate of what hazards may exist. This model can then be quickly made available to assist response teams in clean-up efforts, and serve as an initial damage assessment until more accurate data can be collected. One model currently in widespread use is the Hazard Prediction and Assessment Capability (HPAC) software package, produced by the Defense Threat Reduction Agency (DTRA). Being able to incorporate a Numerical Weather Prediction (NWP) model to produce extremely accurate weather data, and using this data in conjunction with HPAC's powerful modeling capability, could vastly improve the prediction accuracy.

Motivation

As the US is no longer testing nuclear weapons, and the countries that are currently testing or developing weapons are not willing to share their data, there exists no opportunity to model current test data prior to a physical test. Instead, historical data must be obtained, and the modeling process is reversed, attempting to model data that has already been experimentally collected. At the time of testing, collection of meteorological data was primitive and sparse compared to today's capabilities. As the tests will not be repeated, it is necessary to acquire reanalysis data for the weather conditions present at the time of the test. The "*Compilation of Local Fallout Data from Test Detonations 1945-1962 Extracted from DASA 1251, Volume I – Continental U.S. Tests*", subsequently referred to as DASA-EX, contains maps of fallout from historical testing, and can be used as a data source for the reverse validation process.

Presently, a low-resolution incorporation of historical meteorological data is possible, coupled with high-resolution terrain data. As the data do not match in scale, the disunity of the data sets allows for poor interpretation of the downwind fallout prediction currently performed by the HPAC software.

Scope

This research focuses on using HPAC in conjunction with nested weather prediction supplied by the Regional Atmospheric Modeling System (RAMS) to provide the most accurate historical weather data coupled with high resolution terrain data to best model historical nuclear test involving fallout. It is a continuation of research performed by MAJ Kevin D. Pace, in which he transformed reanalysis weather data into a form usable by HPAC, compared terrain resolution and weather domains to determine the most accurate, and initiated tools to automate utilities for incorporation of weather data. This work will focus solely on the ability of HPAC to model the local residual radiation pattern of a nuclear event that produced fallout in a historical test.

Problem Statement

This thesis addresses three problems. The first is to modify RAMS software to accept low-resolution reanalysis weather data and incorporate a nesting program modification that produces the most accurate high-resolution meteorological data. Secondly, this data must be formatted so that HPAC recognizes the data as a weather file, and utilizes the data in a same-scale, spatial-temporal prediction of fallout. Third is to compare the "reverse-predicted" fallout pattern to actual data contained in the DASA-EX and to determine if the high resolution terrain and weather data significantly improves the prediction capabilities of the HPAC software.

It is my objective to increase the resolution capability of the weather data supplied to HPAC by nesting weather-prediction models within the area of interest in order to obtain a better representation of actual local fallout data collection.

Approach

Previous researchers Chancellor and Pace both compared six tests in their research, and for continuity sake I will focus on the same six tests that were in their data set. The data used was compiled from the DASA-EX, which contains test data such as weapon yield, height of burst, test location, and dose-rate contour plots from the fallout. Using the two-step method of digitizing the contour data from the DASA-EX, it can be compared to the HPAC output with numerical algorithms. There are two utilizable parameters produced using these algorithms; first, a Cartesian coordinate designated as the Measure of Effectiveness (MOE), and second, a Normalized Absolute Difference (NAD) [9].

HPAC predictions are based on weather and terrain temporal and spatial data. The DASA-EX weather data consists of a single balloon sounding, and may be supplemented by additional weather data from the Air Force Combat Climatology Center (AFCC), consisting of soundings from numerous locations and times in the vicinity of the test detonations. Though this data is valuable, gaps in time and space exist, and the data must be interpolated by the software, resulting in error propagation. Reanalysis data from the AFCC is a modern weather analysis based on historical weather observation, and has been filtered for the types of error explained above by gridding the data, eliminating the need for interpolation. Pace used weather data produced by this method in his thesis, and concluded, in short, that because of the resolution capabilities of the HPAC software, inclusion of medium-resolution terrain data in conjunction with the medium-resolution weather data produced the best model for historical fallout data.

For this research, reanalysis weather data from the AFCC will be used as an input to the RAMS software to generate a mesoscale model of the weather at the time of the test, and then a nesting technique will be used to faithfully reproduce the high-resolution (10km) actual weather data at the test location. This weather data will then be saved as a weather file in a format that HPAC can utilize in conjunction with high-resolution (10km, near same scale) terrain data. The research will culminate in a comparison of which meteorological input to HPAC produces the best model of historical fallout data, and the possible reasons why.

Document Structure

Chapter two describes the physical process of fallout production and dispersion, as well as how the multiple programs used throughout this research interpret, manipulate, and model the variables involved in fallout transport. A brief summary of previous research in this area is included at the end of the chapter. Chapter three describes the methodology used in a chronological format, from obtaining initial reanalysis weather data to comparison of HPAC output to DASA-EX data. Chapter four contains the results and analysis of the weather data, HPAC data, and DASA-EX comparison, with a separate section for each of the six tests. Chapter five summarizes results and identifies trends found in the analysis. It contains conclusions and possible directions for future research in this subject area. The appendices contain data necessary for reproduction of this research and further detail on subjects identified in the text of the document.

II. Literature Review

Fallout Production and Dispersion

All nuclear explosions produce fallout, and a "clean" nuclear bomb does not exist. The major factors that affect the pattern and dispersion of fallout include the weapon yield, height of burst (HOB), topography and soil properties (if at or near surface), and weather. Fallout production and transport have been studied in depth since the first nuclear tests, and the following paragraphs provide a short summary of the current widely-accepted knowledge of the subject.

When there is a nuclear explosion, the fission weapon residue reaches a maximum temperature in the several tens of millions of degrees, and all of the materials are converted into gaseous form. [5:27] The fireball is much hotter than the surrounding ambient air, and therefore is buoyant, and rises like a hot-air balloon, with the weapon material, including the weapon casing, radioactive fission products, and nuclear material (either uranium or plutonium) in the form of a vapor. The cloud expands as it rises, and is cooled by radiation and convection, causing the vapor and incorporated water droplets to condense into a cloud containing solid particles of the weapon debris. If the HOB is sufficiently high, there will be no local fallout, and all of the radioactive debris will be deposited in the form of global fallout. The height above which no local fallout is expected is approximated as

$$H \approx 180W^{0.4}, \qquad (1)$$

with H being equal to the height below which there will be significant local fallout. [5: 64] If the detonation occurs below the fallout-free HOB the fireball reaches the surface and causes soil and other materials present to vaporize. Local fallout, defined as that fallout that can be expected within 24 hours of the burst, has a HOB at or below the value of H. Additionally, any yields less than about 100 kT stay in the troposphere and do not ever produce global fallout.

Global fallout can occur if the HOB is above the tropopause, and incorporates very little or no debris from the earth's surface. The radioactive material consists of the weapon residue and fission fragments, and unless it is rained out, will disperse in the stratosphere and be deposited over periods from weeks to years. The fallout that poses the most immediate threat to the indigenous population is termed local fallout, and is expected to reach the ground in 24 hours or less. The research in this paper is based on patterns gleaned from local fallout.

Most of the useful data in the DASA-EX is based on fallout that is a result of surface or near surface bursts. It is approximated that 0.3 tons of mass per ton of yield are lofted in the case of megaton surface bursts [2:2]. This occurs as a result of phenomena termed "afterwinds", which is a strong updraft with inflowing winds, caused by the rapid ascent of the fireball. The toroidal circulations of the hot gases within the cloud produces an updraft through the center of the toroid, and the mass that has been sucked up into the cloud in early times can itself become vaporized or molten due to the intense heat. The material is in intimate contact with the vaporized fission products, and when the vaporized fission products condense on the foreign matter, it creates highly radioactive particles.

The cloud continues to rise and cool, reaching a stabilized height where it is in buoyant equilibrium with the ambient surrounding air within minutes after burst. The toroidal circulation of gases in the cloud may continue for up to a few hours following the burst, increasing the contact between the radioactive fission fragments and non-radioactive dust particles.

Fallout modeling can be most conveniently separated into three distinct processes, occurring in the sequence of cloud rise and dust formation, dust settling and transport, and calculation of doses on the ground and still retained in the cloud as a result of the dust. At this juncture, it is important to differentiate between the terms “fallout” and “dust”, both of which fall into the category of the debris mentioned above. Fallout is a reference to radiation that occurs as a result of radioactive fission products and neutron activation, whereas dust is a term used to describe the lofting of soil and other debris by the physics of the detonation. [2:1].

The ultimate height achieved by the cloud depends upon weapon yield and atmospheric conditions. The greater the amount of heat generated, the greater the buoyancy of the cloud, and therefore the greater the maximum height of the cloud. Assuming the cloud reaches the tropopause, most of the upward motion of the cloud is distributed laterally due to the boundary conditions caused by the difference in the unstable air of the troposphere and the relatively stable air in the stratosphere. The final dimensions of the stabilized cloud depend heavily on the meteorological conditions, which are variable with time and space, and by proxy, the fallout pattern.

At first the buoyancy of the cloud and afterwinds cause the radioactive fission products, weapon residue and entrained debris to rise. When sufficient cooling has occurred, condensation of vaporized fission products occurs and a conglomeration of earth, debris and radioactive material is formed. Though some of the particles formed contain a volumetric distribution of radioactive fission products and other weapon residue, more often the contamination is found as a thin shell near the surface of the particle. Gravity and wind then act upon the particles, and causes them to fall to the earth's surface at rates dependant upon their size. The energy yield and design of the weapon, the topography and surface roughness of the terrain, the height of burst, and the meteorological conditions all contribute to the extent and nature of the fallout, and can vary over wide extremes.

As the radioactive particles are deposited on the earth's surface, they continue to decay until they reach a stable product. The main biological damage mechanism is the ionizing radiation caused by radioactive decay. Dose-rate is the rate at which radioactivity is absorbed over a given period of time. As stated above, the activity of the particle may be deposited volumetrically, termed refractory, or deposited as a thin shell on the outside of the particle, termed volatile, depending upon the parent isotope and time after burst that temperatures reach a level that allows the isotope to condense. The separation of volume and surface distributed activity is known as fractionation. Fractionation affects the amount of radiation generated by individual fallout particles, which, in turn, affects measured dose rates. The dose-rate is recorded in the DASA-EX, and will be the comparative value used throughout this research.

DASA-EX

The DASA-EX is a compilation of chronologically organized test data collected from nuclear tests conducted in the Continental United States (CONUS) prior to 1963. The stated purpose for the publication is, "to provide a ready reference of fallout patterns and related test data for those engaged in the analysis of fallout effects" in an unclassified format. The document includes data on dates, times, and locations of each test, as well as the ambient wind speed and direction as a function of altitude. Each test has a dedicated data sheet that describes the type of burst (below ground, air burst, tower shot, etc.), HOB, crater depth, cloud top height and bottom height, and then wind tables for heights up to at least the height of the detectable nuclear cloud, taken "for times as close to shot time as possible and for several times after shot." The data as presented was adjusted and normalized to an H+1 standard reference time using the $t^{-1.2}$ "law" developed by Way-Wigner. The off-site graphs, which provided larger-distance data, were used for this research. Below is a table of the tests pertinent to this thesis.

Table 1. Selected test data

OPERATION: **Test**	Date and Time (ZULU)	Location (DD.MM.SS) LAT	LON	Yield [kT]	HOB [ft]
Tumbler Snapper: **George**	01 JUN 1952 1155	37.02.53	116.01.16	15	300
Teapot: **Ess**	23 MAR 1955 2030	37.10.06	116.02.38	1	-67
Teapot: **Zucchini**	15 MAY 1955 1200	37.05.41	116.01.26	28	500
Plumbbob: **Priscilla**	24 JUN 1957 1330	36.47.53	115.55.44	37	700
Plumbbob: **Smoky**	31 AUG 1957 1230	37.11.14	116.04.04	44	700
Sunbeam: **Johnie Boy**	11 JUL 1962 1645	37.07.21	116.19.59	0.5	-2

HPAC

HPAC is a counter-proliferation, counter force tool that predicts and models the effects of hazardous material releases into the atmosphere, and the consequent effects on the environment and population. Through the GUI, the user may define the source of the hazard from pre-defined choices in the program; the incident definition considered for this research is the nuclear weapon single event. This definition allows the user to select weapon yield, HOB, and fission fraction, which is the amount of yield produced by fission, not fusion. It is important to note that HPAC uses only ^{238}U as the fissile material, though some of the CONUS tests may have contained other fissile material.

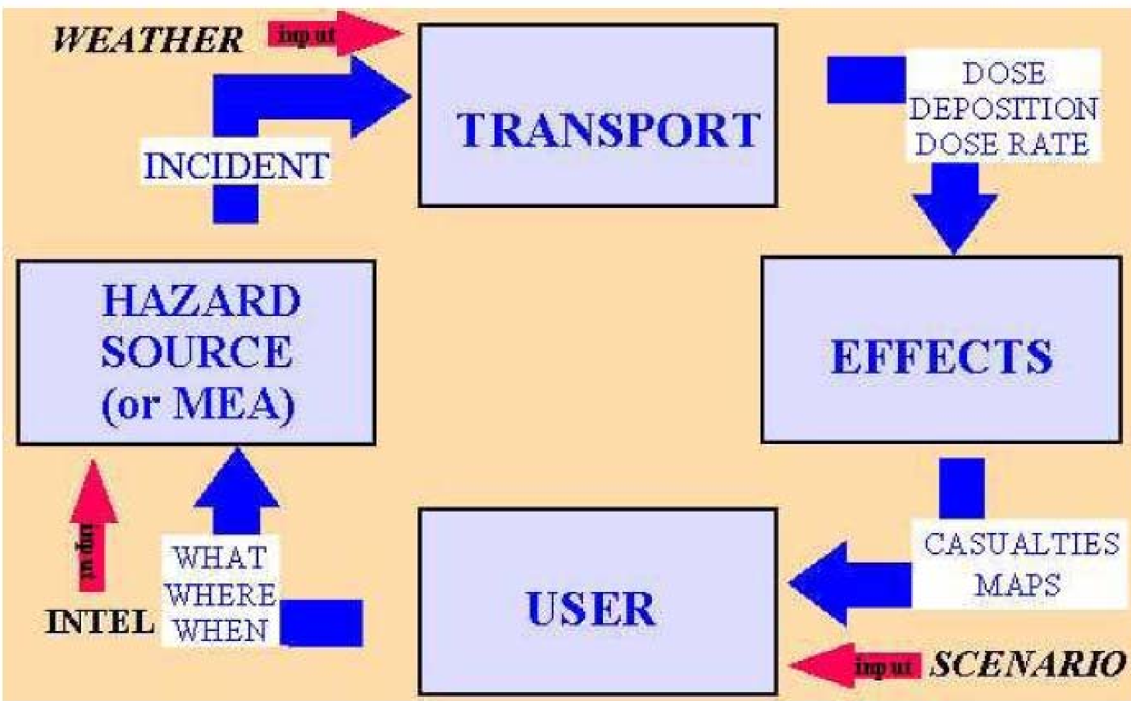


Figure 1. Brief overview of how HPAC prediction functions

HPAC then uses internal algorithms to model a stabilized nuclear cloud, defining fractionation, particle-size distribution, activity, height, and dimensions. The cloud information is passed to the atmospheric transport algorithm, which models weather and terrain effect on downwind transport and surface deposition. The user is then allowed to select the format of output, to include integrated dose, dose rate, populated areas affected, and hazardous effects on populations. The results are displayed on contour maps which can be overlaid on high-resolution terrain or urban maps.

Hazard Definition

HPAC integrates portions of the Defense Land Fallout Interpretive Code (DELFIC) to model cloud rise using observed atmospheric data and a one-dimensional integration scheme, predicting the height of cloud at stabilization. In the absence of DELFIC, cloud height is based on a parameter fit to nuclear test data [16:507]. It is imperative that the particle-size distribution and activity distribution be accurately defined for correct modeling of fallout. Even a slight variation in particle-size distribution within the cloud as a function of height can result in a considerable effect on the recorded pattern due to wind shear. The mode of activity released is also proportional to whether the activity is surface or volumetrically distributed, and can create disparity between what activity is predicted, and what is actually recorded. About 70% of the activity is estimated to be distributed volumetrically in a surface burst, with the remainder surface distributed. Incremental changes in this ratio have been shown to markedly change the activity readings within fallout areas. [3:405]

Research into the DELFIC cloud rise module resulted in uncovering a possible area of disparity between what would be expected in a cloud rise model, and what is actually incorporated. The HPAC manual states, "The Delfic cloud rise model uses observed atmospheric data and a one-dimensional integration scheme to predict the cloud height at stabilization time." [8:424] Reviewing the DELFIC user manual, it was found that, "Multiple wind profiles which may be used later for atmospheric transport… are not used here; single wind profile is input especially for the cloud rise calculation." This information, coupled with the initial description of the code suggests to this researcher that little particle transport is accounted for during the initial cloud rise, most likely at the stabilized height for shear between the cloud top and bottom. This appears to be confirmed in the description statement, "Calculation begins at about the time the fireball reaches pressure equilibrium with the atmosphere."[16:7] which is described by Bridgman as the time of cloud stabilization [3:403]. The DELFIC manual further states, "Rise, growth and stabilization of the nuclear cloud is computed by a dynamic model that treats the cloud as an entraining bubble of hot air loaded with water and contaminated ground material…. After cloud stabilization, representative parcels of fallout are transported through an atmosphere that is defined by input data. The user may specify a single vertical wind profile and assume a steady state." [16:7]. This information indicates that once the cloud reaches stabilization, the parcels used in the transportation portion of the code are subject to the input weather fields, but prior to this, a single wind profile is used for any fallout calculations. With extremely precise weather data at levels from 1000mb to 100mb input into HPAC, the use of a single wind designation could significantly skew the fallout data calculations for early times, especially during cloud rise.

Weather

Weather is the single most important definable parameter for an accurate fallout prediction. It can be defined in HPAC using a single wind observation, climatological averages, external server weather forecasts, or by the intrinsic HPAC weather editor. The more accurate the weather data, the more likely it is that the prediction of the hazardous footprint will be correct, and below are some of the advantages and disadvantages of using each of the weather definitions.

A single wind observation is the easiest and fastest to use, as the user only inputs the predominant wind speed and direction, and allows the software to produce a fallout pattern from the data. The result of this model is a linear pattern of fallout, with slightly scalloped edges, showing a Gaussian deposition. Horizontal wind shear and down range wind variation is not accounted for. Though this method may be useful for a quick decision-making plot by military and civil authorities, it is at best a short-term solution until a better analysis can be produced.

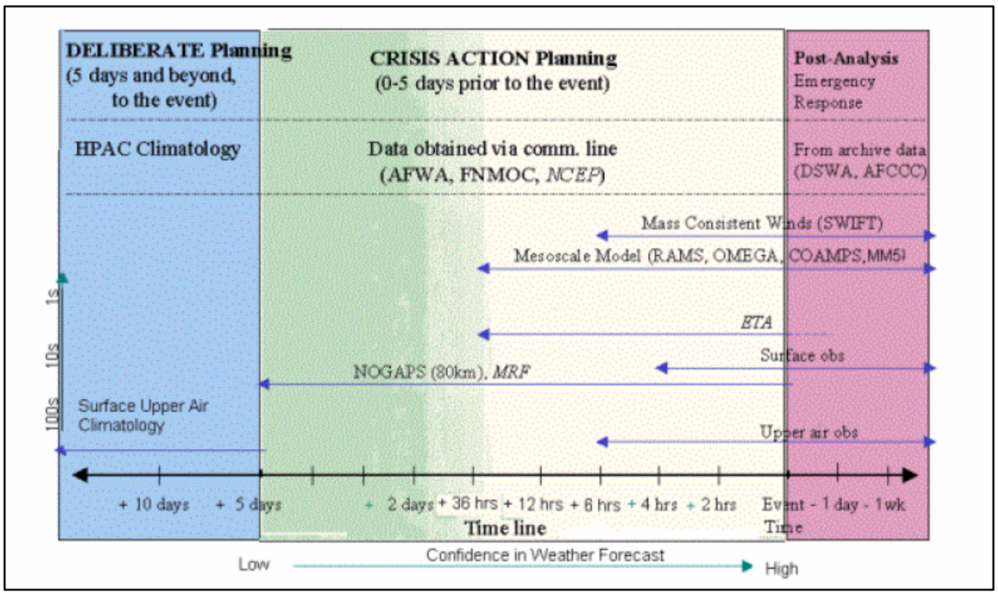


Figure 2. Various weather model input timelines

Climatological averages are based on data collected over months and years, and do not represent current conditions or variations between morning and evening observations. It is an average weather for the area, and will not capture the mesoscale or microscale conditions found in the immediate area of the test. The results of a prediction using this data is useful for planning purposes, but most likely will not reflect the pattern produced by the test.

External server weather data are available only for the previous 30 days and therefore do not contain data for the tests conducted over 40 years ago. A researcher could conceivably attempt to find a current pattern that mirrors the conditions at one of the historical tests, but is not likely to find an exact match, precluding a direct comparison of fallout patterns.

The intrinsic HPAC weather editor allows the user to define weather conditions for HPAC. It is the objective of this research to provide the most accurate weather data possible to HPAC, and determine if the improvement in weather data translates to a comparable improvement in fallout prediction based on comparison with historical fallout data. This will be accomplished by nesting NWP models in the RAMS software to create, as accurately as possible, the weather conditions found at the test site on the date and time of test.

Terrain

HPAC terrain data is available though external software read and compiled by the HPAC software. Resolution ranges from hundreds of points per square mile down to a few points per square mile, depending on the area of interest. The data for the Nevada Test Site (NTS) has a resolution of 9 to 10 points per square mile, though some of the spatial domains in this research cover other portions of the CONUS. It is the objective of this research to match the resolution of the weather data to the resolution of the terrain data to create a best-fit for accurately modeling historic fallout pattern data.

Reanalysis Weather Data

As previously outlined, the weather data that is available from the 1950s and early 1960s is sparse and incomplete, compared to today's capabilities. A program was launched by the National Centers for Environmental Prediction (NCEP) in 1991 for the purpose of reconstructing weather dating back to 1 January 1948 in order to study changes in global climate and accurately model historical weather patterns. The data produced by the reanalysis project for the time of interest, 1952-1962, stems mainly from rawinsonde data, and has been compiled and formatted in a database, used as the raw input for the reanalysis project.

The reanalysis system is separated into three distinct modules, each of which performs a specific task in producing accurate output. The first module will analyze the raw input and identify any data errors and anomalies by comparing spatial and temporal observations collected for continuity. If a disparity is detected, the system's preprocessing capability can use optimal interpolation (OI) or statistical analysis to determine the most likely cause of the error and derive the best probable solution. Removing the detected discontinuities allows the analysis module to perform its function without the algorithm failing or producing non-physical results. [15:438]

The assimilation module parameterizes all of the major physical weather processes such as gravity wave drag, convection, large-scale precipitation, boundary layer physics, radiation with diurnal cycle and interaction with clouds, shallow convection, an interactive surface hydrology, and horizontal and vertical diffusion processes. It uses the NCEP's 210 km horizontal resolution global spectral model, termed T62, in the module to perform an iterative process that compares the final reanalysis data to the raw input data, using spatial and temporal interpolation to ensure agreement between the two.

The archive module outputs the reanalysis data as a four-dimensional field of weather data, formatted in several different ways depending on the projected use by researchers. Previous studies have found that the output with a temporal resolution of six hours and a spatial resolution of evenly spaced latitudinal and longitudinal points provides the best input for HPAC [6:14]. A global grid of 73 x 144 points of reanalysis weather data, which will contain temperature, height, relative humidity, and wind direction and speed at 17 pressure levels ranging from 1000 (sea level in standard atmosphere) to 10 mb (60 km altitude in standard atmosphere), will be used as an input to RAMS software for nesting. For continuity, this research will use the same data format, which will be paramount to feeding the RAMS software the same data for analysis on improved HPAC prediction capability.

HPAC Transport

HPAC uses an integrated mass-consistent wind model to transport the plumes produced by the hazard source. There are two available models incorporated in the HPAC software, the Stationary Wind Fit and Turbulence (SWIFT) and the Mass-Consistent Second-order Closure Integrated PUFF (MC-SCIPUFF). Both models use the interpolated weather data to create a gridded three-dimensional wind field that satisfies mass-continuity, and ensure that the wind flows around or over the terrain and obstacles defined by the HPAC terrain software. SWIFT is the default model used by HPAC, but is limited to a projected domain with meridional or latitudinal axis of 1000 km or less, and can only be used when locations are entered in via Cartesian coordinates. As the area of interest is contained within an axis of this size, the default SWIFT will be used throughout this research.

HPAC Effects

HPAC has the capability to display effects in several formats, ranging from integrated dose to tabulated population hazard, to color-coded contour plots over urban maps. The DASA-EX lists dose-rate contours for threshold levels, normalized to one hour after detonation. HPAC has the capability of displaying an exact dose-rate at any known grid reference, but can be adjusted to display the effects in the same format, which allows for a direct comparison of output and historical data. As this research focuses on comparing HPAC output to the DASA-EX data, the areas enclosed by each contour will be directly correlated using a method described in a later section of this work.

RAMS

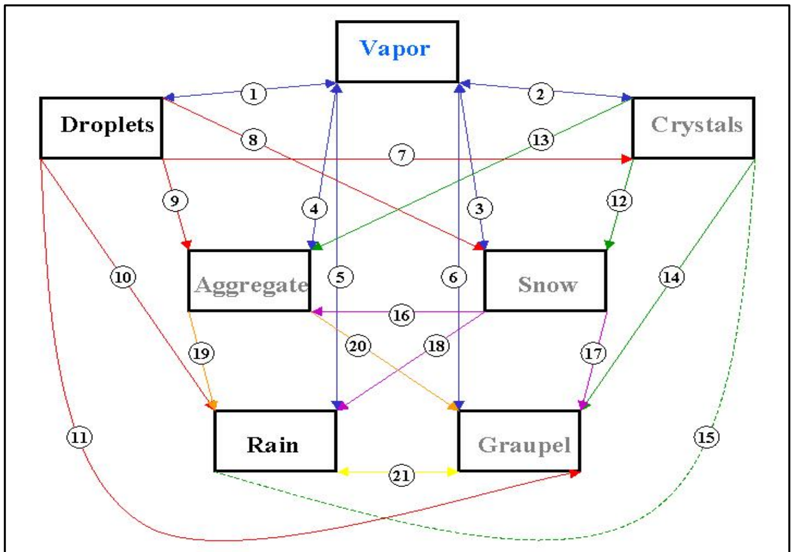
Capabilities

RAMS is a multipurpose, numerical prediction model designed to simulate atmospheric circulations spanning in scale from the hemisphere down to large eddy simulations (LES) of the planetary boundary layer. Most frequently, it is applied to simulate mesoscale (horizontal scales from 2 km to 2000 km) atmospheric phenomena for such varied purposes as operational weather forecasting to air quality regulatory applications. [10:4]

Because of the options available in RAMS, it can be used in various applications. It is designed so that the code contains a variety of structures and features ranging from hydrostatic to non-hydrostatic codes, resolution ranging from less than a meter to the order of a hundred kilometers, domains from a few kilometers to an entire hemisphere, and a variety of physical options. The equation set most used by RAMS is the quasi-Boussinesq non-hydrostatic equations described by Tripoli and Cotton (1982). There are prognostic equations for all state variables including u, v, w, potential temperature, mixing ratio and scaled pressure in the primitive dynamical equations. This allows for an easy selection of the appropriate options for a different spatial scale or different locations. RAMS does not use physical or numerical routines that are global. Pressure, for example, is solved locally either using the hydrostatic approximation or non-hydrostatically using a time-split compressible approximation. Advection is calculated using local finite difference operators rather than using non-local spectral methods. [10:7]

The major components of RAMS are: a data analysis package that accepts observed meteorological data and processes it for the atmospheric model, an atmospheric model which performs the required simulations, and a post-processing model which formats the analyzed data and interfaces the output for visualization and analysis. The atmospheric model is built upon the primitive dynamical equations that dictate atmospheric motion, and supplements the primitive equations with optional parameterizations for solar and terrestrial radiation, turbulent diffusion, cumulus convection, and sensible latent heat exchange between the atmosphere and terrestrial surface, incorporated in a Land Ecosystem-Atmosphere Feedback model (LEAF), to adjust for the underlying terrain.

The microphysics package (MP) is a bulk-type module that incorporates selectable parameters for moist processes that account for compensation among various categories of precipitating liquid, shown in Figure 3.



1. V to D: Condensation D to V: Evaporation 2. V to C: Deposition C to V: Sublimation 3. V to S: Deposition S to V: Melting-Evap 4. V to A: Deposition A to V: Melting-Evap 5. V to R: Condensation R to V: Evaporation 6. V to G: Deposition G to V: Melting-Evap	7. D to C: Riming C to D: Ignored 8. D to S: Riming S to D: N/A 9. D to A: Riming A to D: N/A 10. D to R: Autocon/Coll R to D: Ignored 11. D to G: Riming G to D: N/A	12. C to S: Collection S to C: N/A 13. C to A: Autocon/Coll A to C: N/A 14. C to G: Collection G to C: N/A 15. C to R: N/A R to C: N/A	16. S to A: Autocon/Coll A to S: N/A 17. S to G: Coll/Rime G to S: N/A 18. S to R: Melting R to S: N/A 19. A to R: Melting R to A: N/A 20. A to G: Coll/Rime G to A: N/A 21. R to G: Rime/Freeze G to R: Melt/Shed

Figure 3. Compensation diagram of processes used in RAMS

It can be called from any dynamics model, and the dynamic module's variables can be passed to the MP. The MP module calculates the total concentration and mixing ratio tendencies for all the categories of hydrometeors, and then passes this information back to the dynamics module for processing in the overall output.

The weather prediction is performed by algebraically combining energy and water conservation equations, which are formulated in implicit numerical form for all hydrometeor categories and air. The combination results in a single predictive equation for future vapor mixing ratio of air, and after applying diffusive heat and water transfer, all of the terms on the right hand side of the equations are known and may be evaluated explicitly. This removes the necessity to iterate to solve the hydrometeor compensation values, and makes the algorithm much more efficient and stable over long time steps. [14:2]

Nesting Boundary Conditions in RAMS

The RAMS software is capable of nesting multiple grids within each other, starting with a coarse-scale grid where the time dependant model solution is first updated. Tri-quadratic spatial interpolation is performed, and the resultant values are passed on to the spatial boundaries of the next finer grid. The nested, finer-grid model then uses the values to solve the model equations for a smaller scale, and then pass this information back to the coarser grid to simultaneously update the coarse-grid values for the same temporal domain.

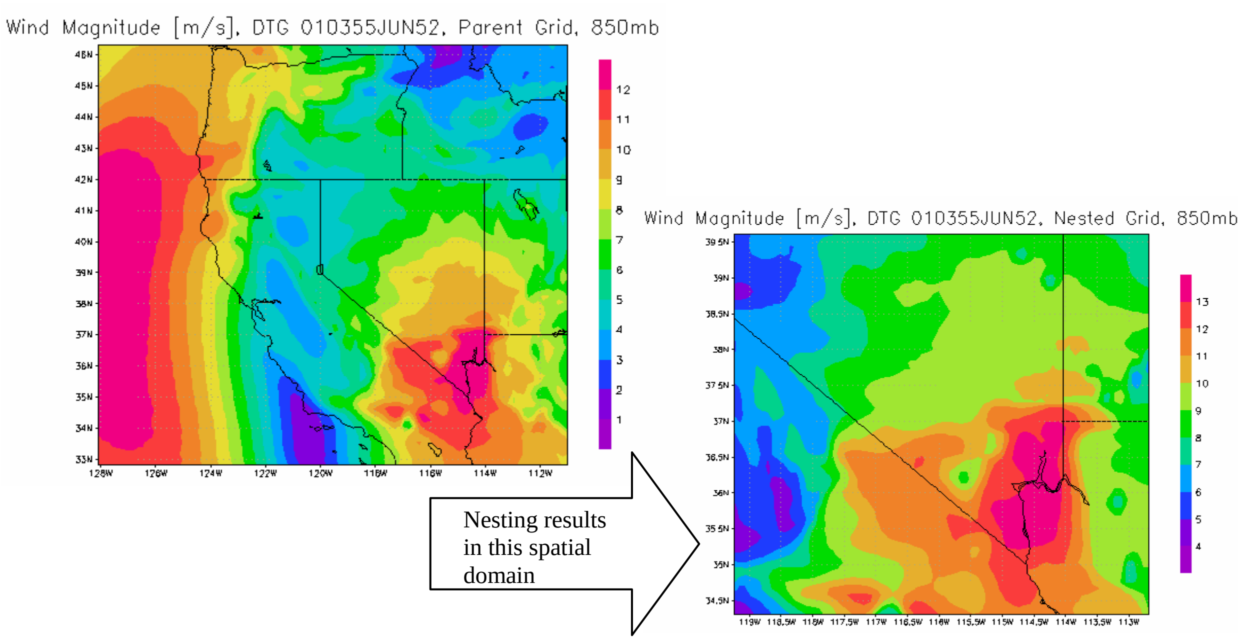


Figure 4. Example of nesting in RAMS

The coarser meshes are used to model the environment encapsulating the finer meshes, providing updated boundary conditions to the fine mesh region, and simulating larger scale atmospheric systems which interact with the mesoscale systems resolved on the finer grids. Each finer level of gridding provides a weather model for a smaller spatial domain, with the highest resolution meshes used to model the details of smaller-scale atmospheric systems, such as flow over complex terrain and surface-induced thermal circulations. The code has been written such that the interpolation and averaging cycles are reversible, and that mass and momentum are conserved at the grid interfaces, providing seamless data and avoiding anomalies along boundaries between meshes. [10:8]

Comparison of Output

Measure of Effectiveness

Comparison of observation data (AOB), predicted data (APR), and the overlap between the two is conducted using Warner and Platt's Measure of Effectiveness (MOE) method. [12:59]. In this research, it was deemed fundamental to capture the area of overlap (AOP), but also be able to identify where the HPAC software over predicted and under predicted dose rates based on the RAMS input. The area where there was an observed dose-rate, yet HPAC failed to predict any deposition is known as the area of false negative (AFN). Conversely, the area where HPAC predicted a dose-rate, yet none was observed, is termed the area of false positive (AFP). Figure 5 shows graphically the areal divisions for MOE comparison.

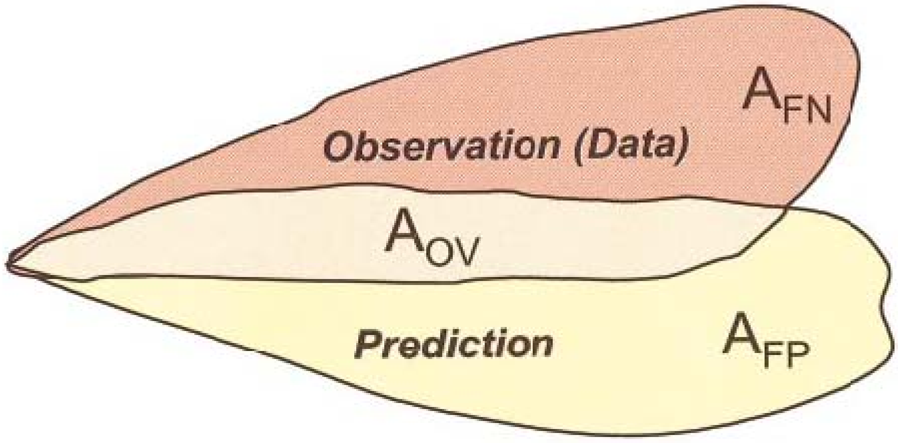


Figure 5. Areal divisions for MOE comparison

The areas are mutually exclusive; for example, you can not have an area that overlaps and is also an area of false negative. For areas of overlap, the observed and predicted values must have at least one point of commonality. As the area of release is exactly known, the first point of commonality in all of the compared data is the test site location (ground zero). As the relative direction of the wind was also known based on the balloon soundings, a second point of commonality is the relative downwind direction. Both of these points will be used as reference identities, and given a model without any error, the AOV will be of identical shape and location, that is

$$AOV = APR = AOB \qquad (2)$$

Without pinning the release point at ground zero for APR and AOB, the plumes could be of identical shape, but have no overlap as shown in Figure 6.

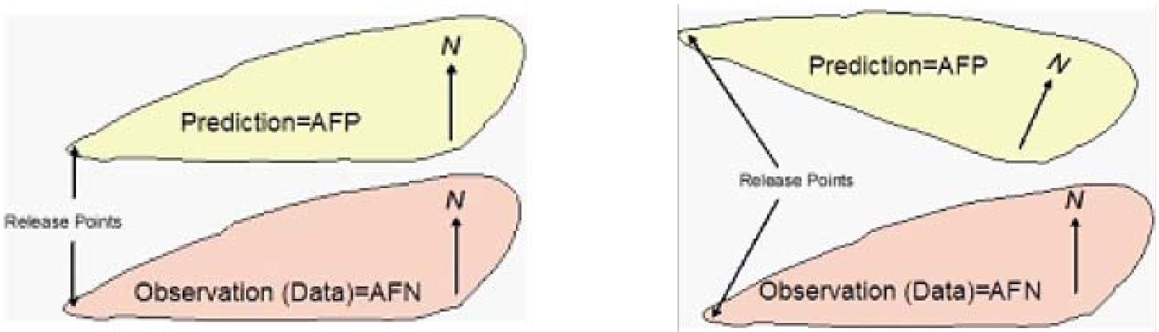


Figure 6. Same shape, no overlap plumes

If the reference direction was unknown, or improperly input, the plumes could have the same size and shape, yet have little or no overlap, as shown in Figure 7.

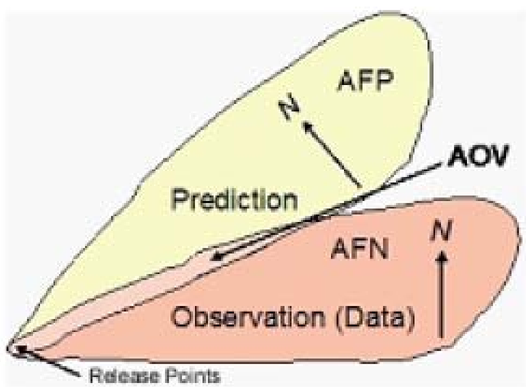


Figure 7. Little overlap due to directionality disparity

The desired result is that found in equation 2, where there is perfect overlap between observed and predicted data, shown in Figure 8.

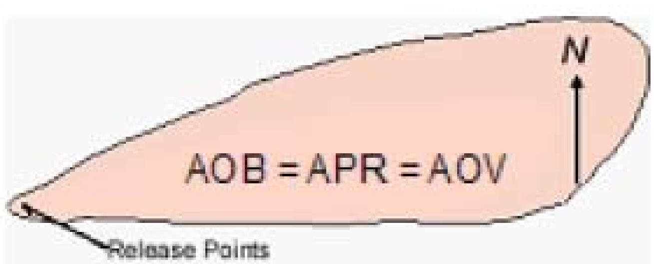


Figure 8. Perfect overlap

When AOB and APR are correctly aligned, they can be numerically compared using the equation

$$\text{MOE} = (x,y) = \left(\frac{\text{AOV}}{\text{AOB}}, \frac{\text{AOV}}{\text{APR}}\right) = \left(\frac{\text{AOB-AFN}}{\text{AOB}}, \frac{\text{APR-AFP}}{\text{APR}}\right), \qquad (3)$$

where the MOE is a two dimensional Cartesian coordinate pair whose x-coordinate and y-coordinate are the values of interest. The resultant coordinate is plotted on a graph where the x and y axes range from zero to one, with (0,0) signifying absolutely no overlap (shown in Figure 6) , and (1,1) representing complete point-by-point overlap of the AOB and APR, (shown in Figure 8). The key characteristics of the two-dimensional MOE space are shown in Figure 9.

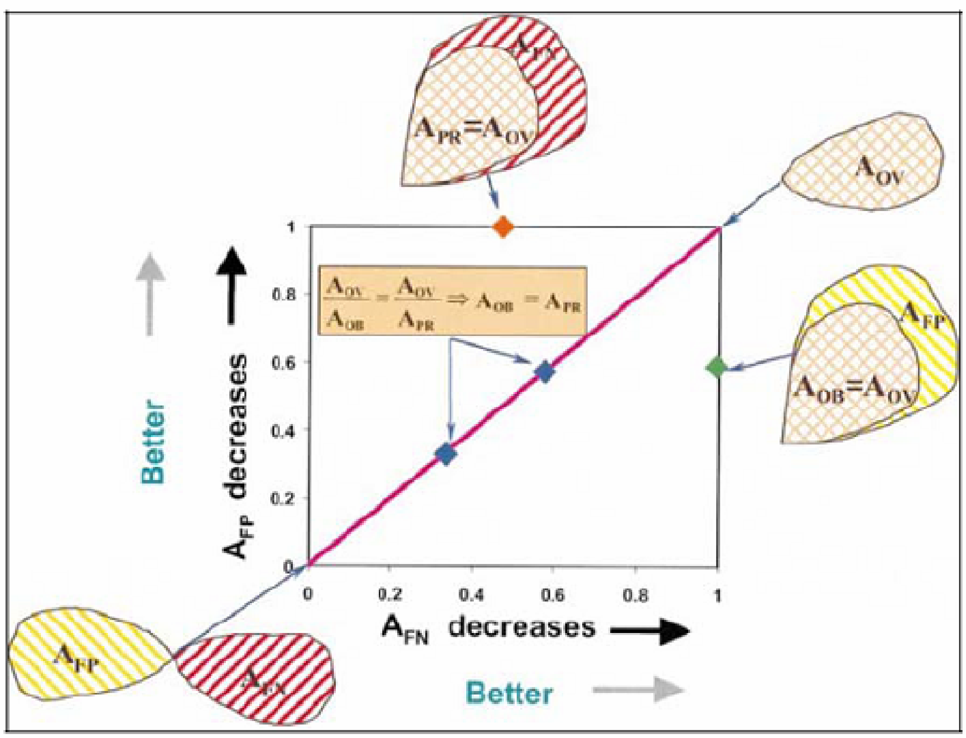


Figure 9. Characteristics of 2-D MOE space

The MOE is a useful tool because it produces a single coordinate for plotting, and can also be used to compare two (or more) models simultaneously against a known standard. This allows a numerical determination of which model is producing the desired results when compared to a benchmark. An example would be using a dose-rate level from HPAC output using reanalysis weather data compared to HPAC output using RAMS data, both of which can be compared against the DASA-EX dose-rate level data. Figure 10 illustrates how the MOE can be used in the evaluation of two models.

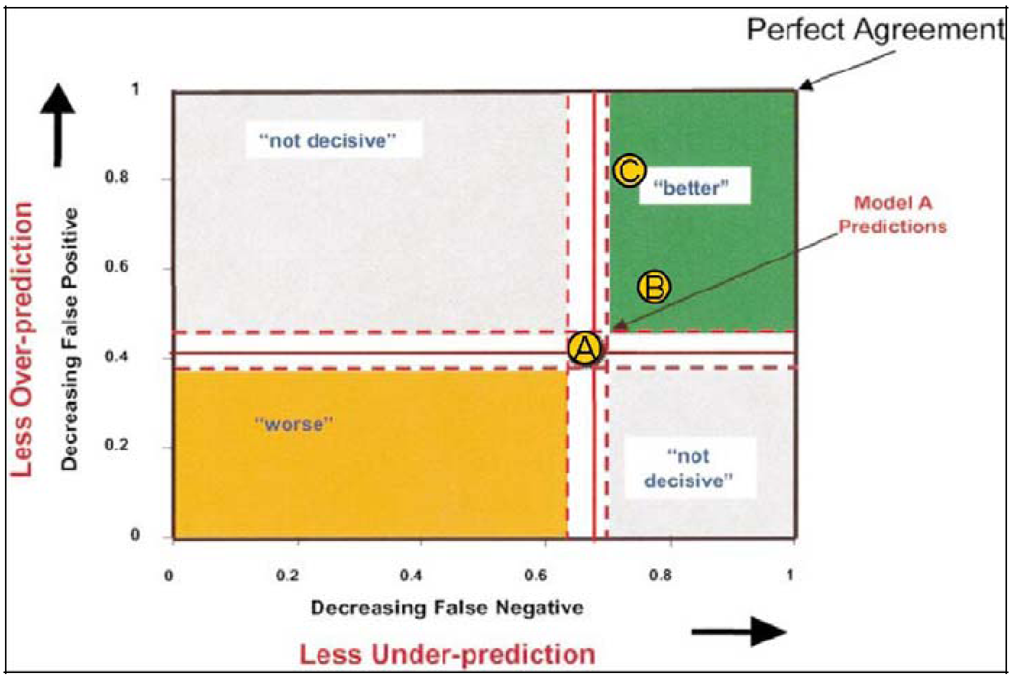


Figure 10. Regions of predictability in MOE, model comparison

Some subjectivity is necessary when comparing more than two models. For example, as shown in Figure 10, both models "B" and "C" have a better MOE value than model "A", but when "B" and "C" are plotted against each other, one will lie in the "not decisive" category. This is where the researcher must determine if it is more important to reduce AFP or AFN, and select the model which produces the best results. The

Normalized Absolute Difference (NAD) is a metric that reduces the subjectivity, and gives numerical merit to the choice between similar results in models.

Normalized Absolute Difference

The NAD is used to characterize the differences between observed and predicted quantities, and can be used to evaluate the deviation of a model from the standard. The closer that a model's value is to perfect agreement (1,1) with the standard, the smaller the distance between the MOE and the standard. This difference, when normalized, can be used as a standard metric. The distance from (1,1) to any opposing axis is one. For example, in the NAD coordinate system, the distance from (1,1) to (0,0.8) is the same value as the distance from (1,1) to (1, 0.4). Figure 11 shows the isolines of various NAD values plotted on the MOE coordinate system to emphasize the relationship between the MOE and NAD values.

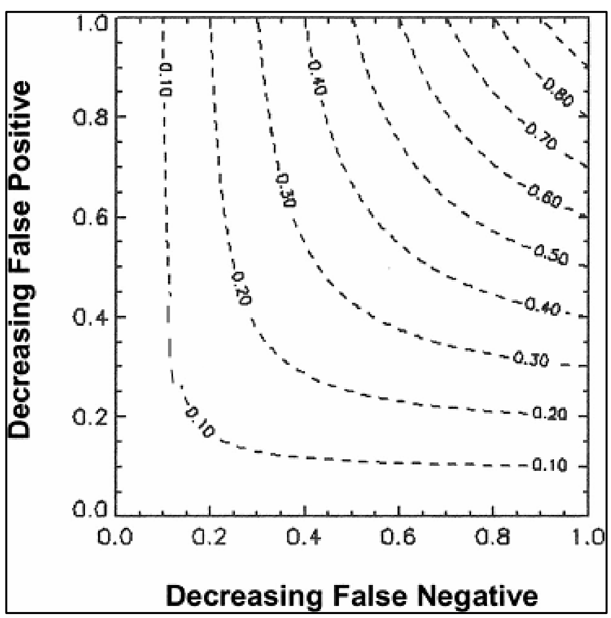


Figure 11. Isolines of NAD, lower value equals better model

The NAD allows the researcher to weight the value that has more importance, either AFP or AFN. As this research is focused on determining the best model to use for the maximum AOV, neither AFP nor AFN are more weighted, but the NAD can be used as a tool to better characterize the output for comparison. The resulting formula for the NAD in this case is

$$\text{NAD} = \frac{\text{AFN} + \text{AFP}}{2 \cdot \text{AOV} + \text{AFN} + \text{AFP}} = \frac{x + y - 2 \cdot x \cdot y}{x + y}. \qquad (4)$$

Summary of Previous Research

Pace used reanalysis weather data with resolution of 210 km, and varying resolutions of terrain in his research to compare results against historical dose-rate contours. He found that inclusion of high-resolution terrain data available through intrinsic HPAC files actually produced a poorer match to historical data than low or medium resolution terrain data. A major difference between Pace's research and this work is the use of RAMS to process the reanalysis weather data and produce high-resolution weather files for HPAC. In this way, high resolution weather data, with a fine mesh of 10 km or less, can be more closely matched with the same-scale high resolution terrain data, eliminating the disparity in the spatial domain while maintaining temporal resolution.

III. Methodology

Overview

This section provides a brief description of the entire method used in this research. The process starts by acquiring a set of raw meteorological reanalysis data from the NOAA website. The data is formatted and analyzed by RAMS to output a forecast for the time specified by the user. The output files are then reformatted into standard gridded binary (GRIB) files which may be translated by software downloaded from the Meteorological Data Server, or through the included GRIB2HPAC Fortran code found in Appendix C. This file is then recognizable by HPAC as weather input, and used in the simulation runs. Following an HPAC simulation, the data is digitized and numerically compared with digitized historical observations from the DASA-EX.

Reanalysis Weather Data Acquisition

Much of the research performed centered on manipulation of raw meteorological data using the RAMS program developed at CSU [10:1]. The reanalysis weather data is acquired through the National Oceanic and Atmospheric Administration's Operational Model Archive Distribution System (NOMADS) website. The website contains archived reanalysis weather data from 1948 to the present date, and contains selectable parameters to limit the size of the file that the user wishes to download. A complete step-by-step guide on obtaining the data is found in Pace's thesis [6:84-88], and is summarized here. The user selects the month and year of the data required, the meteorological variables (i.e. windspeed, pressure heights, temperature, relative humidity) required for analysis, the pressure levels desired, the observation times (four are available per day) and the limiting latitude and longitude for the data set. This generates a request to the server for the data, which then produces a link to a downloadable file. The file is saved by the user, and then imported in to the “fdgrib” executable folder, where it is reformatted.

Reanalysis Raw Data Reformatting

The program fdgrib, as well as RAMS and RAMS Evaluation and Visualization Utilities (REVU) are run on a LINUX platform, and must be downloaded, unzipped, untared, compiled and restructured in that environment. The programs are available at http://www.atmet.com, the ATmospheric, Meteorological, and Environmental Technologies (ATMET) for no cost. The programs are generically formatted, and all of the paths and pointers must be changed by the user, specifying the environment and library file locations once they are downloaded and compiled. All of the downloads come with README files which will give the user a place to start when making executable files, and should be read carefully by anyone wishing to install the programs on a new node. The working copies of all three programs are located in the /apps/ENP/rams.32 file on the LINUX cluster at AFIT, with read, write and execute permission given to all users.

The fdgrib program converts the raw GRIB data input to a format called RALPH II, which is readable by the RAMS analysis software. The user must specify the date and time that the data begins, whether the simulation they will be used for is two- or three-dimensional, how many meteorological variables are being converted, and what the variables are. The output RALPH II file is now ready to be sent to the "data" folder inside the RAMS directory.

RAMS Analysis

RAMS is a Fortran based code that contains 181 separate modules. The user must download the library files found at the ATMET site and ensure that the RAMS executable is configured to point to the correct library paths for supporting modules. Once correctly configured, specifying values for each of the variables in the atmospheric model namelists (see appendix A) is the primary method for a user to indicate the desired model configuration and select the options available for a particular model run [9]. There are five namelist in the atmospheric model component, and two in the isentropic analysis (ISAN) component, and Appendix A provides a brief description of each.

The choice of RAMS as the atmospheric model used for this research was largely due to the program's ability to "nest" weather patterns within each other in order to provide high spatial resolution and capture mesoscale events such as mountain wave and Venturi effect, updrafts, convection, and microphysical processes normally missed or averaged by synoptic-scale prediction models. By nesting a smaller model within the boundaries of a larger model, boundary effects for the nested grid can be minimized or even eliminated, using the same method as extracting a synoptic forecast from a hemispherical forecast. The nested grid occupies a region within the computational domain of the coarser parent grid, and coincides with, instead of replaces, the parent grid mesh in that region. There is a setting in the namelist input for the timestep of the parent grid, while the nested grid is user-defined as a fraction of the parent's timestep. Two way communications of all prognostic variables is accomplished at the end of each parent grid timestep, at which point the variable in the nested grid is interpolated sequentially at the boundary, and the nested grid is able to compute new values in smaller incremented timesteps until it catches up to the parent grid. In this way, information is passed in at the boundary, the same calculations performed by the parent grid on the variable is performed in the nested grid, but with smaller timesteps, and then the values are updated at the time when the nested grid's time matches the parent grid's time. This is a very powerful tool in determining fine spatial resolution, as boundary conditions are not only updated at every timestep, but the microphysics for the nested grid is fed real-time updates which allow a check on system interpolation.

Another operation performed by RAMS is the multiplication by density of prognostic velocity components, potential temperature, and moisture variables prior to communication from one grid to another. The interpolation and the averaging operators are both designed to conserve the volume integrals of these density-weighted quantities between the grids, which imply that the nesting algorithm conserves mass, momentum and internal thermodynamic energy. By conserving these quantities, an accurate portrayal of weather phenomena at the permeable boundaries is accomplished without neglecting such characteristics as gravity and acoustic waves. Figure 12 shows a partial RAMS analysis run script, showing the dimensions of a representative parent grid, labeled “Location and Dimensions of GRID 1” and a nested grid within the parent, labeled “Location and Dimensions of GRID 2”.

```
---------------Location and Dimensions of GRID   1---------------------------

 NW lat/lon      NE lat/lon (deg) =  41.4539,-116.6542     40.5020,-107.2533
      Center lat/lon (deg)        =               37.5000,-112.5000
 SW lat/lon      SE lat/lon (deg) =  34.2475,-117.3694     33.4491,-108.7252

    West PS coord (km) =   702.047              East PS coord (km) =  1512.047
   South PS coord (km) =   497.133             North PS coord (km) =  1307.133
        Delta-X (m) =   10000.0                    Delta-Y (m) =   10000.0

   Bottom coord (m) =       0.0           Top coordinate (m) =   19583.6
 Bottom Delta-Z (m) =     100.0

     Outer N lat (deg) =        41.4539
     Inner N lat (deg) =        40.3292
     Outer W lon (deg) = -117.3694  -107.2533  = Outer E lon (deg)
     Inner W lon (deg) = -116.4182  -108.9353  = Inner E lon (deg)
     Inner S lat (deg) =        34.4262
     Outer S lat (deg) =        33.4491


---------------Location and Dimensions of GRID   2---------------------------

 NW lat/lon      NE lat/lon (deg) =  37.1541,-116.8522     36.8955,-113.4603
      Center lat/lon (deg)        =               35.6805,-115.3101
 SW lat/lon      SE lat/lon (deg) =  34.4339,-117.1084     34.1921,-113.8196

    West PS coord (km) =   724.547              East PS coord (km) =  1029.547
   South PS coord (km) =   519.633             North PS coord (km) =   824.633
        Delta-X (m) =    5000.0                    Delta-Y (m) =    5000.0

   Bottom coord (m) =       0.0           Top coordinate (m) =   19583.6
 Bottom Delta-Z (m) =     100.0

     Outer N lat (deg) =        37.1541
     Inner N lat (deg) =        36.8070
     Outer W lon (deg) = -117.1084  -113.4603  = Outer E lon (deg)
     Inner W lon (deg) = -116.7405  -113.9269  = Inner E lon (deg)
     Inner S lat (deg) =        34.5233
     Outer S lat (deg) =        34.1921
     Outer S lat (deg) =        34.1921

-------------------------------------------------------------------------------
```

Figure 12. Parent and nested grid dimensions as specified in RAMS

Adjusting the values in the namelists allows the user to control all of the variables that RAMS uses in atmospheric and isentropic analysis. The first step in executing RAMS is to make the surface files that the program will later use for atmospheric analysis. The surface files necessary for the run are defined by the namelist, and the RAMS program will go to the library files to check the validity of the resource, read, and then retrieve the necessary data. For example, if the user is performing an analysis on area encompassing a square from 30° N to 20° N latitude, and -120° W to -105° W longitude, RAMS would gather the surface files of all of the surface, at 2.5° increments from the library files, analyze them, and convert them into .sfc files for the next run. The same process is repeated to generate the sea surface temperature (sst) files, and the vegetative cover (ndvi) files.

The next step is to make the “varfiles” used in ISAN. Based on the variable definitions in the ISAN namelists, RAMS will produce one isentropic analysis file per day of simulation for each of the grids. If an observation file is unavailable for RAMS to check against, it will interpolate a best-guess based on rawinsonde and pressure data provided above. This data is then used in the final run of the simulation.

The final simulation run analyzes the sfc, sst, ndvi, and isan files to produce a forecast. On the initial run with a dataset, it is necessary to produce a microphysics table that defines hydrometeor categories for the duration of the simulation. Included in this table are all water categories provided by the observation files, as well as probable results of the weather affecting the atmospheric water content. The output is analysis files that can be specified to be generated as often as required for each of the grids. For this research, hourly output was chosen to ensure capture of the forecast as close as possible to H-hour. Figure 13 shows a partial list of the analysis files produced for the George test, with g1 being the parent grid, g2 is the nested grid.

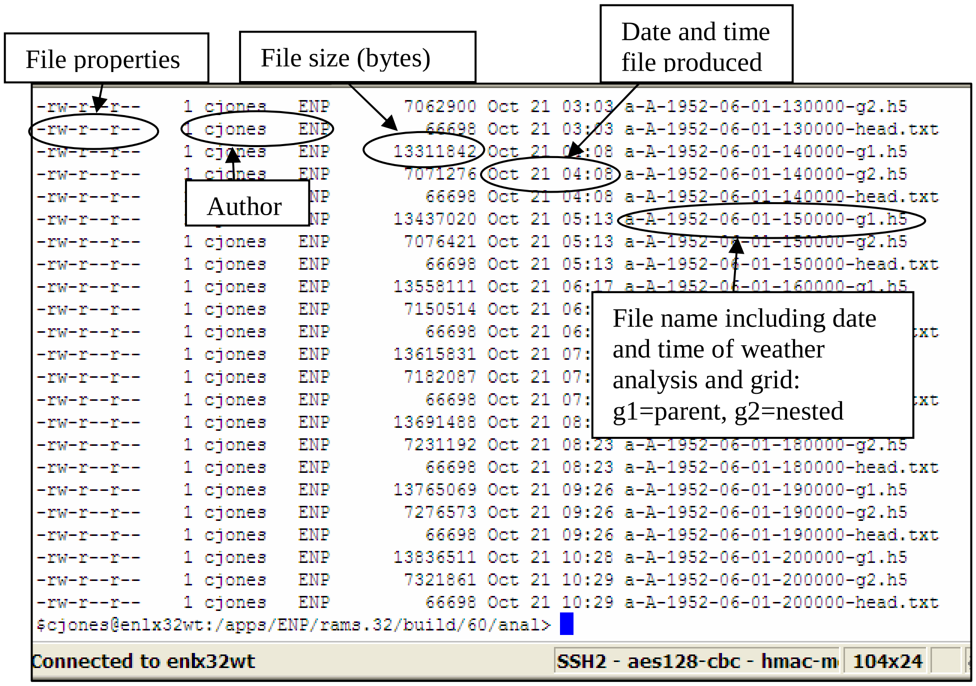


Figure 13. Analysis output files generated by RAMS

REVU

The REVU program reformats the analysis files produced by RAMS and outputs them in one of 5 formats based on user requirements. For this research, only the GRIB output was used, as the control files produced for the Grid Analysis and Display System (GRADS) output was not compatible with the GRADS visualization software. This allowed the use of GRIB files both for visualization and for HPAC input. Appendix B shows a typical REVU input namelist, with selectable input definitions.

GRADS 1.94b Utility

The GRADS utility was used to produce the control and index files necessary for input to the GRADS visual output software. A control file, a document that describes the variables and allows the GRADS software to define the spatial and temporal environment, is produced using the PERL script grib2ctl.pl and shown in Figure 14.

```
dset ^a-AP-1952-06-01-000000-g1.grb
index ^a-AP-1952-06-01-000000-g1.grb.idx
undef 9.999E+20
title a-AP-1952-06-01-000000-g1.grb
*  produced by grib2ctl v0.9.12.5p39a
dtype grib 255
ydef 76 linear 32.820000 0.18
xdef 96 linear -128.095000 0.180000
tdef 66 linear 01Z01jun1952 1hr
*  z has 11 levels, for prs
zdef 11 levels
1000 925 850 700 500 400 300 250 200 150 100
vars 6
HGTprs 11 7,100,0 ** (profile) Geopotential height [gpm]
PRESprs 11 1,100,0 ** (profile) Pressure [Pa]
RHprs 11 52,100,0 ** (profile) Relative humidity [%]
TMPprs 11 11,100,0 ** (profile) Temp. [K]
UGRDprs 11 33,100,0 ** (profile) u wind [m/s]
VGRDprs 11 34,100,0 ** (profile) v wind [m/s]
ENDVARS
```

Figure 14. GRIB control file

The PERL script gribmap is used to produce a binary index file, which relates the control file and the GRIB file. The index file's function is to inform the GRADS visualization software where different pressure levels and variables reside within the binary GRIB file. The control file, index file, and GRIB file are all necessary as input for the GRADS software, and must be copied into the root directory where the GRADS executable is located.

GRADS Visualization Software

GRADS is a DOS-based visualization tool that allows visualization of two-dimensional grided data produced by various atmospheric models. It can be animated to show progressive temporal output on a spatial domain of any selected variable or combination of variables. This allows the user to ensure that the data is smooth across all boundaries and to observe the movement of any particular system of interest across the spatial domain.

In this research, GRADS was used to visually compare the output of the parent and nested grid for agreement, as well as RAMS output and historical weather charts.

Figure 15 below shows a representative snapshot of GRADS output, displaying the six variables; Geopotential Height, Pressure, Relative Humidity, Temperature, U wind, and V wind for the date-time group of 1200 on 23 March 1955, at a pressure level of 850 mb, just prior to the ESS test.

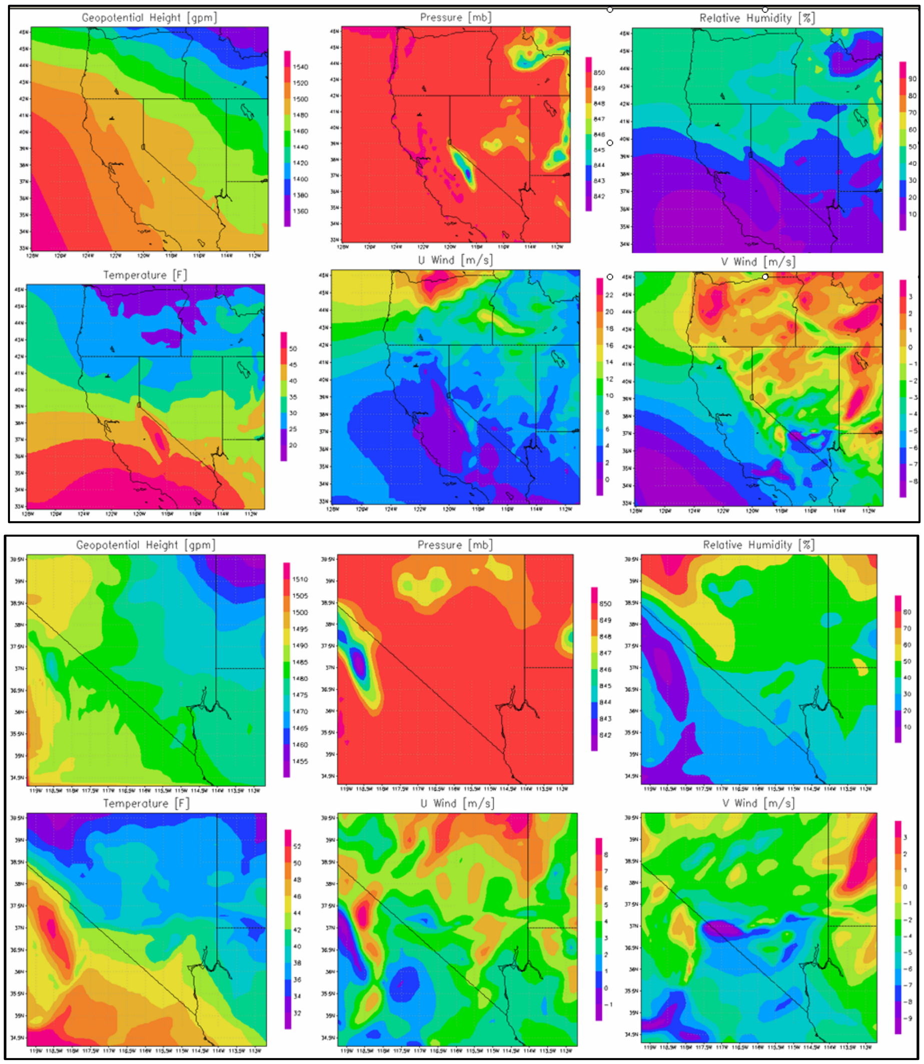


Figure 15. GRADS output of parent and nested grid variables

The first sequence of six is the parent grid output, while the second sequence is the nested grid.

GRADS also contains implicit functions and allows the mathematical manipulation of the input data, in order to perform such functions as determining the horizontal relative vorticity via finite differencing, conversion of temperatures (i.e. from Kelvin to Fahrenheit or Celsius), calculating the magnitude of wind, determining mean values over time, displaying a vector analysis of wind, etc. All of this manipulation assists in the comparison process with historical data, allowing the user to match the specific parameters displayed in the observation document, downloaded from the historical NOAA record files at:

http://docs.lib.noaa.gov/rescue/dwm/data_rescue_daily_weather_maps.html

An example of a historical weather chart used in validation of RAMS output is shown in Figure 16 below.

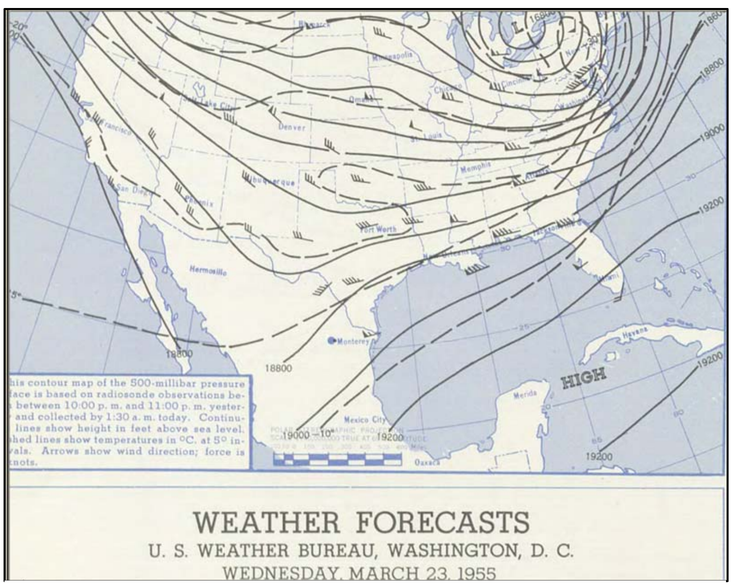


Figure 16. Historical weather forecast map

GRIB to HPAC

The GRIB files produced by RAMS are moved from the LINUX environment back to the PC environment. They are transformed into two data files using a third-party software utility called wgrib, available from http://dss.ucar.edu/libraries/grib/ , and finally reformatted through the Fortran transformation utility modified by this author (see Appendix C). This process produces an upper air profile (.prf) file that is readable by HPAC as an input weather file.

The original code produced by Pace allowed the transformation of six hour reanalysis data directly, at a 2.5^{o} resolution. As this researcher modified the original reanalysis data through RAMS, the code could not understand the input GRIB file, which was a forecast, and not observational data, and also had a resolution of 0.18^{o} (about 20 km) or 0.09^{o} (about 10 km). The spatial domain consisted of 74 x 60 points, or 4440 distinct locations for which elevations were input using Google Earth. This increased the size of the arrays in the code to a point that required restructuring of the various loops when manipulating the data. The use of forecast data also required modification of the temporal update portion of the code, using the forecast timestamp (i.e. 60 min, 120 min, … 4320 min) to update the time of observational output. As this research produced hourly forecasts, the preset in the code for 6 hour input was modified also.
It is important to note that the modified code will only work with forecast data, and the elevations are only valid for the spatial domain output by RAMS for this research. Although the .prf file can be read by HPAC with elevation data of zero meters, this would only produce acceptable results with the flat-earth (no terrain) assumption.

HPAC Simulation

Once the .prf file was produced, it could be directly introduced to HPAC as weather input file. Appendix D shows a step-by-step process of how to input the file into

HPAC and run the simulation. Depending upon the terrain resolution selected, the simulations lasted between 40 minutes and 7 ½ hours. The maximum usable terrain resolution, as documented in Pace's thesis, was 35,000 points, or about 3 points per square mile. Any addition to the terrain beyond this point resulted in output failure from HPAC, at the expense of more than 18 hours simulation time.

As Pace's research was focused on terrain resolution improvement to HPAC and DASA-EX match, this research was focused on weather resolution improvement to HPAC and DASA-EX match. The spatial domain considered for this research was limited to what Pace termed "small" as this researcher did not want to outdistance the available forecast produced in RAMS. In one instance, on the Zucchini test, the larger spatial domain had to be used due to the smaller domain not encompassing the spatial domain of the weather. In all instances, the time of simulation was maximized up to 48 hours, but in some instances HPAC ran out of puffs prior to 48 hours. The legend on all HPAC contour plots is included for the reader to identify the time of the plot.

Contour plots of both dose-rate and integrated-dose were comparatively analyzed with the DASA-EX output. It was determined that in order to visually capture the true pattern of fallout produced by HPAC, the integrated-dose has to be displayed, as the dose-rate contour plots after extended periods, for example H+48, already show reduction in footprint size due to decay. Therefore the actual numerical output compared to the DASA-EX data is dose-rate, normalized to H+1, while the visual comparison of pattern only was accomplished by comparing the integrated-dose contour plots to the DASA-EX output.

The data from HPAC was output as a text file in order to provide input for the Compare HPAC to DASA-EX Program. Figure 17 below shows a portion of an actual output text file that was used by the code.

```
#Model ModelName    :HPAC
#Model ModelVersion:4.1
#Model Description :Atmospheric dispersion hazard prediction model
#Model Comments    :Sponsor:Defense Threat Reduction Agency (DTRA)
#Model Comments    :Model  :Hazard Prediction and Assessment Capability
#Output CreationDate  :Sun Nov 19 12:51:29 EST 2006
#Output Description   :U238TN(Dose Rate);NWPN Radiation Dose;25-Jun-57 18:30:00Z (36.0 hr)
#Output Source        :HPAC project: client=Prisc3x235k server=Prisc3x235k
#Output Classification:Unclassified
#Output Analyst       :Chris Jones
#Output Comments      :Project date   :19 NOV 06
#Output Comments      :Project version:HPAC 4.04.011
#Output Comments      :Project title  :Priscilla 3x2 35k point
#Export :ModelOutputPointData (simple ASCII)
#Time   :06/25/1957 at 18:30:00
#Notes  :U238TN(Dose Rate)
#Notes  :NWPN Radiation Dose
#Notes  :25-Jun-57 18:30:00Z (36.0 hr)
#Tag    ::HPAC
#Tag    :SouthWest Corner:(-117.47107E, 35.16510N) (  457.10031, 3891.45410,11)
#Tag    :NorthEast Corner:(-112.51026E, 37.32911N) (  897.85986, 4140.84619,11)
#Tag    :Field min value:1.0E-30 Rad/hr
#Tag    :Field max value:0.5976982 Rad/hr
#Field 1           :Mean
#Field 1 Units     :Rad/hr
#Field 1 Max Value :0.5976982
#Field 1 Min Value :1.0E-30
G0       (-116.10965E, 36.65337N)   1.659700E-15
G1       (-116.10361E, 36.65337N)   2.238252E-15
G2       (-116.09758E, 36.65337N)   2.953355E-15
G3       (-116.09155E, 36.65337N)   3.896919E-15
G4       (-116.08551E, 36.65337N)   5.141942E-15
G5       (-116.07948E, 36.65337N)   6.784968E-15
G6       (-116.07345E, 36.65337N)   8.750601E-15
G7       (-116.06741E, 36.65337N)   1.145137E-14
G8       (-116.06138E, 36.65337N)   1.502764E-14
G9       (-116.05535E, 36.65337N)   1.972079E-14
G10      (-116.04931E, 36.65337N)   2.587961E-14
```

Figure 17. HPAC text output of Priscilla simulation

The number of data points output for each test varied according to the spatial domain, but was curtailed in the Compare HPAC to DASA-EX Program to match the DASA-EX gridded data. The center of the dataset was pinned to ground zero, with the spatial domain being defined by the distance encompassed in each cardinal direction when selecting the number of data points. This allowed for a point-by-point spatial comparison in the Compare HPAC to DASA-EX Program code.

DASA-EX Digitization

In order to ensure exact comparison results between this research and previous research, the digitization of the DASA-EX data was accomplished in the precise manner described by Pace to check for validity of procedure [6:34]. Once it was confirmed that

Pace's method was reproducing the same results as described in his thesis, the actual original files produced in his research were also utilized in this research for comparing output in the Compare HPAC to DASA-EX Program. Because the identical numerical files were used, there is no opportunity for disparity in comparison from this research and previous efforts.

It is important to once again emphasize the conversion of HPAC dose-rate units to those used in constructing the DASA-EX. In HPAC, the dose-rate is given in units of Rad per hour, while the data in the DASA-EX is in units of roentgens per hour. In the HPAC v 4.04 user's manual [8:649] , one REM is equated to one RAD, while in the HPAC v 4.03 user's manual [7:H-6], one REM = 0.7 roentgen. The HPAC radioactive decay power law [7:H-6] varies slightly from the Way-Wigner approximation, where the decay power value is approximated at 1.2, as the authors estimated that this better approximated early-time deposition, where HPAC could be most effectively used. HPAC's conversion is given as:

$$R(t) = R_0 \left(\frac{t - t_{rel}}{t_0} \right)^{-p} \tag{5}$$

where

$R(t)$ = time dependant dose-rate

R_0 = reference dose-rate

t_0 = reference time (one hour)

t_{rel} = time of release

p = decay power value = 1.3.

Compare HPAC to DASA-EX Program

This code computes the MOE and NAD values between the HPAC output and the digitized DASA-EX contour data. It is a point-by-point comparison program as described by Warner [12]. The output is manipulated to the correct dose-rate after simulation, and provided as a spreadsheet in appendix RRR. It provides a simplified means of comparing output using the MOE and NAD, as described in chapter 2.

This code was kept almost original to the code produced by Pace in his thesis, with the exception of the dose-rate contour selection module. This was identified as a bug, and modified to ensure that the correct number of contours was being sent to the analysis module. Without this fix, the code still functions, with the exception that the final contour level is duplicated at output to screen. The calculations however are correct, and therefore it is not being appended to this document, as it was code that was utilized, and not necessarily improved by this author.

IV. Results and Analysis

Chapter Overview

This chapter contains the results of the methodology described in the previous chapter, providing both numerical and visual results of analysis for the six tests. The results and analysis are laid out sequentially by test date in each section, and then a final analysis of overall results is presented at the conclusion of the chapter. In each test section, satellite imagery from Google Earth is incorporated to show the terrain on which the test was conducted. Next, the comparison of historical weather charts and RAMS output are displayed, followed by examination of vector wind fields at early and D+1 times for compliance with both the DASA-EX and HPAC output. This is followed by the visual representation of the DASA-EX data as produced by Fortran output manipulated in color and aspect ratio, followed by contour plots of integrated-dose produced by HPAC simulations. Finally, statistical analysis and numerical comparison of DASA-EX and HPAC dose-rate measurements is shown using the NAD metric, followed by expanded wind field analysis for each test.

Operation Tumbler-Snapper: George

Figure 18 shows that George was a test conducted in a valley with ground elevation of the test at about 4030 feet, surrounded by ridges on the east, higher by about 900 feet, and west higher by about 300 feet. George was a 15 kT tower burst, with cloud top height at 37,000 ft, which was the same height as the tropopause. The combination of winds up to and at the tropopause and the surrounding terrain, with various protrusions in the path evident due to ridgeline intrusion on the fallout field indicates a north-northwest deposition pattern. This would suggest that higher resolution terrain selection in HPAC would produce more accurate results due to the prominent terrain features and exposure of fallout to a variable wind column.

Figure 18. George test terrain

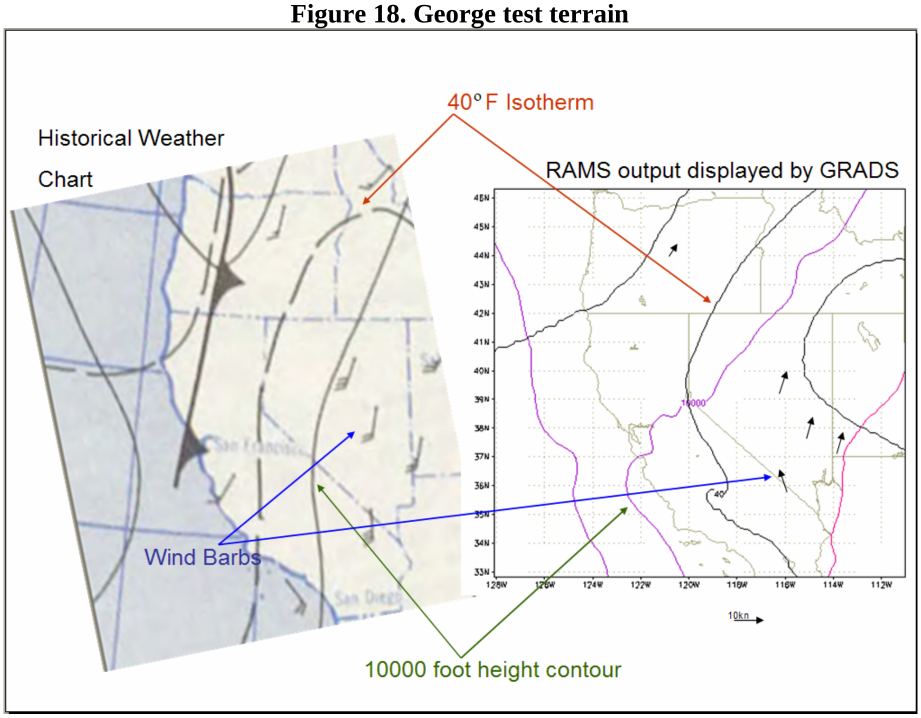


Figure 19. Validation of George RAMS input

A validation of RAMS output against historical weather observations is shown in Figure 19. Comparison shows that the height contours, wind direction and velocities, and isotherms provide a close match, indicating that the weather data used as input for the HPAC simulation was indeed valid. Examining the prevalent winds using GRADS at M+5, and M+65, it is evident at these pressure levels that the HPAC fallout pattern is accurately following the wind field at early times.

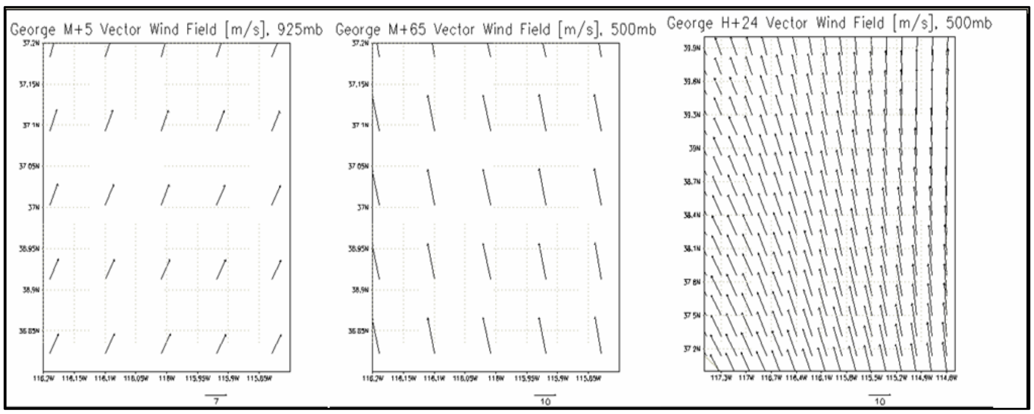


Figure 20. George vector wind fields

At H+24, when most local fallout is considered to be deposited, the wind field has not significantly shifted, though instead of winds from the southwest, they are trending from the south-southeast. This would suggest that the fallout field, if unaffected by terrain, should have deposited in a generally north by northeast pattern in early times, followed by a shift to north by northwest at greater distance from ground zero.

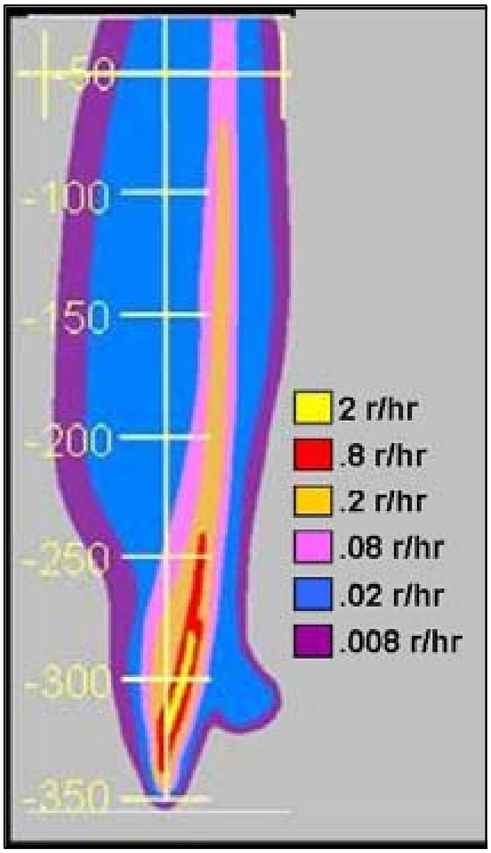


Figure 21. DASA-EX digitized George contour plot

A visual inspection of the digitized and color-coded DASA-EX data in Figure 21 shows that the previous assumptions appear to be correct. The lobe found in the southeast portion of the contour plot at about the -300 km marker was not reproduced in any of the simulations, and is most likely a result of deposition in a small bowl shaped valley located approximately 50 km north of ground zero. The bulge that is observed beginning approximately 100 km north of ground zero closely follows a ridgeline to the northeast of ground zero. This feature is evident in all of the HPAC contour plots below, even those simulations made without using the HPAC terrain software.

Coupling the analysis of the weather data with varying terrain resolution produced the integrated-dose contour plots found in Figure 22 and Figure 23, numbered for the

NAD comparison found in Figure 25. See Appendix E for definitions of the terrain resolution sizes.

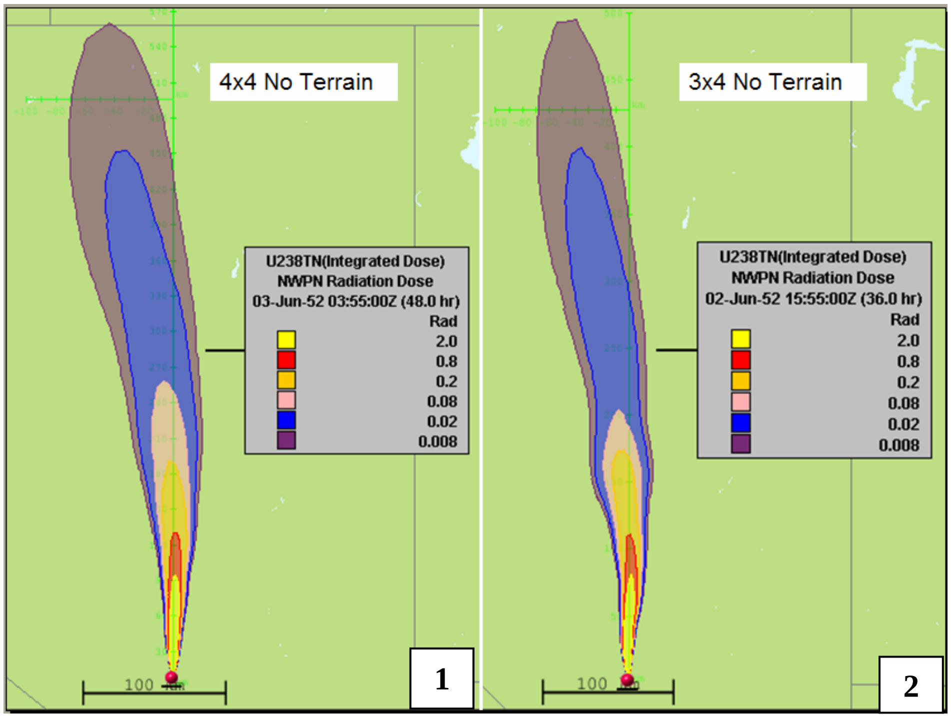


Figure 22. George, NWP terrain only

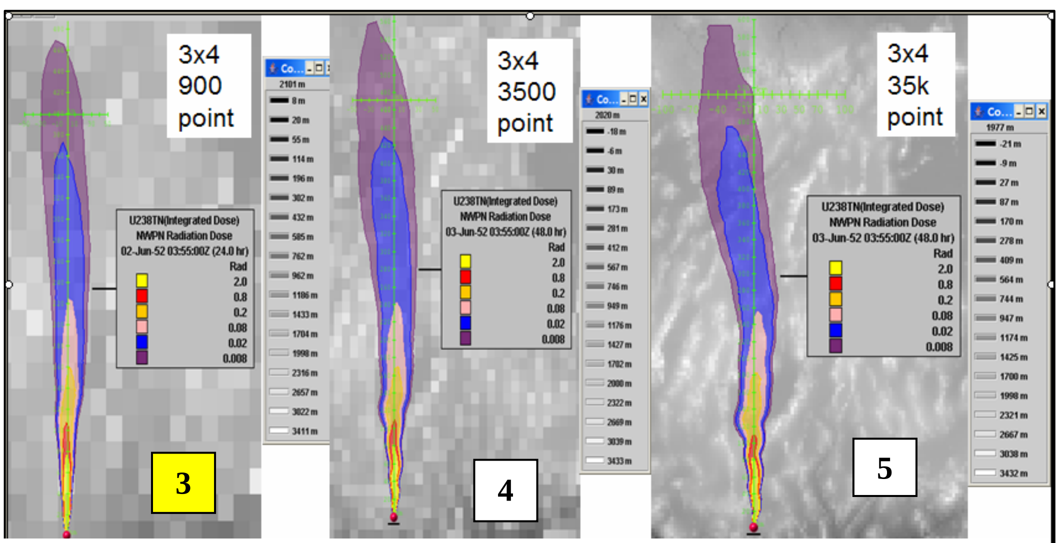


Figure 23. George, various terrain resolutions

The gray background displayed in Figure 23 is the HPAC resolution of terrain, with the legend found to the right of each contour plot. It is important at this point to define the term “no HPAC terrain”. As previously stated, the upper air profile (.prf) files that were produced for weather input contain elevation in meters for all of the defined spatial coordinates, as shown in Figure 24.

```
# CREATOR:        CPJ
# DATE:           Thu Nov  9 17:45:41 2006 Local
# SOURCE:         GRIB
# EDITED:         no
# REFERENCE:      msl
# TYPE:           forecast
# ANALYSIS:       1952 06 01 01.00
# START:          1952 06 01 01.00
# END:            1952 06 03 18.00
# TIMEREFERENCE:  UTC
# MODE:           Profile All
PROFILE
6 6
ID       YYYYMMDDHOUR    LAT      LON      ELEV
                 HOURS   N        E        M
Z        WDIR    WSPD    P        T        HUMID
M        DEG     M/S     MB       K        %
-9999
ID: 001001   19520601 01.00  34.3665 -119.1282       274
      57 220          5.0       1000          294.6       44
     724 222          5.2        925          287.8       64
    1439 196          3.9        850          285.1       62
    3048 169          4.0        700          277.0       30
    5687 191          5.8        500          258.1       44
    7335 210          6.1        400          246.2       52
    9354 234          6.7        300          232.9       69
   10581 242          7.4        250          226.6       72
   12048 249          7.7        200          222.3       73
   13912 235          7.7        150          218.8       72
   16495 214          6.9        100          216.1       71
```

Figure 24. Partial .prf file with elevation [m] highlighted

This means that although the supplementary HPAC terrain files are not used in conjunction with the “no terrain” simulations, it is not a “flat-earth” assumption, but rather a simplified terrain, with only elevations and not ground cover included. This explains why in many cases, the “no terrain” files produce a closer match to the DASA-EX data than when using HPAC terrain files in conjunction with the .prf file.

A comparison of NADs between each of the 5 tests is found in Figure 25, expanded for ease of readability, and a statistical comparison between the NAD values is found in Figure 26. Visually, test number 3 provided the least normalized absolute difference in the tests, and a statistical analysis of relative difference between the 5 test showed that test number 3 (highlighted in Figure 23), the 3x4 spatial domain with 900 points of terrain did have the least normalized absolute difference of the 5 tests compared.

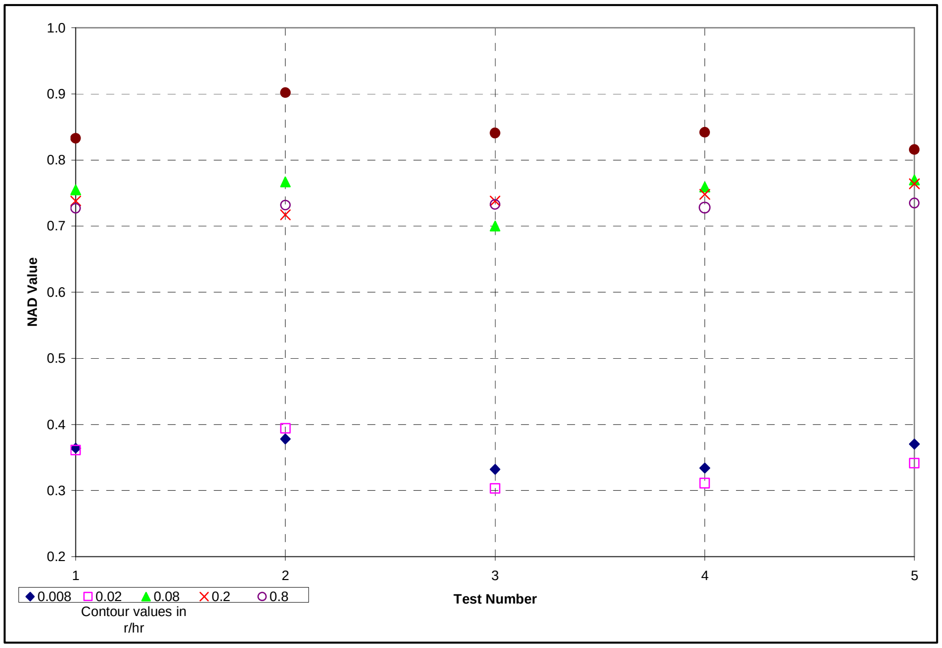


Figure 25. Comparison of George NAD values by test, lower value is better

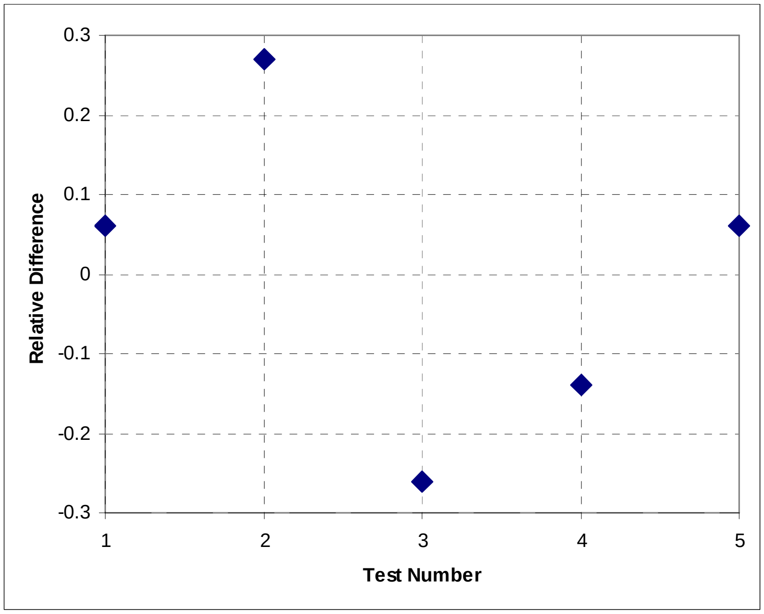


Figure 26. Statistical comparison of George NAD values, lower value is better

In Figure 27, vector winds are examined from the input GRIB file at H+0, and the table in Figure 28 is a direct excerpt from the DASA-EX.

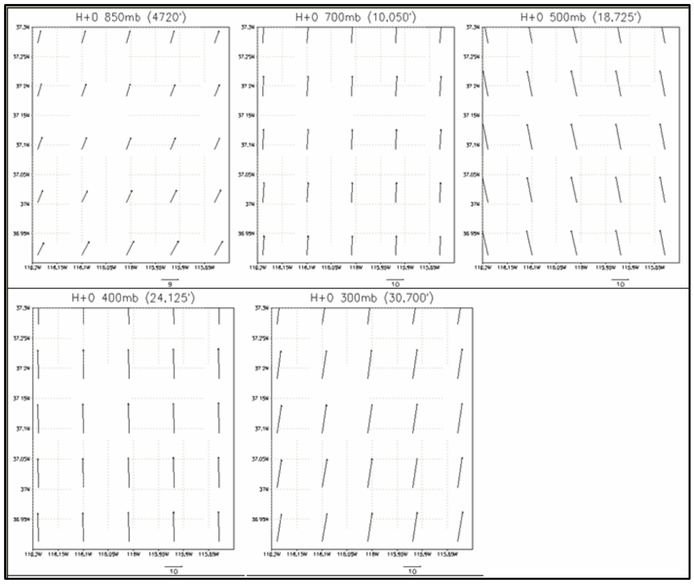


Figure 27. George expanded wind field

TABLE 20 NEVADA WIND DATA FOR OPERATION TUMBLER-SNAPPER-GEORGE

Altitude (MSL)	H-hour		Altitude (MSL)	H-hour	
	Dir	Speed		Dir	Speed
feet	degrees	mph	feet	degrees	mph
Surface	Calm	Calm	14,000	180	30
5,000	Calm	Calm	15,000	170	30
6,000	170	20	16,000	170	33
7,000	170	21	18,000	190	35
8,000	170	20	20,000	190	51
9,000	160	20	25,000	200	48
10,000	160	17	30,000	190	41
12,000	180	20			

Figure 28. George wind data DASA-EX excerpt

The wind data supplied for George shows excellent correlation with the DASA-EX data at all levels that can be displayed. The cloud top height was recorded as 37,000 ft, with no data on the cloud bottom. It is not possible to determine where DELFIC instantaneously placed the cloud, but based on the HPAC contour plots, the initial direction of the fallout plume is in a north to slightly east of north direction. Based on this observation, the particles were most likely initially subject to winds at the 400mb level and above. The NAD values for the low dose-rate contours were consistently about twice as good as the NAD values for high dose-rate contours, suggesting that the initial deposition of radioactive particles, those with the highest dose, was not as accurate as the smaller particles that were transported further downrange. This would suggest that initial, low-altitude winds were not accounted for by HPAC due to incorporation of a stabilized cloud from the DELFIC cloud rise module. Further examples of this observation are found in subsequent tests.

Operation Teapot: ESS

ESS was conducted about 13.4 km north of George, so the terrain was similar for this test. Figure 29 shows the topography east of ESS, as this was the direction of the prevailing winds on the day of the test. ESS was also conducted in a valley with ground elevation of the test at about 4300 feet, with ridges and hilltops to the east, higher by 400 to 1900 feet, and shown highlighted in the figure.

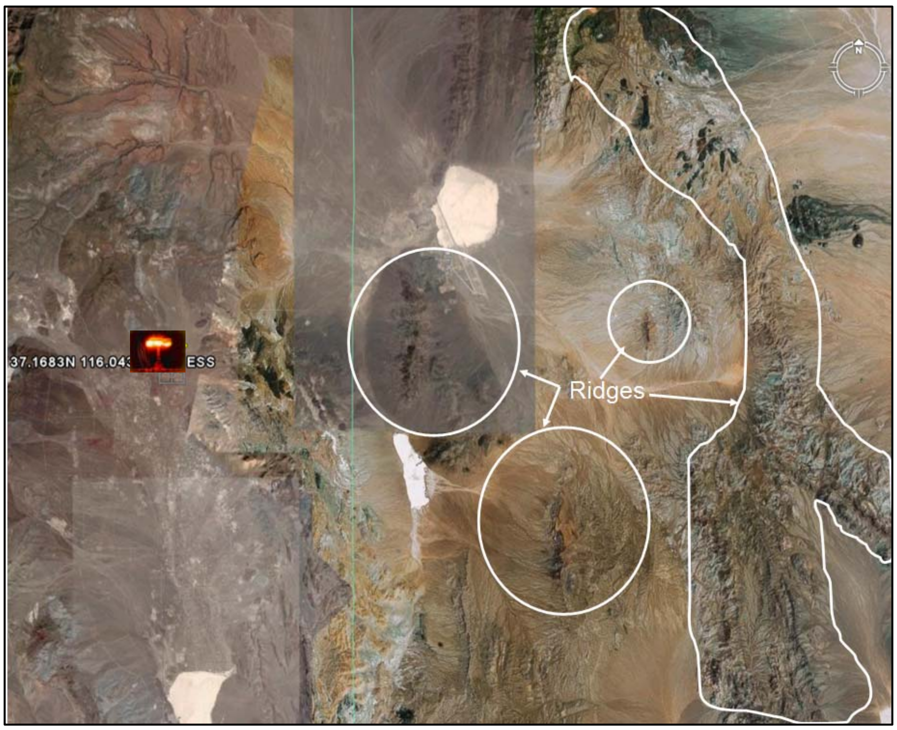


Figure 29. ESS test terrain

The test was a 67 foot subsurface 1 kT burst in a filled shaft, with a cloud top height of 12,000 feet. An interesting detail mentioned in the DASA-EX is that some residual contamination "from shot 6 – Bee is included in the readings" [4:201] Bee was an 8 kT tower shot, and it is unknown how much of the residual contamination is attributable to the DASA-EX contour profile [4:195].

As the test was subsurface and the cloud top height was relatively low, surface and low-level winds would most likely affect the fallout distribution to the greatest degree. The washboard terrain and subsurface burst would suggest greater deposition on the lower ground, with fallout settling in the valley located to the east.

Validation of RAMS output and historical weather observations is shown in Figure 30.

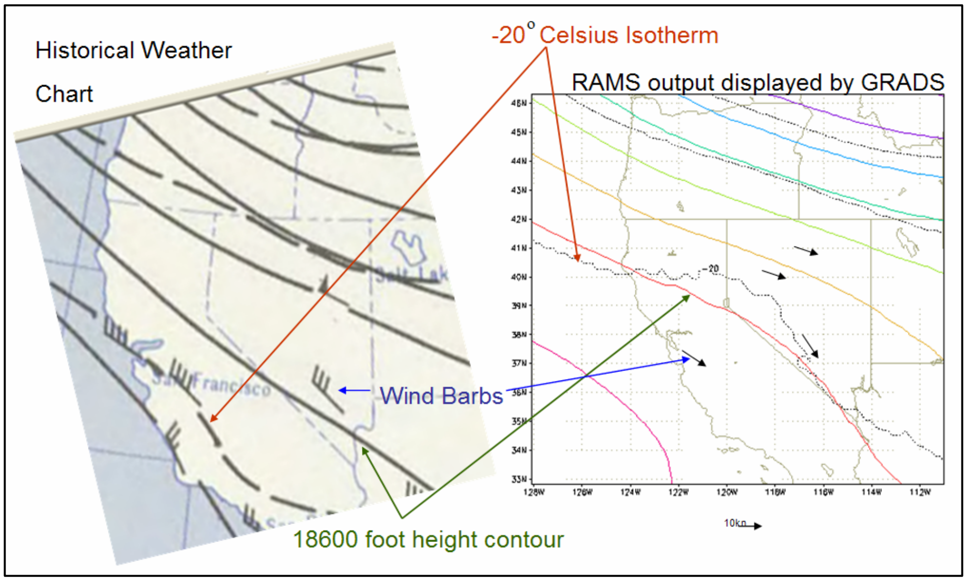


Figure 30. Validation of ESS RAMS output

The height contours and wind direction and velocities provide a very good match, and the isotherm is reasonably close to the correct location. A possible disparity between the historical and RAMS output is that the historical data was collected between 10:00 pm and 11:00 pm on 22 March 1955, approximately 1 to 2 hours prior to the RAMS calculation of the data. The difference is relatively minor, however, and shows a definite correlation between the historical and simulation data. Examining the prevalent winds using GRADS at M-30, and M+30, it is evident that the HPAC fallout pattern is accurately following the wind field at early times at the selected pressure levels, as seen in Figure 31.

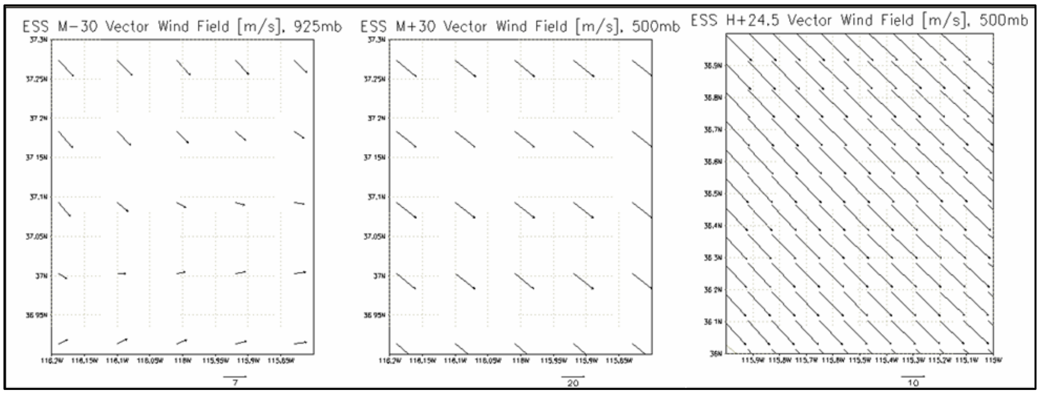


Figure 31. ESS vector wind fields

The prevailing wind is from the northwest, and indicates that the fallout pattern on a "flat earth" would be directly to the southeast.

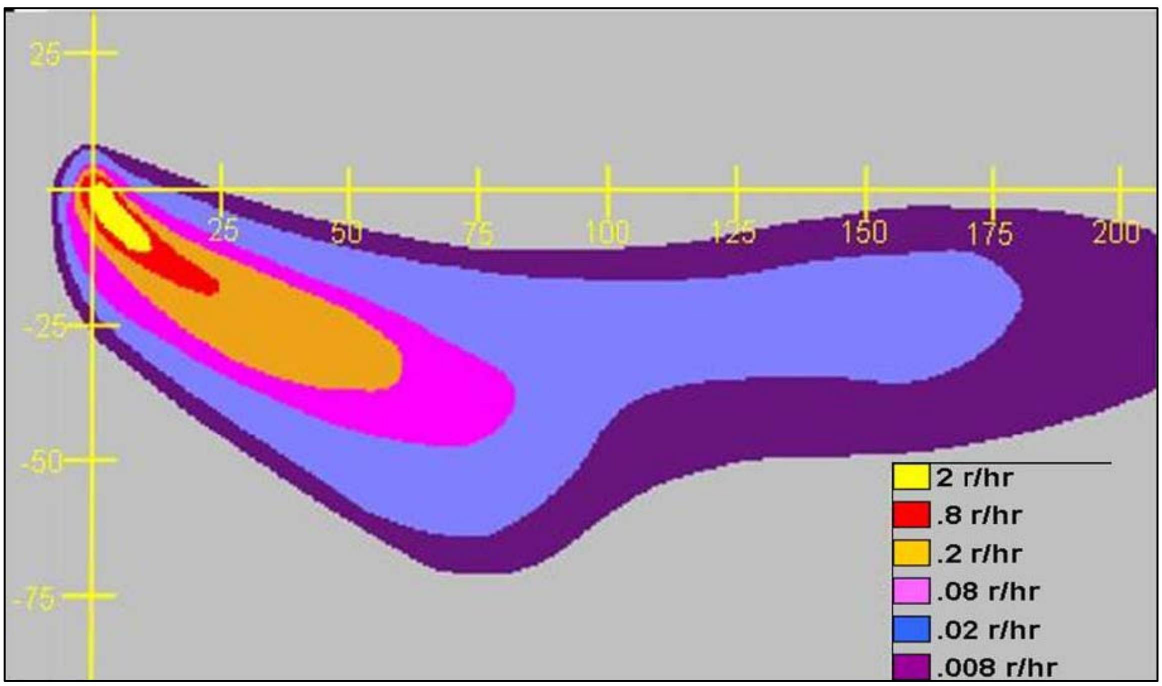


Figure 32. DASA-EX digitized ESS contour plot

The DASA-EX plot in Figure 32 shows this southeast trend, and then smears the fallout almost directly east. The eastward smearing was not reproduced in any of the HPAC simulations, and evidence for a direct easterly wind was not found in analyzing 72 hours of vector wind fields at all pressure levels produced for this test.

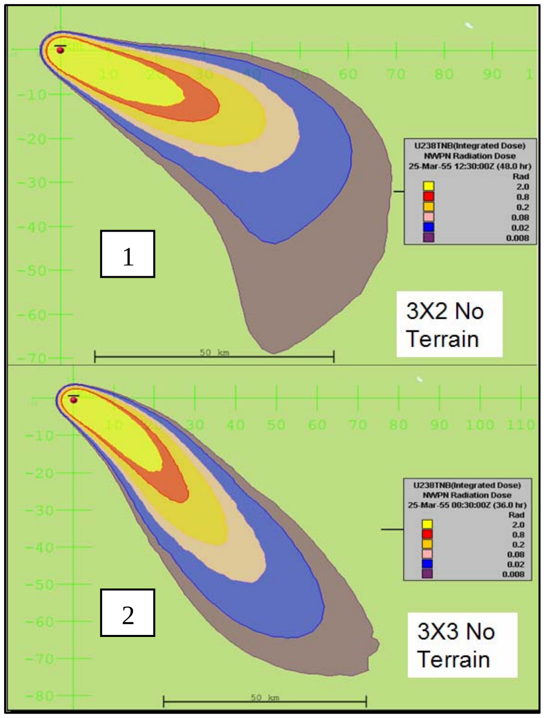


Figure 33. ESS, NWP terrain only

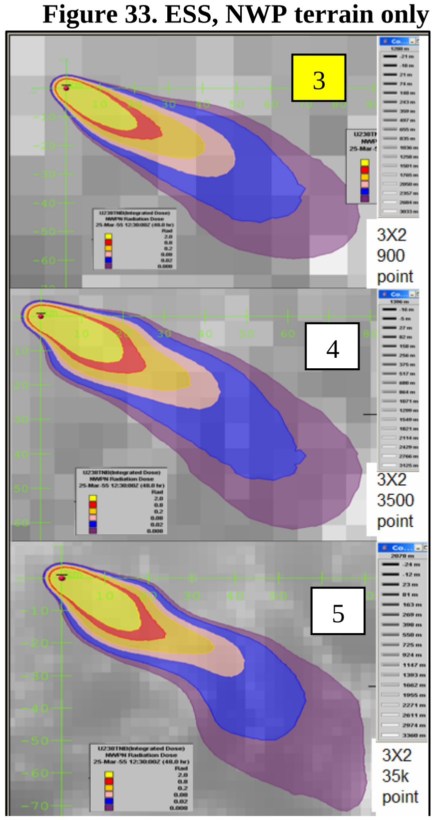


Figure 34. ESS, various terrain resolutions

The southeast trend is faithfully reproduced in all HPAC simulations as shown in Figure 33 and Figure 34. A visual inspection shows that test number three, the 900 point terrain, presents the closest match to the contour data displayed in the DASA-EX and is highlighted above. Though the smear in the cardinal eastward direction is missing, the fallout pattern did remain closer to the east-west axis than any of the other tests. A comparison of NADs shows that test number three did have the least normalized absolute difference between the HPAC and DASA-EX data, as shown in Figure 35, expanded for ease of readability.

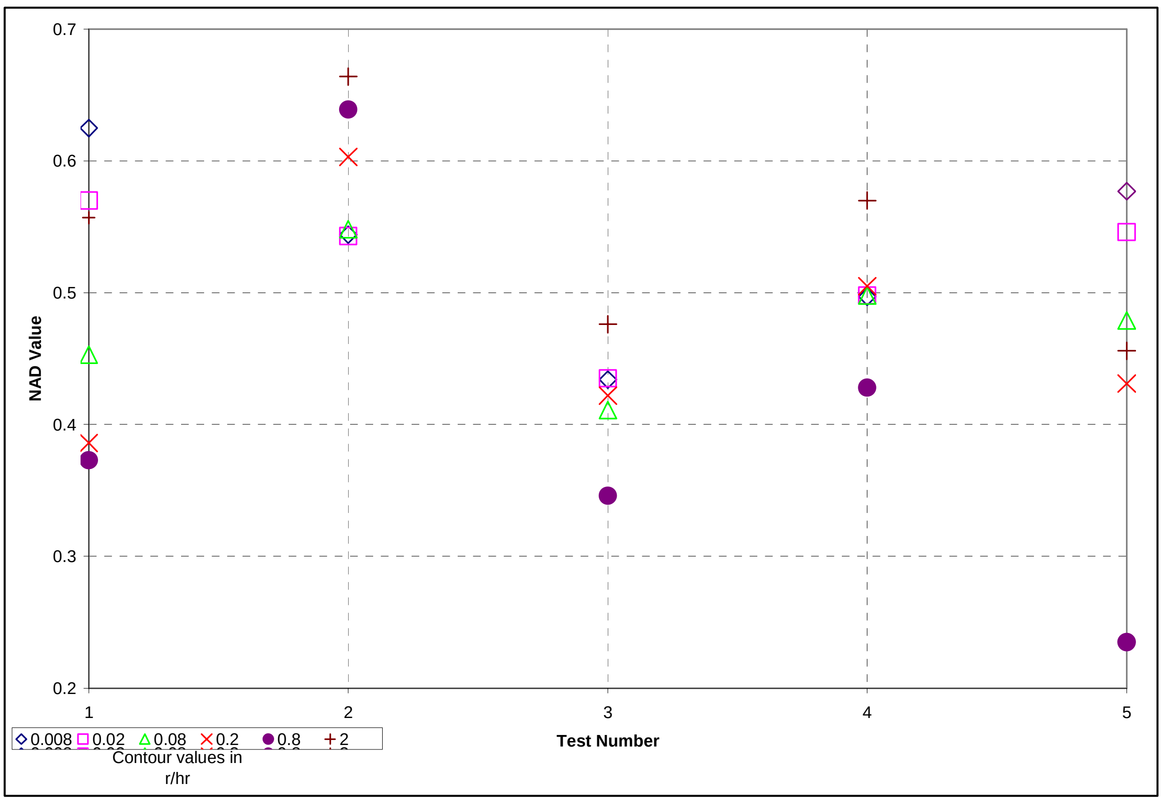


Figure 35. Comparison of ESS NAD values by test, lower value is better

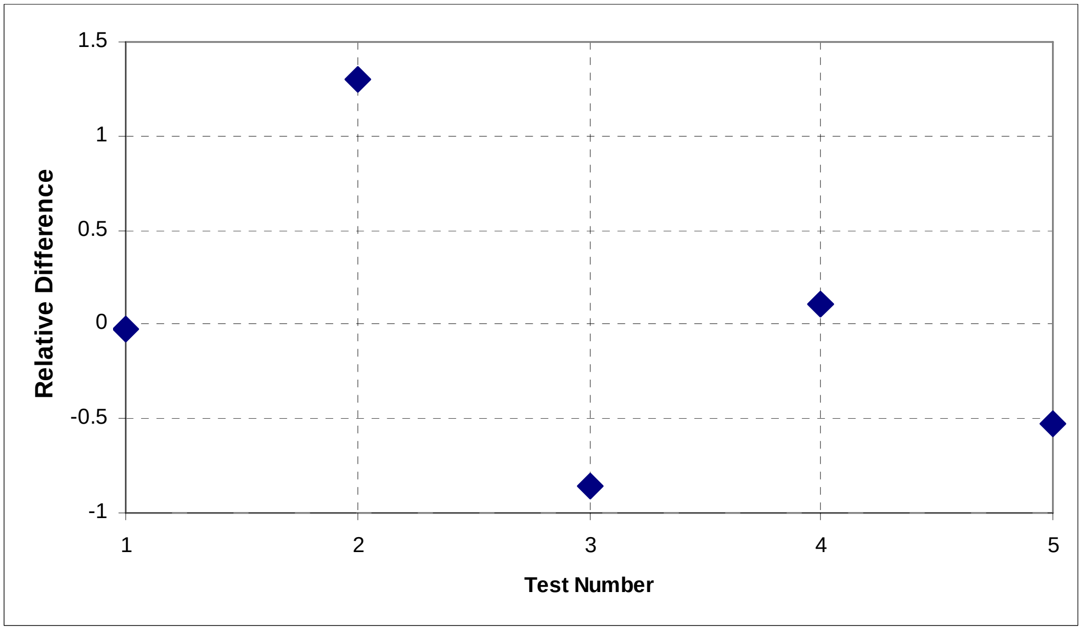


Figure 36. Statistical comparison of ESS NAD values, lower value is better

In Figure 37, vector winds are examined from the input GRIB file at H+0.5, and the table in Figure 38 is a direct excerpt from the DASA-EX.

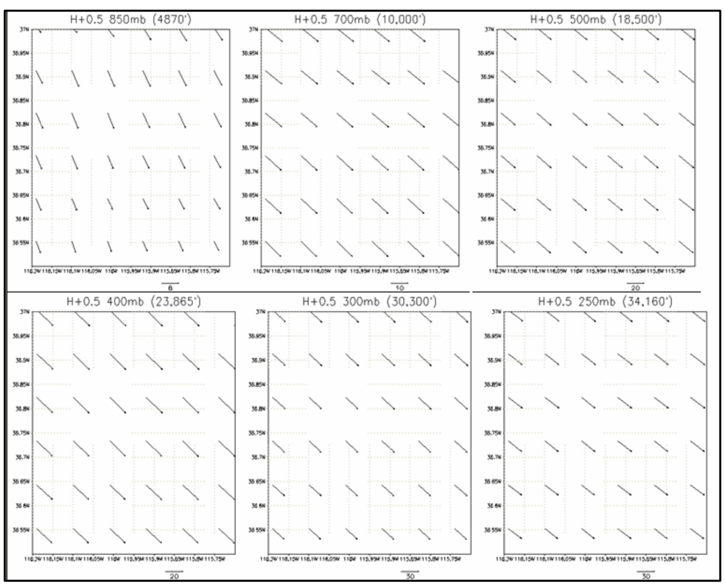


Figure 37. ESS expanded wind field

TABLE 39 NEVADA WIND DATA FOR OPERATION TEAPOT- ESS

Altitude (MSL) feet	H-hour Dir degrees	H-hour Speed mph
Surface	310	12
5,000	310	14
6,000	310	17
7,000	320	17
8,000	320	18
9,000	330	23
10,000	340	29
11,000	350	26
12,000	360	29
13,000	340	26
14,000	330	29
15,000	330	36
16,000	310	39
17,000	300	40
18,000	290	41
19,000	290	40
20,000	290	43
21,000	290	43
22,000	290	46
23,000	290	50
24,000	290	55
25,000	290	54
30,000	290	66
35,000	300	59

Figure 38. ESS wind data DASA-EX excerpt

The winds available for display from RAMS in the ESS simulation straddled the dramatic shift found between 10,000 and 18,000 feet, but shows good correlation at all comparable altitudes. Due to fairly consistent winds at all levels, if there was an effect due to HPAC's incorporation of a stabilized cloud from the DELFIC cloud rise module, it was not identifiable in this test. It should be noted that the ESS test provided the closest match to DASA-EX data, and could be because of the aforementioned reason. If particle transport is consistent at all altitudes, skipping one will not affect the deposition pattern.

Operation Teapot: Zucchini

The Zucchini shot was located between tests George and ESS, and much of the same terrain was shared by all three. Again, the terrain to the east of the burst was of interest, as the fallout footprint trended in the east-northeast direction. Figure 39 shows much the same terrain as used in the ESS analysis, with particular emphasis placed on the ridgelines located in the immediate vicinity of the shot. The washboard ridgelines with the valley to the east are most likely the terrain features that would affect the fallout distribution, as well as the cloud top height of 40,000 feet. Zucchini was a 28 kT tower shot with much more susceptibility to winds near the tropopause, located at 44,000 feet on the day of the test.

Figure 39. Zucchini test terrain

Validation of the RAMS output showed remarkable consistency with historical data, and reproduced a very difficult low pressure system in the Pacific Northwest, as displayed in Figure 40.

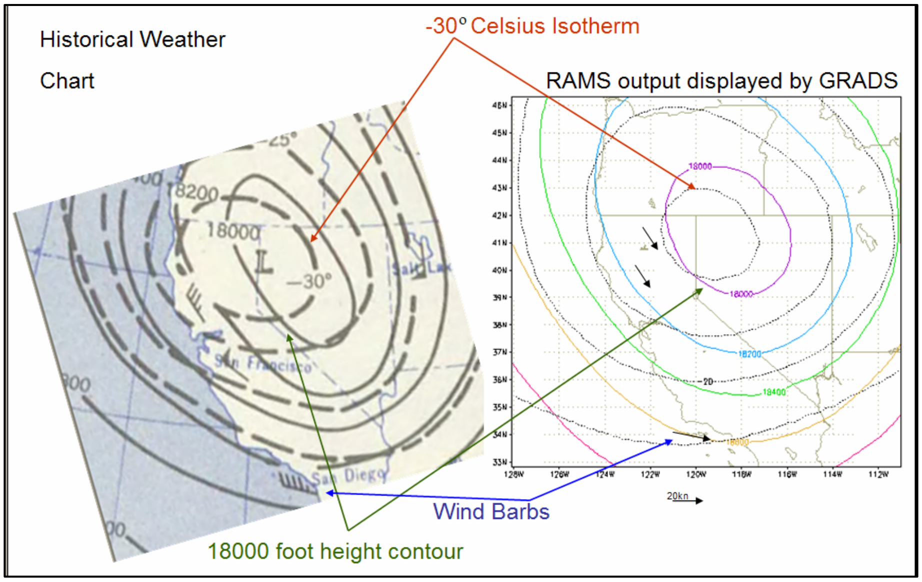


Figure 40. Validation of Zucchini RAMS output

The visualization of the weather patterns on this test date shows a typical wind circulation in a low-pressure system, and was most likely a large factor in fallout distribution. In view of this, one would expect winds to shift throughout the temporal domain observed for this test.

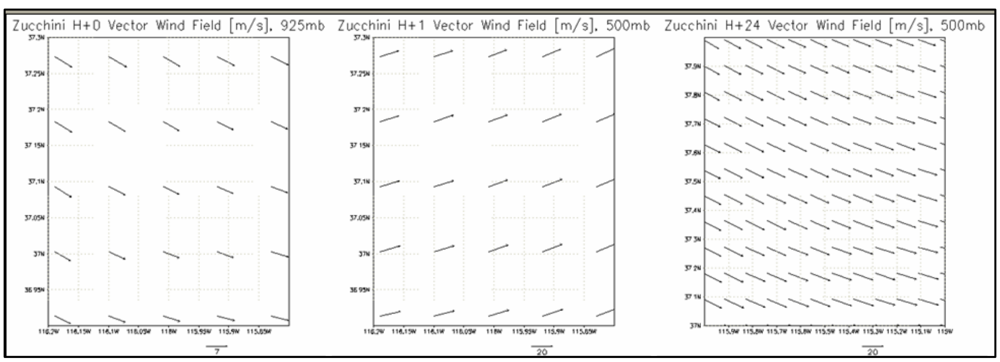


Figure 41. Zucchini vector wind fields

The vector wind field in Figure 41 supports this expectation, as winds are initially out of the northwest at the surface, then from the southwest at H+1, followed by winds from the northwest again at D+1. The shifting winds would suggest a sinusoidal fallout distribution on a “flat earth”, and some of this is observed in the figure from the DASA-EX, shown in Figure 42.

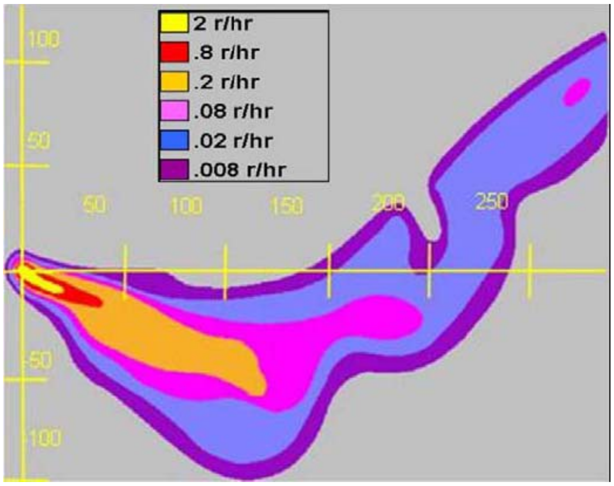


Figure 42. DASA-EX digitized Zucchini contour plot

The initial southeast trend is evident to a distance of about 100 km, and a northeast turn of the plume occurs thereafter. A 7800 foot peak is located where the turn occurs, showing evidence of terrain influence on the fallout pattern. If the elevated terrain was in fact the only reason for the shift, however, there would most likely be a hotspot where the deposited radiation was augmented. As this data is not present, the dramatic shift to the northeast is most likely caused by a shift in wind direction. The notch at 200 km east of ground zero also is located near a series of peaks running east-west near the border of Nevada and Utah. This trend is evident in all three of the HPAC simulations that used terrain data, and the hotspot located in the northeastern corner is present in two of the three HPAC simulations, shown in Figure 44.

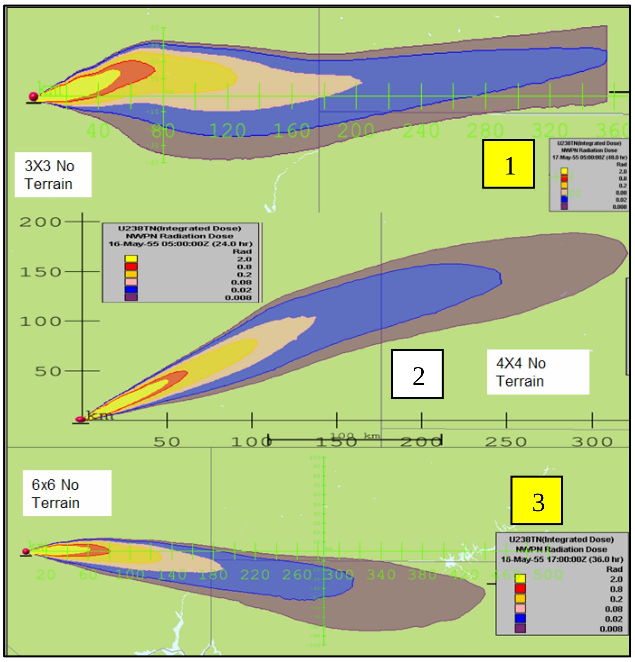


Figure 43. Zucchini, NWP terrain only

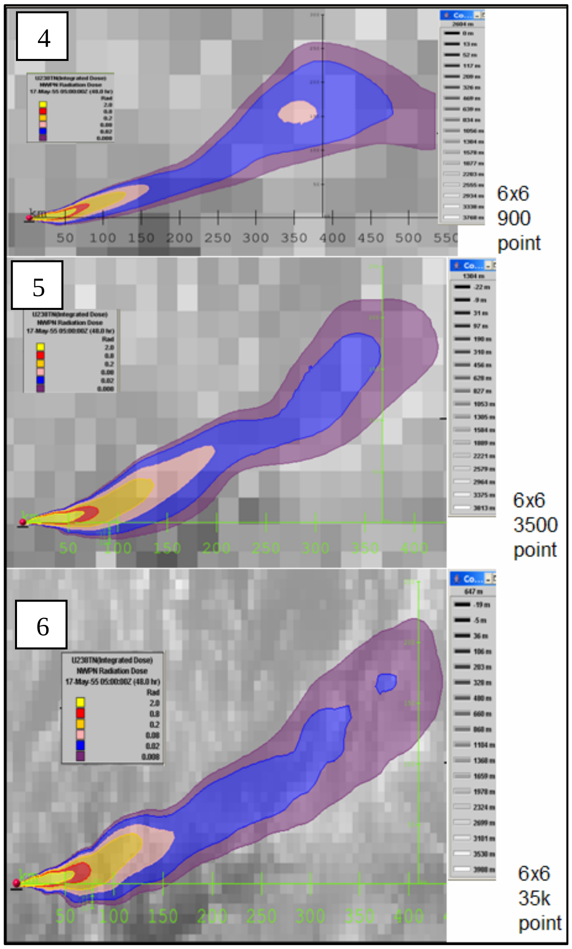


Figure 44. Zucchini, various terrain resolutions

Though the contour plots with the terrain data did faithfully reproduce some of the key features seen in the DASA-EX plot, it was the no HPAC terrain data plots, tests number 1 and 3 that had the least normalized absolute difference, as shown in expanded Figure 45. This is due in large part to the initial southeast trend seen in the two plots. Matching the higher dose-rate contours more consistently gave these plots the advantage in reducing the NAD.

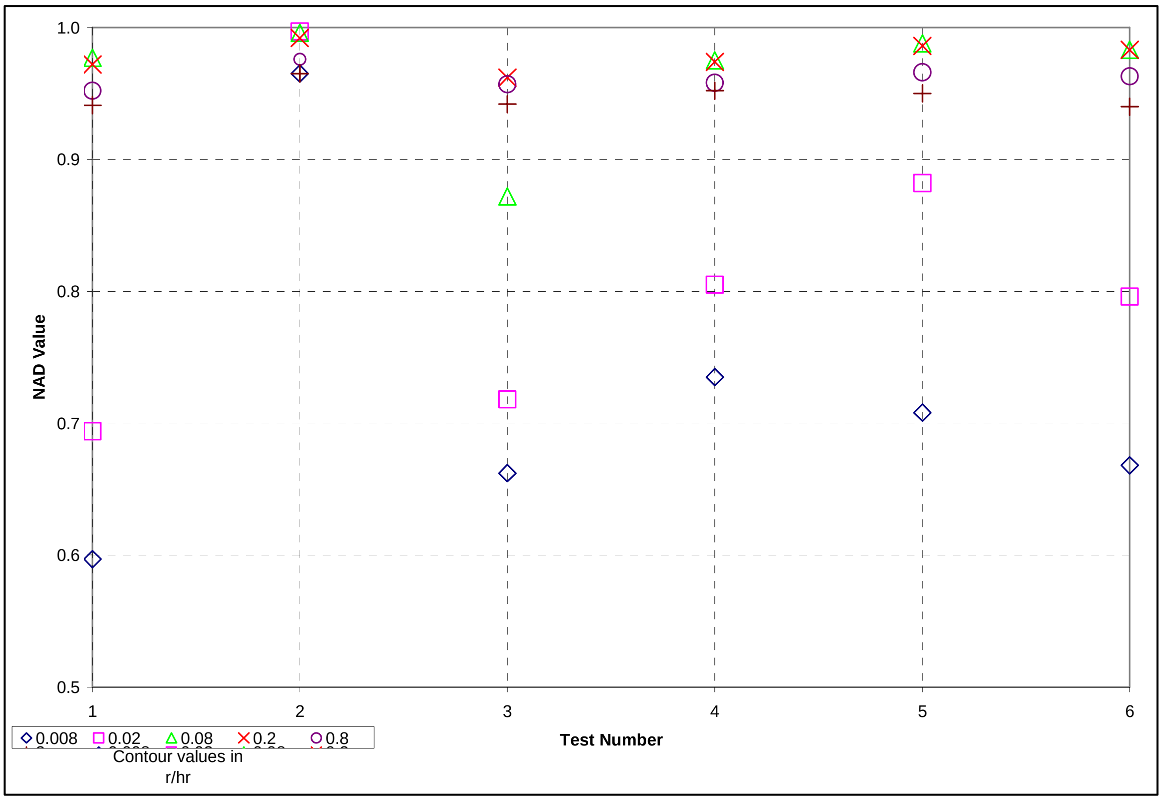


Figure 45. Comparison of Zucchini NAD values by test, lower value is better

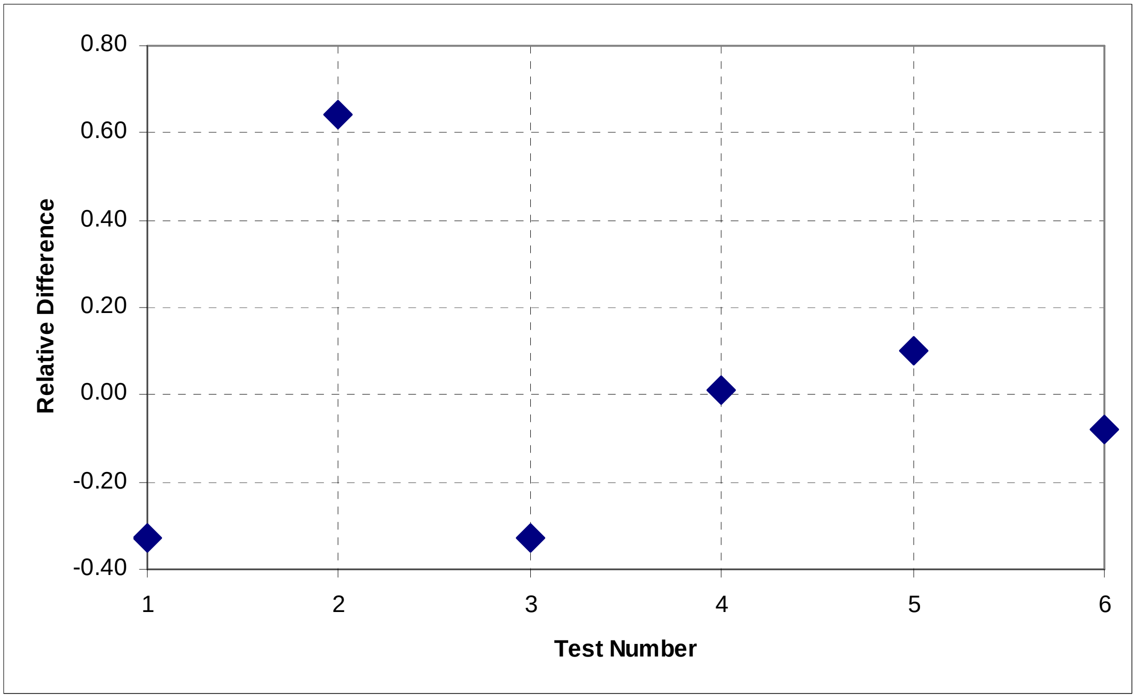


Figure 46. Statistical comparison of Zucchini NAD values, lower value is better

In Figure 47, vector winds are examined from the input GRIB file at H+0, and the table in Figure 48 is a direct excerpt from the DASA-EX.

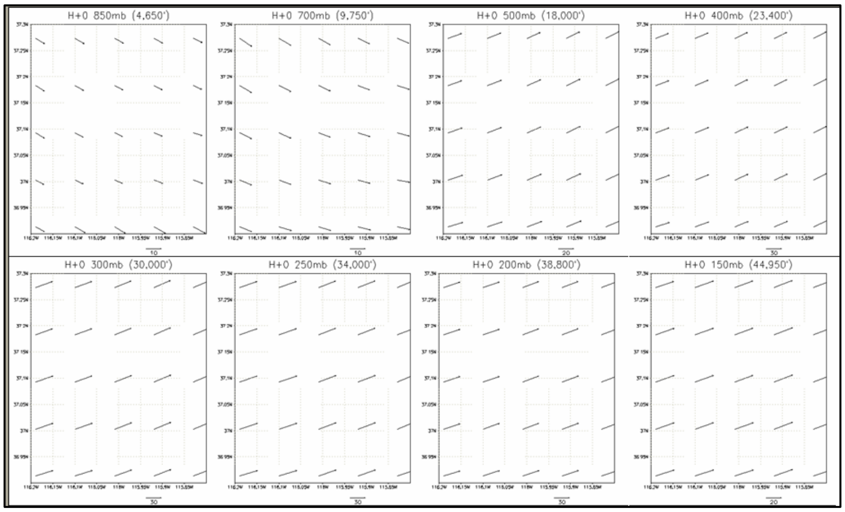


Figure 47. Zucchini expanded wind field

TABLE 46 NEVADA WIND DATA FOR OPERATION TEAPOT- ZUCCHINI

Altitude (MSL)	H-hour Dir	H-hour Speed	Altitude (MSL)	H-hour Dir	H-hour Speed
feet	degrees	mph	feet	degrees	mph
Surface	320	07	26,000	260	74
5,000	330	14	27,000	260	77
6,000	340	13	28,000	260	82
7,000	340	08	29,000	270	83
8,000	340	07	30,000	270	83
9,000	330	09	31,000	270	82
10,000	310	13	32,000	260	80
11,000	300	17	33,000	260	77
12,000	310	25	34,000	260	75
13,000	310	29	35,000	250	74
14,000	310	35	36,000	250	74
15,000	310	40	37,000	250	76
16,000	310	45	38,000	250	79
17,000	300	48	39,000	260	80
18,000	300	49	40,000	260	78
19,000	290	46	41,000	260	72
20,000	290	46	42,000	260	63
21,000	290	49	43,000	260	67
22,000	280	59	44,000	260	41
23,000	270	59	45,000	250	39
24,000	270	63	46,000	240	41
25,000	260	69	47,000	230	46
			48,000	240	45
			49,000	250	40
			50,000	250	31

Figure 48. Zucchini wind data DASA-EX excerpt

Figure 48 shows that the winds at the 850mb, 700mb and 500mb level shift from about 330^{o} to about 260^{o}, and then remaining in this general direction. The wind direction and speed correlate well with the DASA-EX data, making some exception for the singular DASA-EX weather reading. The direction of the surface and low altitude winds would suggest an initial southeast deposition of fallout, especially for the high dose-rate contours. This pattern is prominent in the DASA-EX data, and missing in the HPAC output, as shown in the high NAD values for the higher dose-rate contours.

A probable explanation for this disparity is the instantaneously stabilized cloud used by HPAC's incorporation of the DELFIC cloud rise module. The DASA-EX states that the cloud bottom was at 25,000 ft, and the cloud top was at 40,000 ft. If HPAC calculations assigned values reasonably close to this for cloud dimensions, and instantaneously placed the bulk of the cloud at these levels, then the wind effect at 850mb and 700mb was completely neglected. The fallout distribution was accomplished by gravity motion of particles beginning at about 25,000 ft and descending through the wind fields to ground level. With this methodology, there would be a small amount of high dose-rate deposition toward the southeast from ground zero, with a majority of the deposition occurring in the direction of the prevalent winds at the 400mb level and above, due to the particles having to fall through all layers below its current position before reaching the 700mb wind level. As an example, a particle initially at the 25,000 ft level descending at 1 ft/s would take about 7 hours to reach the ground. The initial 4 of those 7 hours, it would be subjected to 60 mph winds from 260^{o}, with the remaining 3 hours being subjected to 10 mph wind at 320^{o}. This would suggest a pattern mostly in the 260^{o} direction, with a mild turn to 320^{o} at later times, as seen in the HPAC output.

Operation Plumbbob: Priscilla

Priscilla was a 37 kT burst from balloon at 700 ft, located approximately 30 km south of the George test location. The cloud top height was at an elevation of 43,000 ft, with the tropopause at 49,000 ft. The DASA-EX data states that, "…the shapes of the close-in contours were estimated due to a lack of data." [4:274]. Again, the general trend of the fallout deposition was to the east, and the terrain in that direction is shown in Figure 49 with the high ground highlighted. The same washboard effect would be expected close to the surface as in the two previous tests.

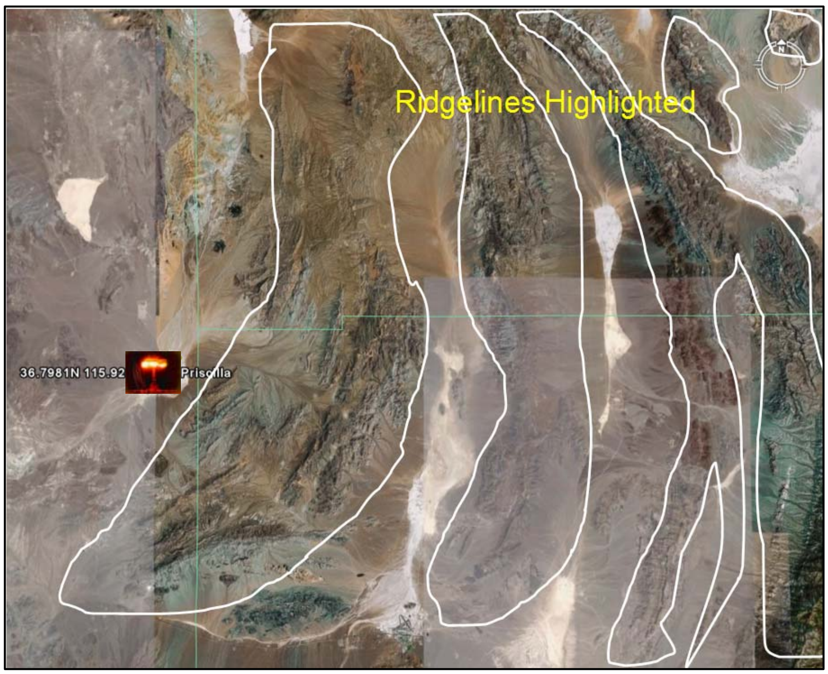


Figure 49. Priscilla test terrain

Validation of the RAMS output with historical weather observations is shown in Figure 50. Although a reasonable match, the data available for historical comparison was taken between 6 pm and 7 pm, 5 to 6 hours prior to the data produced by RAMS. This researcher believes that this is the reason for the obvious disparities between the two data sets, and that although not exact, the values are reasonably close.

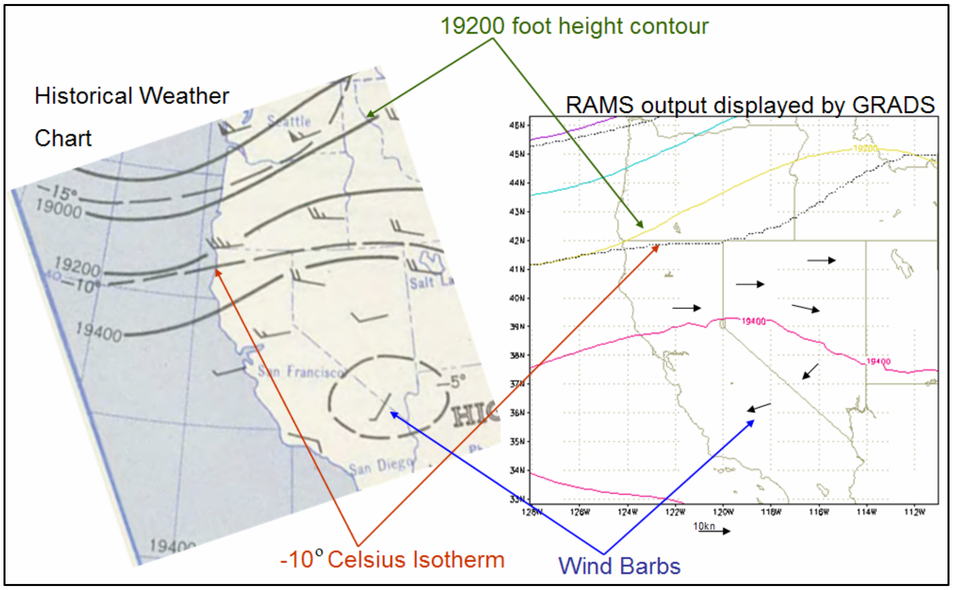


Figure 50. Validation of Priscilla RAMS output

It should be noted that the wind direction in southern Nevada and California is a weak, somewhat circular pattern, as is observed in both charts. This circulating wind pattern is somewhat identifiable in the vector wind fields shown in Figure 51, though the prevalent wind direction is most definitely east by slightly northeast.

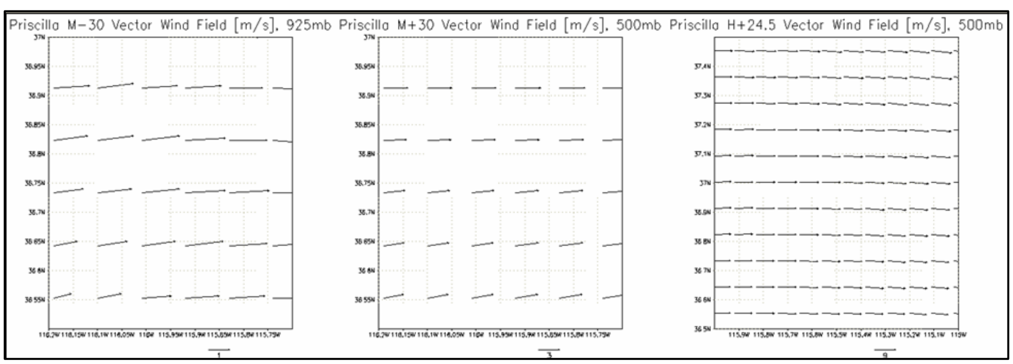


Figure 51. Priscilla vector wind fields

In a "flat earth" situation, the fallout would be expected to be deposited in an east, possibly slightly northeast pattern. Figure 52 shows the digitized DASA-EX contour plot, exhibiting these traits. The small ripples along the southern boundary of the plot loosely follow ridge contours, though cannot be matched exactly.

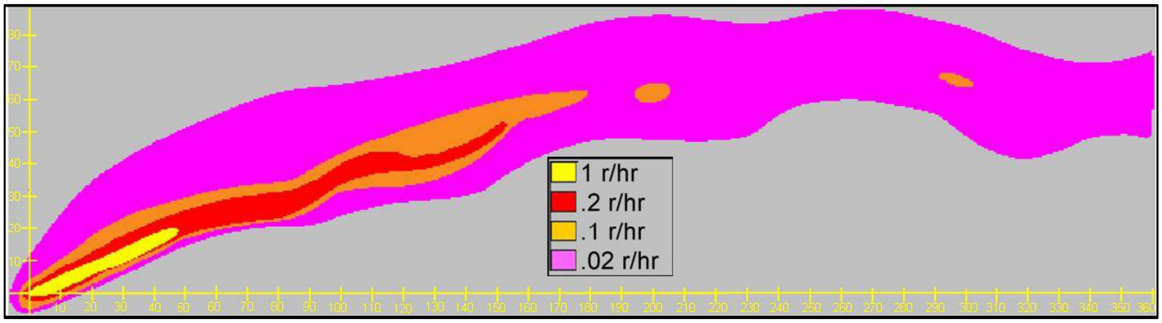


Figure 52. DASA-EX digitized Priscilla contour plot

HPAC simulations were unable to reproduce the initial northward trend of the fallout distribution, and this may indicate an issue with HPAC use of the stabilized cloud produced by the DELFIC cloud rise module. If the surface winds were not accounted for, as seen in Figure 51, most of the mid- and high-altitude winds trend directly east.

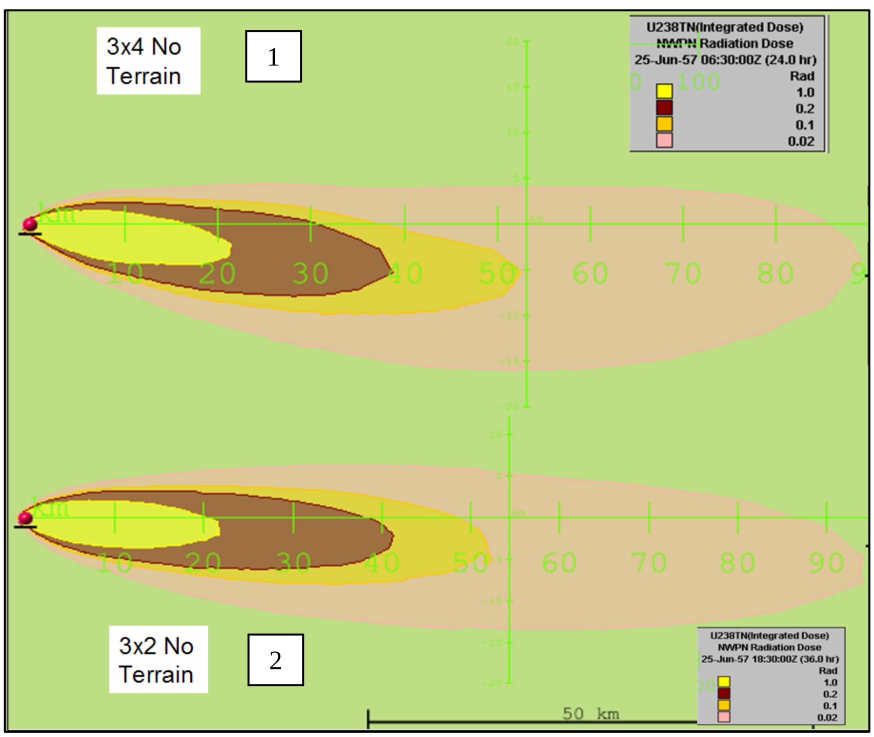


Figure 53. Priscilla, NWP terrain only

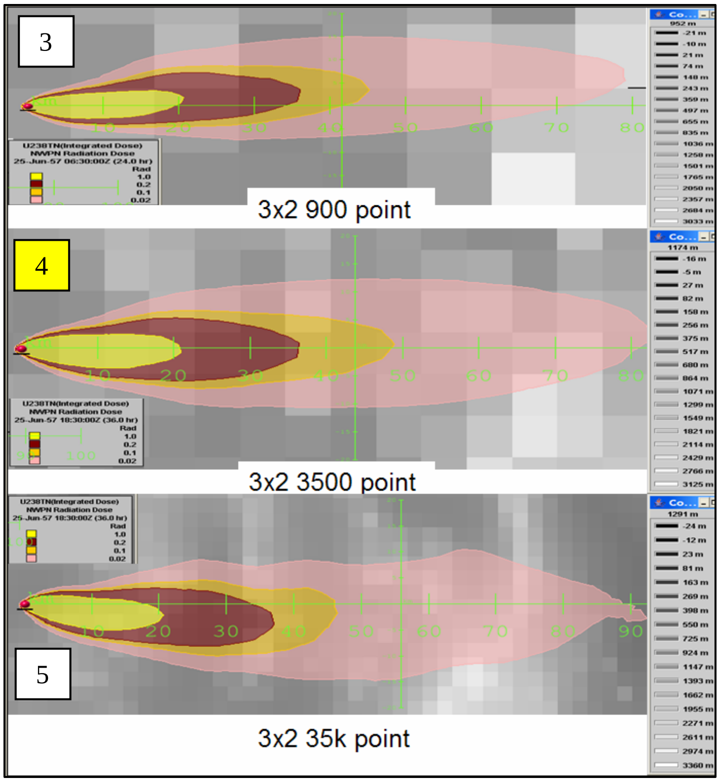


Figure 54. Priscilla, various terrain resolutions

None of the HPAC simulations provided a contour NAD value below 0.75, so correlation with the DASA-EX data was difficult to determine. Without the initial northward trend, all of the plots were essentially directly east of ground zero. Test number 5 began to exhibit some of the rippling seen in the DASA-EX plot caused by the washboard terrain. Though statistically similar, test number 4 highlighted above, had the least normalized absolute difference as shown in Figure 54. This is most likely due to the slightly northeast trend of the contours, which, although not a match, is closer to the DASA-EX data than the other tests.

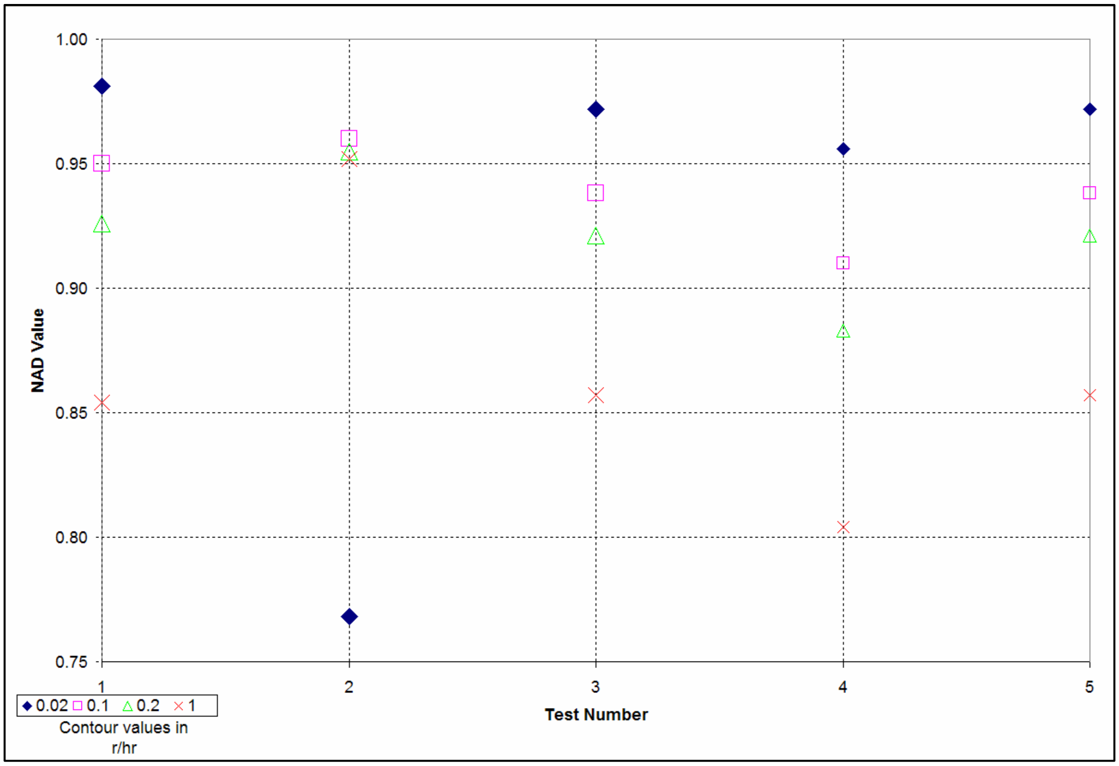


Figure 55. Comparison of Priscilla NAD values by test, lower value is better

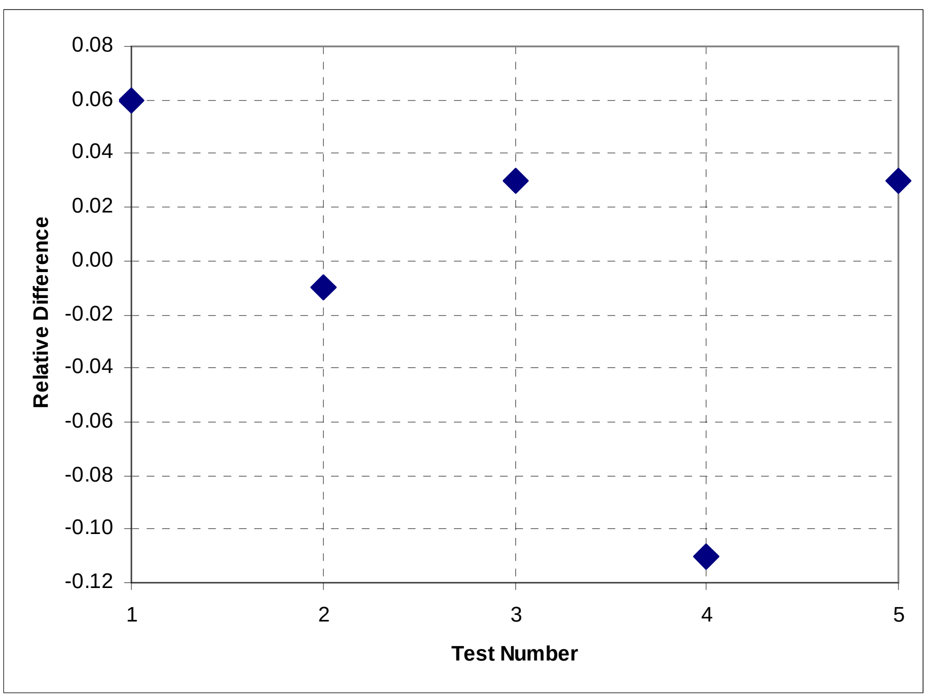


Figure 56. Statistical comparison of Priscilla NAD values, lower value is better

In Figure 57, vector winds are examined from the input GRIB file at H+0.5, and the table in Figure 58 is a direct excerpt from the DASA-EX.

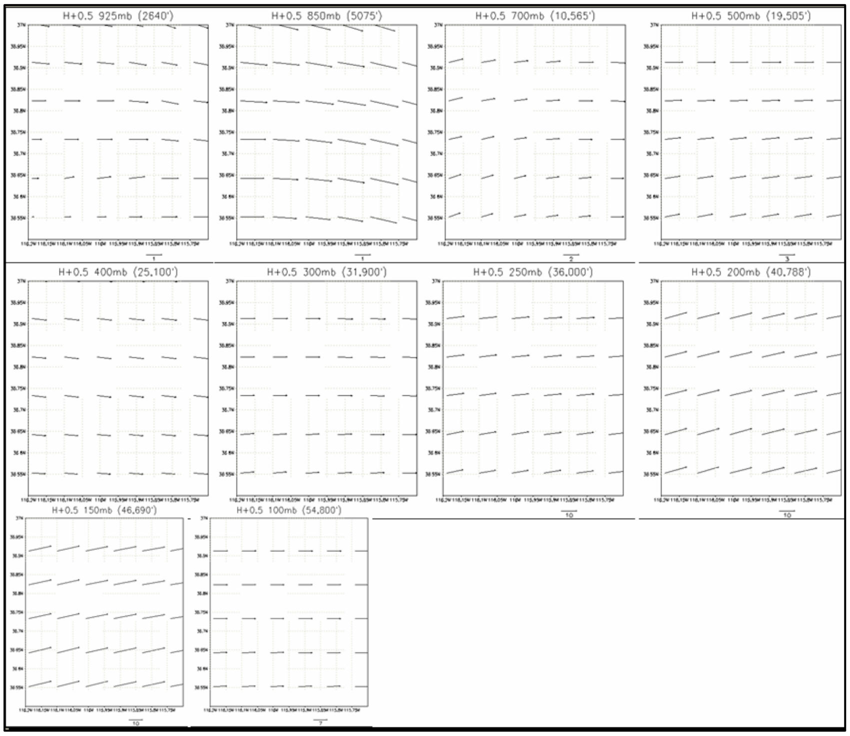


Figure 57. Priscilla expanded wind field

TABLE 51 NEVADA WIND DATA FOR OPERATION PLUMBBOB- PRISCILLA

Altitude (MSL)	H+1 hour		H+4 hours		Altitude (MSL)	H+1 hour		H+4 hours	
	Dir	Speed	Dir	Speed		Dir	Speed	Dir	Speed
feet	degrees	mph	degrees	mph	feet	degrees	mph	degrees	mph
Surface	Calm	Calm	180	05	29,000	250	20	---	--
4,000	Calm	Calm	180	09	30,000	250	20	250	15
5,000	220	03	190	09	31,000	250	18	---	--
6,000	220	07	210	09	32,000	260	16	---	--
7,000	220	07	229	07	33,000	280	12	---	--
8,000	230	09	220	07	34,000	260	15	---	--
9,000	240	09	210	07	35,000	240	15	250	14
10,000	230	09	210	08	36,000	240	20	---	--
11,000	230	07	---	--	37,000	240	23	---	--
12,000	230	08	240	07	38,000	240	26	---	--
13,000	210	09	---	--	39,000	240	32	---	--
14,000	210	08	240	05	40,000	250	41	260	52
15,000	220	07	(250)	(06)	41,000	260	46	---	--
16,000	240	08	260	07	42,000	260	49	---	--
17,000	260	12	---	--	43,000	260	51	---	--
18,000	250	13	240	16	44,000	250	51	---	--
20,000	260	09	240	14	45,000	250	52	250	60
21,000	250	06	---	--	46,000	260	51	---	--
22,000	230	05	---	--	47,000	260	48	---	--
23,000	240	05	230	14	48,000	260	46	---	--
24,000	250	08	---	--	49,000	260	45	---	--
25,000	250	09	240	16	50,000	270	40	270	40
26,000	250	10	---	--	51,000	270	29	---	--
27,000	250	16	---	--	52,000	270	29	---	--
28,000	250	17	---	--	53,000	270	29	---	--
					54,655	270	29	---	--

Figure 58. Priscilla wind data DASA-EX excerpt

The various levels with wind direction to the northeast at about 250^{o} are shown in Figure 57. Although this trend is seen throughout the wind column, the winds from the cloud bottom at 24,000 ft to the cloud top at 43,000 ft correlate to the simulation data from 400mb to 200mb. In this selection seen in Figure 58, the winds are generally from about due west, 270^{o}. Therefore, the particles are initially subject to transportation in the easterly direction, only turning slightly to the north after gravitational descent to about the 700mb level.

There is also some disparity with wind at the 400mb level between the DASA-EX and the RAMS simulation data. In the DASA-EX, the wind direction is listed at 250^{o}, while the simulation produced wind at about 275^{o} for this level. As identified in the historical comparison, the weak low-pressure system in the Pacific southwest could have caused some anomaly in simulation, exhibited in the wind data for this test.

Again, this could demonstrate an area where DELFIC cloud rise is not as accurate a method when varying wind directions are found in a column of air. In this test, the higher dose-rate contours had a lower NAD than the lower dose-rate contours. Gravitation might best explain this, as the more massive particles fall more quickly than the less massive particles. If the massive particles are more quickly affected by the slightly northeast winds, then the pattern of deposition would more closely match initial northeast bend of the fallout footprint. In turn, the smaller particles would be subject to the 270^{o} winds for a longer period of time, producing the results shown in the HPAC contour plots.

Operation Plumbbob: Smoky

Smoky was a 700 foot, 44 kT tower burst approximately 3 km to the northwest of the ESS test site. The cloud top height reached 38,000 feet, above the tropopause height of 35,000 feet on the test date. As the test was in the same general vicinity of the previous four tests described, again with an easterly area of interest. The valley to the immediate east of the test site, and highlighted in Figure 59 was expected to affect the deposition pattern affected by surface winds.

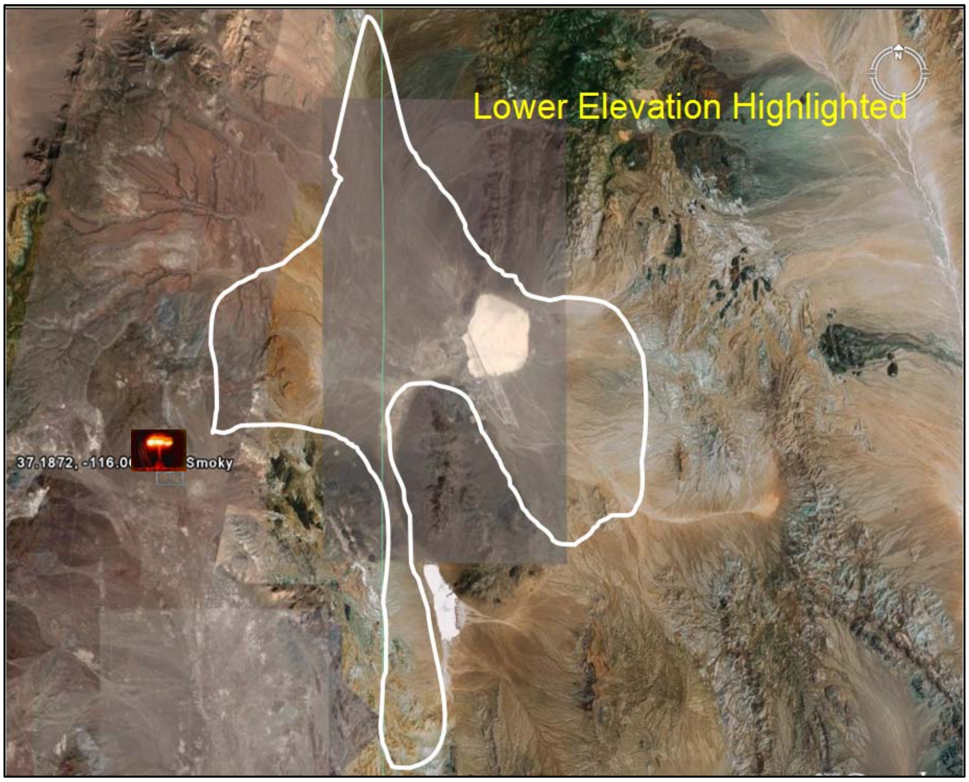


Figure 59. Smoky test terrain

Validation of the RAMS output with historical weather observations is shown in Figure 60. The isotherm, wind barb, and height contour data are consistent with the RAMS output, with little disparity due to temporal variation.

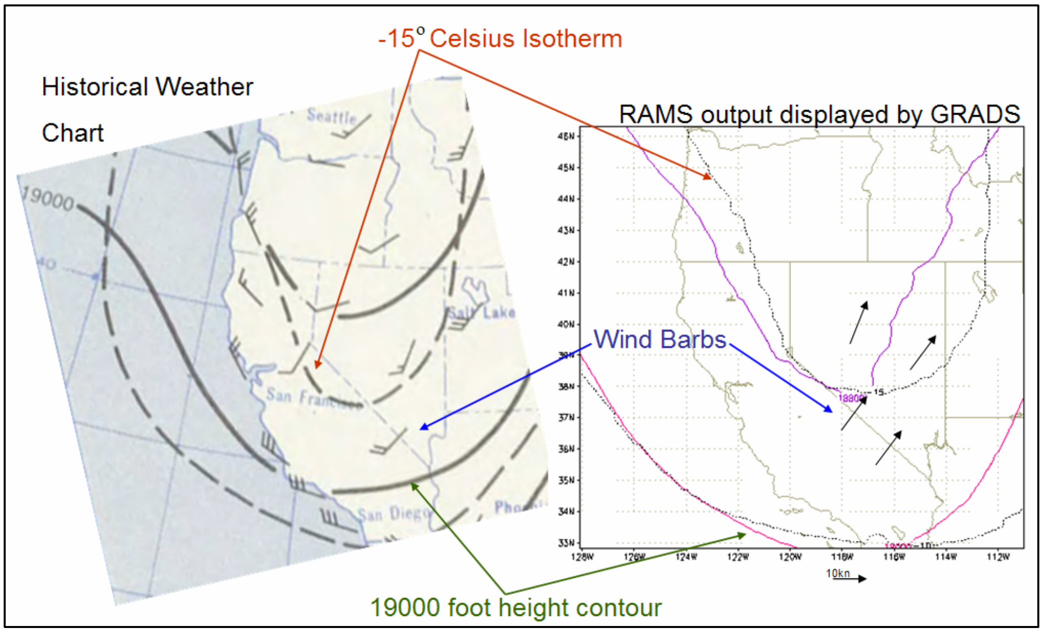


Figure 60. Validation of Smoky RAMS output

As displayed in the comparison above, winds are generally out of the southwest, as shown in the vector wind fields in Figure 61. Although outside of the nested weather input to HPAC, the circulation caused by the weak low-pressure system in the Pacific Northwest are evident in the historical weather chart, and the effects are seen in the figure below with a shift of winds from the southwest to the northwest.

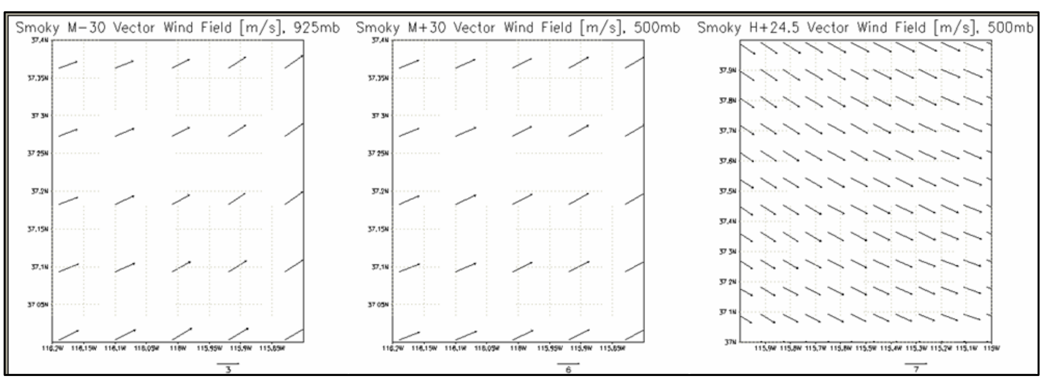


Figure 61. Smoky vector wind fields

Based on the topographical data and wind direction, on a "flat earth" scenario, the fallout would expected to be deposited initially in a northeast direction, then shifting to a southeast direction. The DASA-EX data shown in Figure 62, however, shows an initial southeastern deposition, followed by a turn to the northeast.

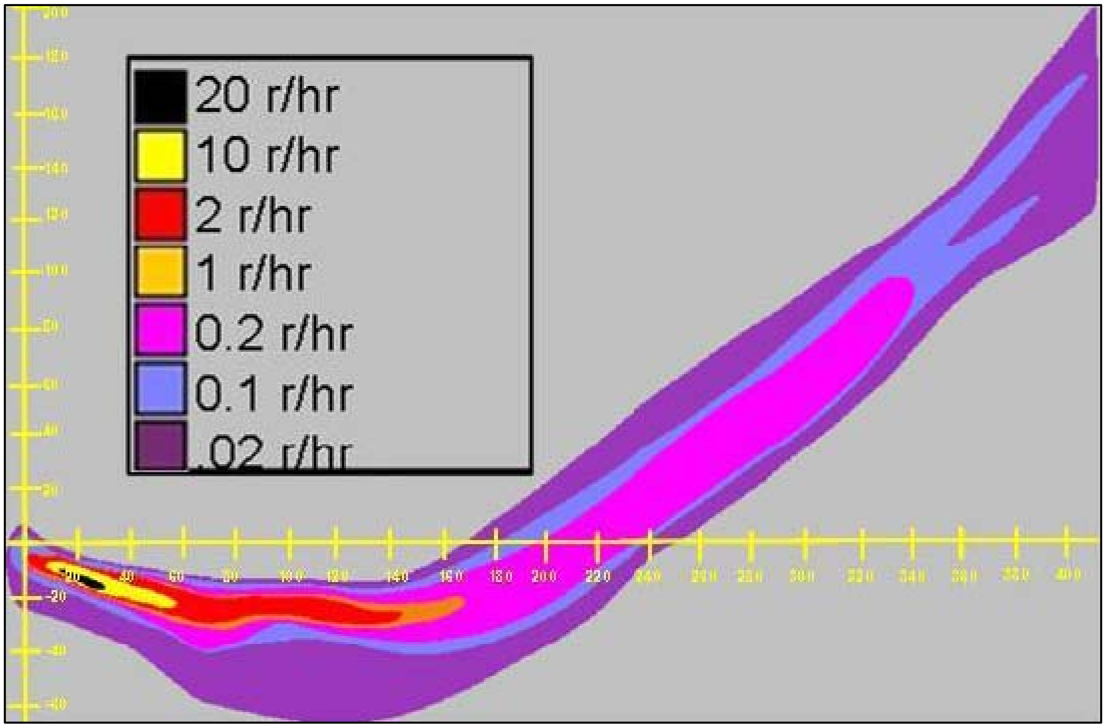


Figure 62. DASA-EX digitized Smoky contour plot

The HPAC simulations conducted were unable to reproduce this pattern, and more closely followed the wind field direction for the temporal domain of the test. Figure 63 shows the tests conducted without HPAC terrain, and test 2 appears to closely follow the wind data viewed over the entire temporal domain for the test. The dramatic turn in the HPAC prediction from the northeast to southeast is not located near any drastic change in terrain, and can only be explained by a shift in wind speed and direction.

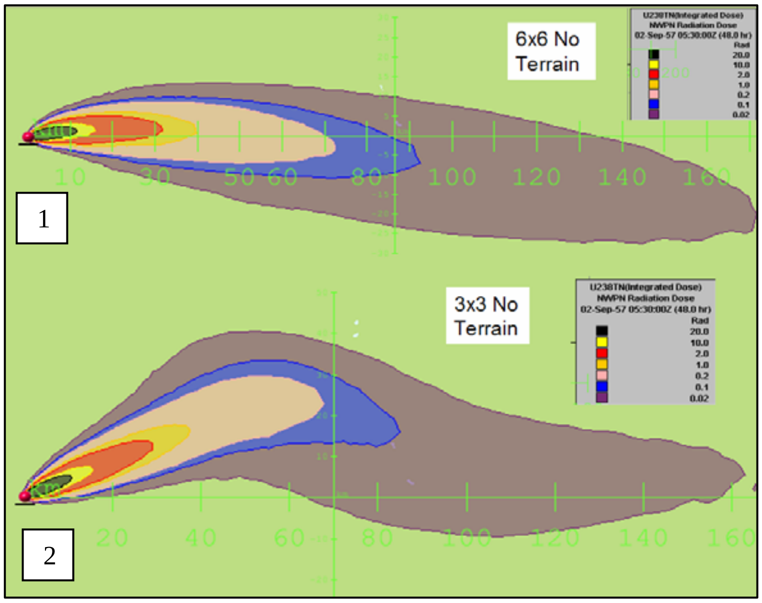


Figure 63. Smoky, NWP terrain only

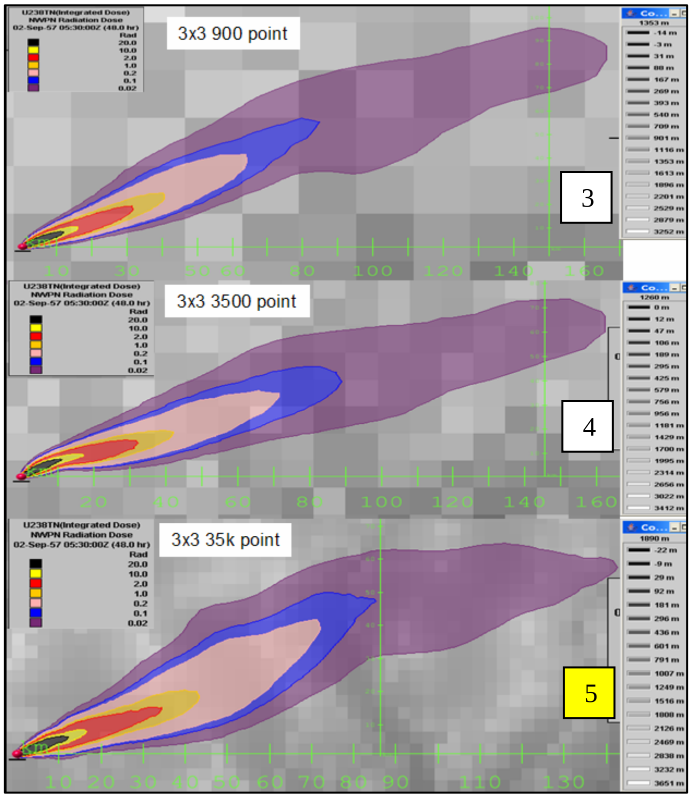


Figure 64. Smoky, various terrain resolutions

As is evident from the contour plots, the NAD was high for all tests, with a minimum of about 0.88, but most of the NADs near 1.0, meaning a total difference between HPAC and DASA-EX data. Figure 65 is the NAD comparison, expanded greatly to show differences in test values, which were statistically similar. Test 5, with 35000 points of terrain data was the closest match, mainly due to the fallout dispersion more closely following the eastern axis from ground zero.

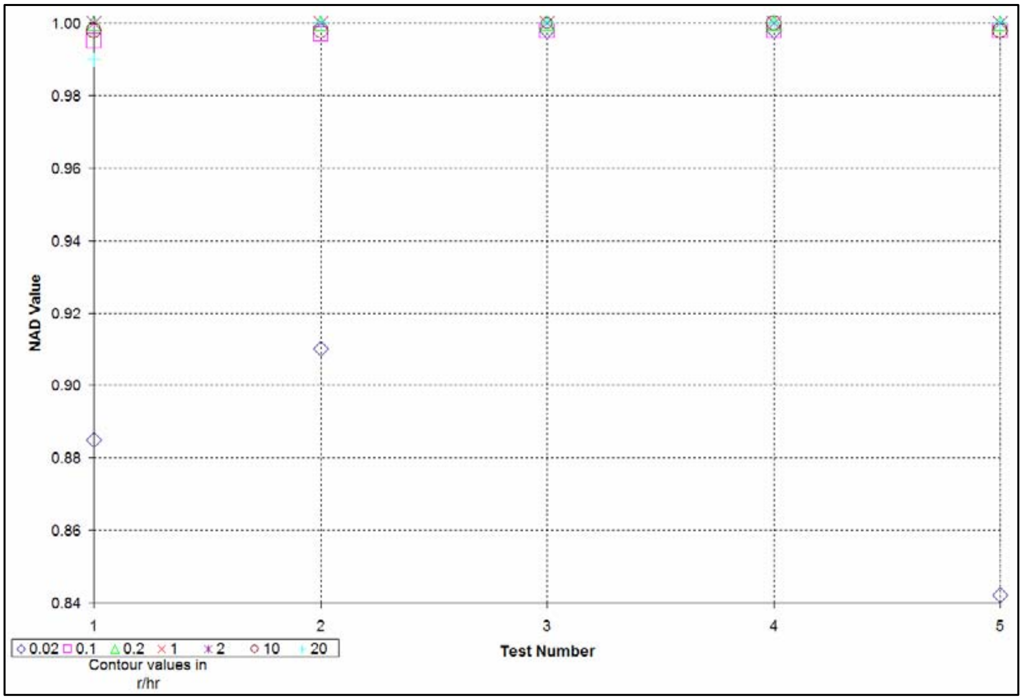


Figure 65. Comparison of NAD values by test, lower value is better

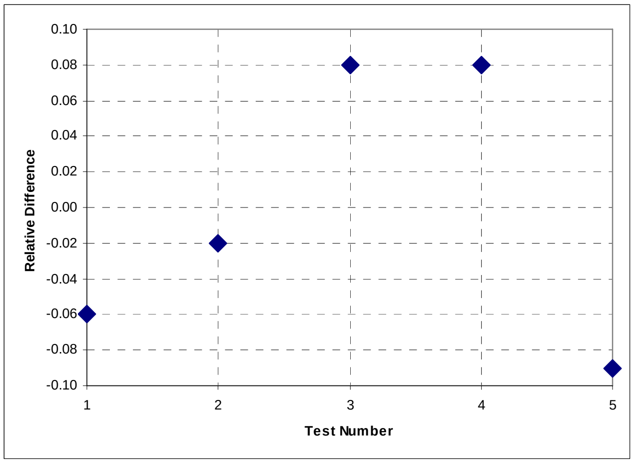


Figure 66. Statistical comparison of Smoky NAD values, lower value is better

In Figure 67, vector winds are examined from the input GRIB file at H+0.5, and the table in Figure 68 is a direct excerpt from the DASA-EX.

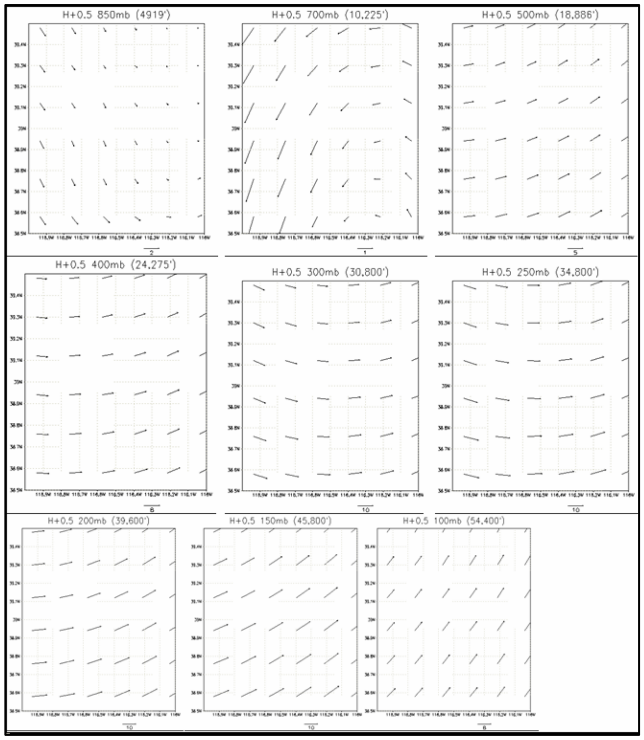


Figure 67. Smoky expanded wind field

TABLE 61 NEVADA WIND DATA FOR OPERATION PLUMBBOB- SMOKY

Altitude (MSL) feet	H-hour Dir degrees	H-hour Speed mph	H+3 hours Dir degrees	H+3 hours Speed mph
Surface	Calm	Calm	Calm	Calm
5,000	Calm	Calm	330	05
5,179 (BH)	Calm	Calm	---	--
6,000	340	06	350	05
7,000	010	07	060	07
8,000	010	07	080	09
9,000	010	10	040	06
10,000	360	12	360	06
11,000	360	09	---	--
12,000	360	07	360	05
13,000	360	07	---	--
14,000	020	07	280	06
15,000	340	09	(280)	(09)
16,000	290	13	280	13
17,000	280	18	---	--
18,000	290	22	290	20
19,000	290	21	---	--
20,000	280	24	300	23
21,000	280	29	---	--
22,000	280	29	---	--
23,000	280	30	280	31
24,000	270	35	---	--
25,000	270	36	280	38
26,000	280	36	---	--
27,000	270	33	---	--
28,000	270	31	---	--
29,000	280	36	---	--
30,000	280	37	300	33
31,000	280	33	---	--
32,000	280	36	---	--
33,000	270	38	---	--
34,000	270	37	---	--
35,000	270	37	300	35
36,000	270	40	---	--
37,000	270	44	---	--
38,000	270	43	---	--
39,000	270	39	---	--
40,000	270	35	250	33
41,000	270	32	---	--
42,000	270	36	---	--
43,000	260	38	---	--
44,000	260	35	---	--
45,000	250	38	250	39
46,000	230	45	---	--
47,000	250	40	---	--
48,000	260	36	---	--
49,000	250	35	---	--
50,000	240	31	240	25

Figure 68. Smoky wind data DASA-EX excerpt

It must be noted that the DASA-EX weather data was taken from “the Yucca weather station.” [4:329] Research into this revealed that the now non-operational station was located about 100km northwest of the test site, in an area affected by the low-pressure system seen in the historical weather chart. The RAMS output faithfully reproduces the winds found at this site, but it is not useful in analyzing the winds at the test site, shown in Figure 69.

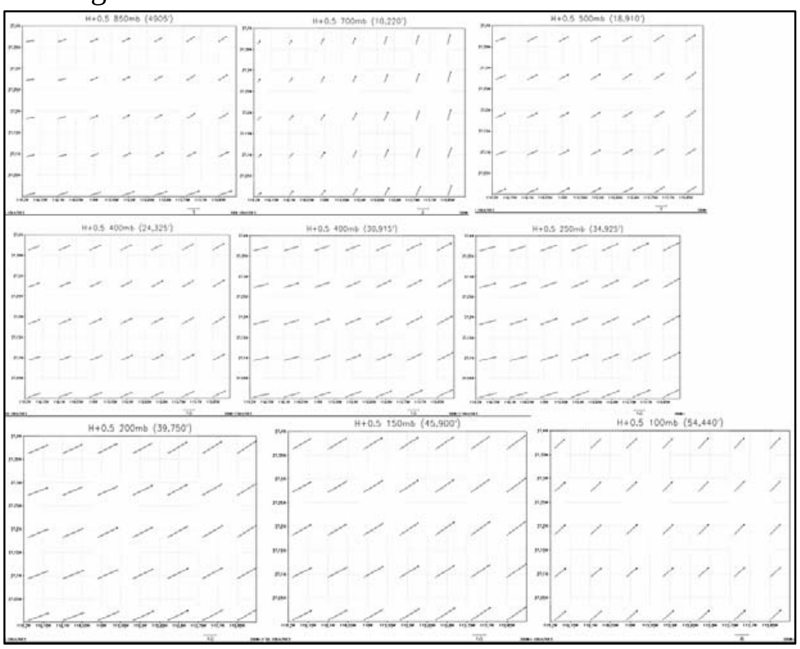


Figure 69. Smoky test site expanded wind field

An analysis of this wind field does not show the expected winds to the southeast, which would allow a correlation to the DASA-EX data, but it does show differing winds at the 700mb level which would explain the exaggerated northward trend of the fallout seen in the HPAC plots. As the cloud bottom height is missing from the DASA-EX data, and the cloud top is at 38,000 ft, the general northeast trend of the fallout at this height is expected, with no logical explanation found for the southeastern curve in the DASA-EX contour plot.

Operation Sunbeam: Johnie Boy

Johnie Boy was a 0.5 kT shallow underground burst conducted over the ridgeline and about 25km to the west of the previous five tests. The dashed lines in the original DASA-EX data (shown in Figure 73A) indicate uncertainty of data, and encompasses most of the contour data. A cloud top height of 17,000 ft was well below the tropopause, located at approximately 41,000 feet on the test date. The area of interest in this test was directly north of the burst, and consisted mainly of a series of ridgelines as shown in Figure 70.

Figure 70. Johnie Boy test terrain

With a relatively low cloud top height and such varying terrain, surface effects were most likely a large factor in the distribution of fallout. Validation of the RAMS output with historical weather observations is shown in Figure 71. The isotherm, wind barb, and height contour data are consistent with the RAMS output, with little disparity due to temporal variation, as was the case in Smoky.

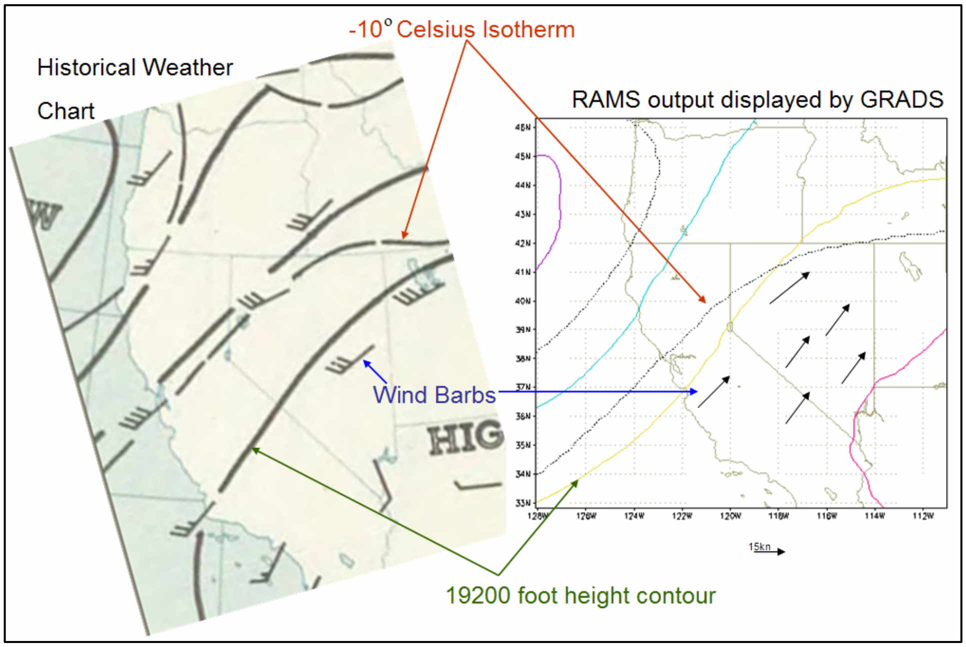


Figure 71. Validation of Johnie Boy RAMS output

Strong winds from the southwest continued from M+15 to D+1, with very little variation, as displayed in Figure 72. Based on the wind data, in a "flat earth" simulation, the fallout would be expected to be distributed directly north-northeast of ground zero.

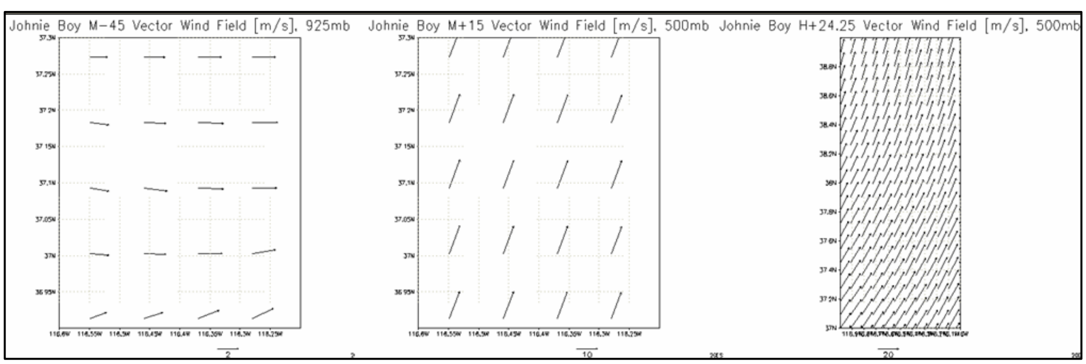


Figure 72. Johnie Boy vector wind fields

Perhaps due to the low cloud top height and rough terrain, the DASA-EX data shows the fallout footprint to be trending northwest, prior to shifting northeast of ground zero, as shown in Figure 73B.

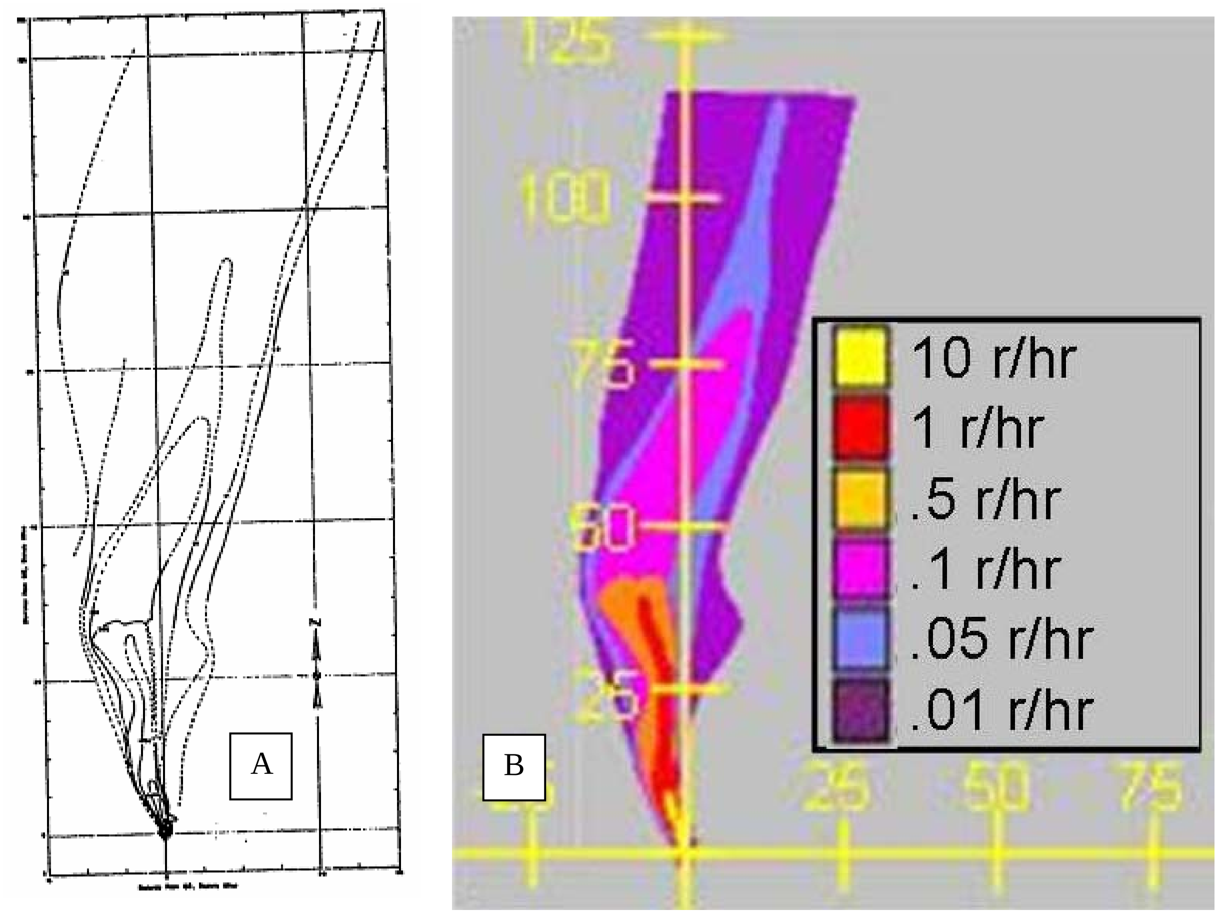


Figure 73 A and B. DASA-EX Johnie Boy contour plots

The HPAC simulations were unable to reproduce the initial northwest trend displayed in the DASA-EX, as shown in Figure 74 and Figure 75. In all cases, the plume computed by HPAC immediately trended toward the northeast, and maintained this directionality throughout the entire temporal domain. As such, the simulations in HPAC had a large NAD, with a minimum value of 0.99, and most values at 1.0, indicating no correlation between the HPAC and DASA-EX data.

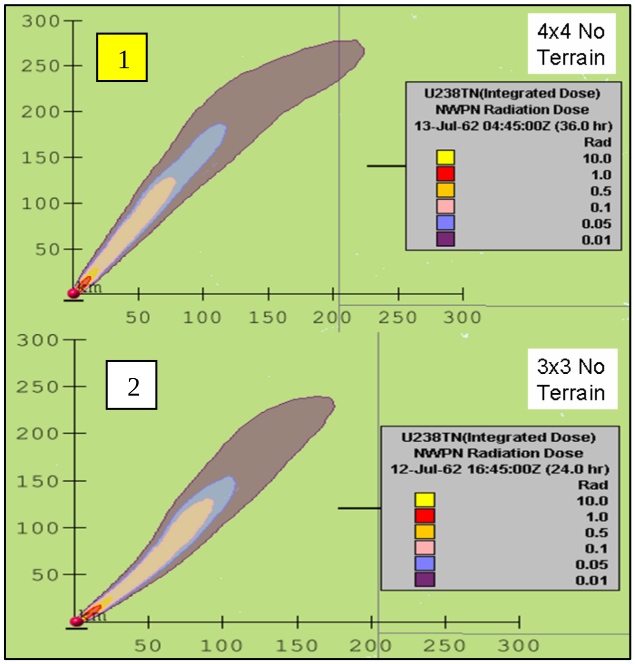


Figure 74. Johnie Boy, NWP terrain only

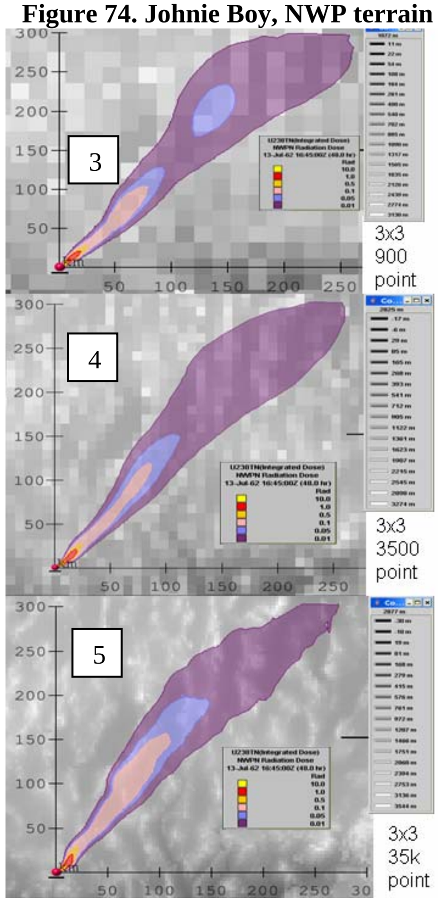


Figure 75. Johnie Boy, various terrain resolutions

Though statistically identical, the comparison of NAD values shows that test 1, without HPAC terrain was the closest match to the DASA-EX data. Figure 76 is a greatly expanded NAD comparison, showing that while the differences were small in each test, there was a measurable deviation, shown in Figure 77.

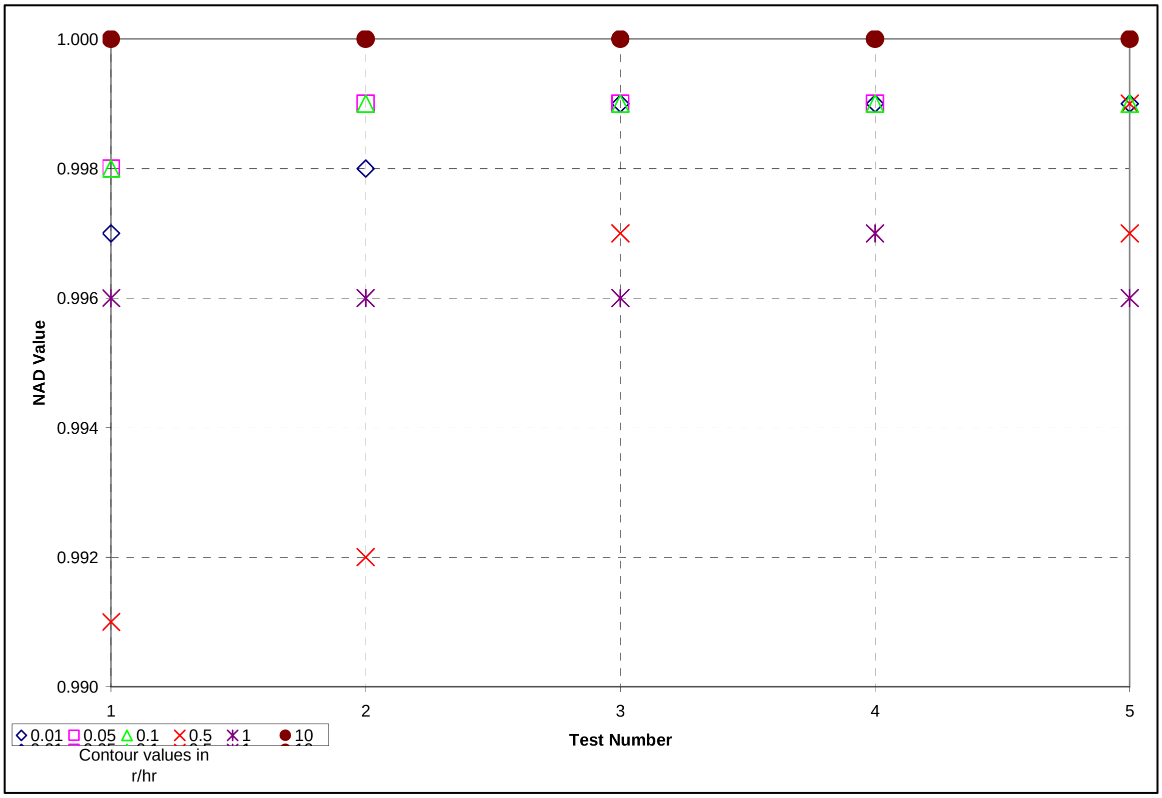


Figure 76. Comparison of Johnie Boy NAD values, lower value is better

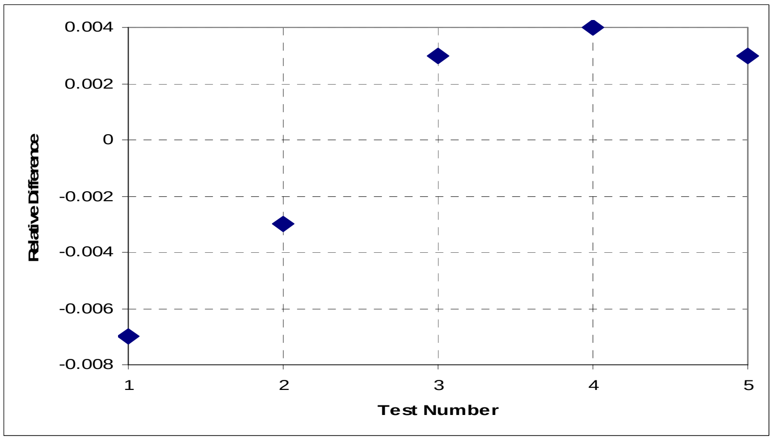


Figure 77. Statistical comparison of Johnie Boy NAD values, lower value is better

In Figure 78, vector winds are examined from the input GRIB file at H+0.25, and the table in Figure 79 is a direct excerpt from the DASA-EX.

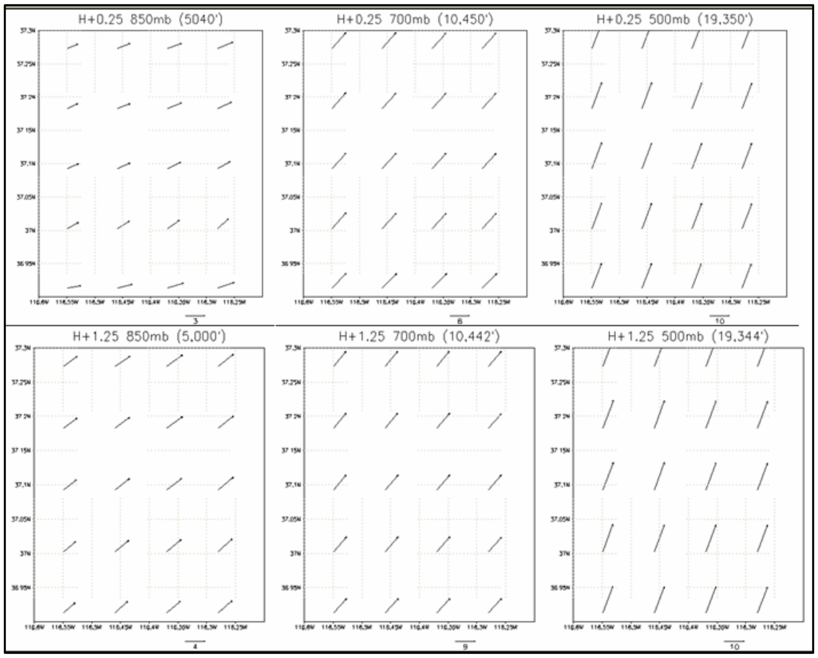


Figure 78. Johnie Boy expanded wind field

TABLE 108 NEVADA WIND DATA FOR OPERATION SUNBEAM - JOHNIE BOY

Altitude (MSL)	H-hour Direction	H-hour Speed	H+1 hour Direction	H+1 hour Speed
feet	degrees	mph	degrees	mph
Surface	195	8.1	210	17.3
6,000	170	8.1	210	11.5
7,000	160	8.1	170	10.4
8,000	160	12.7	150	12.7
9,000	160	18.4	170	12.7
10,000	170	17.3	190	11.5
11,000	180	13.8	200	11.5
12,000	180	17.3	200	17.3
13,000	190	20.0	200	25.3
14,000	200	24.2	200	25.3
15,000	200	25.3	210	29.9
16,000	200	25.3	210	29.9
17,000	200	31.1		
18,000	200	31.1		
19,000	210	29.9		
20,000	200	26.5		

Figure 79. Johnie Boy wind data DASA-EX excerpt

Comparison of both the H+0 and H+1 wind fields were conducted, and in neither case was the elevation resolution available from the simulation data to capture the wind direction between 6,000 and 10,000ft. The winds that bracket this region, at 850mb and 700mb, show a strong correlation to the DASA-EX data, but the assumption cannot be made that the values in between the pressure levels are comparable. The cloud bottom was at 12,500 ft and the cloud top was at 17,000 ft, spanning the 700mb and 500mb pressure levels. Figure 78 shows that the prevalent wind in these levels was east of north, and the fallout pattern produced by HPAC was east of north. With near-instantaneous DELFIC cloud rise, the radioactive particles would not have been subject to winds in the column between 850mb and 700mb until they had fallen to those levels. In this case, the northeast fallout contour pattern seems reasonable, yet it shows little correlation with the DASA-EX data.

V. Conclusions and Recommendations

Chapter Overview

This chapter identifies trends and summarizes the analysis conducted in the previous chapter. Conclusions are drawn based on available data and results found through research that support them. Finally, suggestions for future research in this topic are presented.

Conclusions

High resolution synoptic weather forecasts were produced using the RAMS software, with nesting capability providing extremely fine mesoscale weather data configured for input into HPAC. The weather data was validated against historical observations, with anticipation that improved weather data input for HPAC would produce accurate, comparable results to historical fallout data. Analysis showed, however, that the current HPAC software used the DELFIC / NEWFALL cloud rise module by instantaneously placing the radioactive cloud at stabilized height, and neglecting the weather dynamics at lower altitudes until later times, when gravity induced particle settling occurred. By disregarding the impact of these surface and low-altitude winds, the initial fallout containing the particles with the highest dose-rate was not accurately dispersed on the ground, regardless of the level of terrain selected.

The results of lowest NAD values did not show a trend for a best fit resolution to match the weather input; no HPAC terrain values were selected twice, 900 point resolution selected twice, and the 3500 point and 35,000 point each being selected once. If there were truly a correlation between weather and terrain resolution, it would have been evident in the data analysis. In addition, there was not an identifiable trend in fitting the prediction of contours, as different terrain resolutions provided a better fit for some of the high dose-rate contours, while other simulations fit the low dose-rate contours better within the same data set.

Trends that were observed included the neglect of lower-altitude wind effects on the fallout patterns in all tests. In cases such as ESS and George where the winds had very slight variations throughout the column, there was no significant impact on simulation results, and the HPAC output provided a reasonable correlation with the DASA-EX data. In other cases, with Zucchini as a particular example, ignoring the low-altitude winds caused dramatic results in the output, completely removing an important contour shift in the early fallout deposition. This also results in a trend of higher dose-rate deposition being located further from ground zero, in the direction of the prevalent upper-altitude winds. The result of this trend in HPAC is an improper identification of high dose-rate areas, which could be critical in protection of first responders.

The HPAC user's manual indicates that weather input is paramount in accuracy of results, being the one requirement for input on any simulation [8:483]. This researcher reasonably expected that inclusion of the most accurate weather available would improve the predictive capability of the HPAC software. The overall result of the research is the identification of a probable discontinuity in using the weather input because of the way that the DELFIC code is integrated in HPAC. Further exploration of this subject may result in a method of bypassing or replacing the initial cloud rise algorithms to produce a more accurate predictive tool.

Recommendations for Future Work

With the above conclusions, there are two possible directions for future research that could improve the HPAC predictive capabilities and make it a more useful tool for planning and response teams. First, HPAC's incorporation of the DELFIC cloud rise module output data needs to be carefully examined to ensure that low-altitude winds are accounted for during the initial cloud rise. The inclusion of this primary fallout information could greatly increase the accuracy of predicting highly contaminated locations and assist in accurately recreating the conditions present at the time of testing. This would allow for further research into capturing other atmospheric test data that must be simulated because of a lack of observational data, and validate that HPAC is producing reliable results. Second, the direct incorporation of weather model terrain could eliminate any disparity between weather and terrain resolution. Each of the weather models listed in the HPAC manual contains terrain data upon which predictions are based. The terrain data available for RAMS is at 30 second resolution, and can be a parameter selected for output. The format of the terrain model used, however, is not recognized by HPAC's terrain reader. If, like weather, terrain input was a selectable parameter in simulations, then it is possible that accuracy could be improved in the output without HPAC crashing while using native terrain selection.

In both of the possible research directions above, the high-resolution, nested RAMS data sets produced for this thesis can be reused. The future researcher must recall that the data is temporally and spatially specific to the six tests used in this research, and must use the same parameters to obtain usable results. An electronic copy of the data sets is stored with the thesis advisor on removable media.

Appendix A: Namelist Definitions

Atmospheric namelists

$MODEL_GRIDS: this namelist provides information to the model primarily on the structure of the one or more nested grids used in a simulation, including location, mesh size, number of mesh points, spatial nesting relationships, time step length, and time and duration of the run.

$MODEL_FILE_INFO: this namelist consists primarily of variables that control data input to and data output from the model.

$MODEL_OPTIONS: this namelist is where the majority of choices for specifying model parameterization options are made.

$MODEL_SOUND: this namelist consists of a set of variables for specifying a sounding to be used in initializing a simulation.

$MODEL_PRINT: this namelist provides a means for obtaining a quick look at model fields. It is used to specify selected data from the model to be written to the standard output file generated with a model run.

Isentropic Analysis namelists

$ISAN_CONTROL: this namelist controls the isentropic/σ_z input of observational upper air datasets.

$ISAN_ISENTROPIC: this namelist controls the number of isentropic levels on which to perform objective analysis.

Appendix B: REVU Input Namelist

```
      ! Possible output formats:
 !ANATYPE='GRADS',    ! For plotting with GRADS
 ANATYPE='GRIB',      ! Gridded Binary
 !ANATYPE='SPACE'     ! NCAR Graphics spatial axis plots
 !ANATYPE='V5D',      ! Vis 5D
 !ANATYPE='DUMP',     ! Dump in user-defined format
 !ANATYPE='GRAB',     ! Output at points specified by user
 !ANATYPE='STATS'     ! For statistical comparison
 HEAD1='',         ! top header line (not used)
 HEAD2='',         ! 2nd header line (not used)
 IGRID=0,          ! Grid number to plot
                   !  0 for all grids, negative for abs(igrid) and finer
 IZTRAN=3,          ! If horizontal slab
               !   1=terrain-following surface
               !   2=interpolate to Cartesian surface
               !   3=interpolate to pressure surface
IPLEVEL=925,        ! If pressure surface, pressure level in mb (not used)
               !   Level must be one of the mandatory levels:
               !   1000,925,850,700,600,500,400,300,200,100
MAPFILL=0,          ! Fill map? 0: no, 1: yes, -1: no map (not used)
IBACKGND=1,         ! Plot background color? 1: bg blk, fg white, 2: bg white, fg blk,
               ! 3: bg white, fg blk (output on white paper), <0 as with >0, all
               ! colors set to fg color (tiles, plot scales, etc) and grayscale (map
               ! fills, filled contours and tiles)
IPLTINFO=0,         ! Plot information table? 0: no, 1: yes (not used)
IPANEL=0,           ! Number of plots drawn per frame (1 to 4)
       ! 1: One plot drawn on full frame and # of frames drawn= # specified by CFRAME
       ! 2,3,4: different # plots drawn per frame, *see manual
       ! 0: no plotting done; instead series of tables output
       ! with corresponding color code

 ! Character strings that specify the orientation, location, and size of the 2-D dimensional
 ! slab to be plotted or 3-D field to be extracted

 TVAR(1) = '/F/1:100:1/',  ! Time specification (beg:end:interval)
 ZVAR(1) = '/F/0:0:1/',   ! positive #s count from lower sw corner at the
 YVAR(1) = '/V/0:0:1/', ! beginning of run, negative #s count from the ends
 XVAR(1) = '/H/0:0:1/', ! and 0's go to the ends

      ! Parameters (this line is required by the run scripts)
      ! Note:  all selections for CRFRAME A are in REVU User's Guide
```

```
CFRAME_A(1)='/geo/fb/0./30000./1000.0/m5:c15000.:xdeepskybl/midgreen/slateblue/',
! geopotential height [m]
CFRAME_A(2)='/ue_avg/fb/-50./50./10.0/m5:c0.:xcyan/lightred/gold/',
! eastward wind component earth rotated and averaged to T point[m/s]
CFRAME_A(3)='/ve_avg/fb/-50./50./10.0/m5:c0.:xtan/yellow/forestgreen/',
! northward wind component earth rotated and averaged to T pt [m/s]
CFRAME_A(4)='/tempk/fb/260./330./5.0/m5:c300.:xgray/red/blue/',
! temperature [K]
CFRAME_A(5)='/relhum/fb/-10./100./10.0/m5:c50.:xaqua/darkviolet/brown/',
! relative humidity [%]
CFRAME_A(6)='/press/fb/100./11000./100.0/m5:c5000.:xwhite/cyan/magenta/',
! pressure [mb]
CFRAME_A(7)='/theta/fb/260./330./5.0/m7:c300.:xgray/red/blue/',
! potential temperature [K]
CFRAME_A(8)='/precip/fb/0./30./2.0/m7:c300.:xgray/green/purple/',
! surface accumulation resolved + convective precipitation[mm liq equiv]
$END

 $GLL

IGRIDLL=1,    ! = 0 specifies the size and resolution of the lat-lon grid with
              !     the following namelist varaibles
              ! = 1 finds max size lat-lon grid that will fit within RAMS grid
              ! = 2 finds min size lat-lon grid that the RAMS grid will fit inside

  GLLDLLAT=1., ! latitude grid point spacing
  GLLDLLON=1., ! longitude grid point spacing
  GLLWLON=-131., ! western edge of grid
  GLLELON=-109., ! eastern edge of grid
  GLLSLAT=32.,  ! southern edge of grid
  GLLNLAT=46.,  ! norhtern edge of grid

 $END
```

Appendix C: GRIB to HPAC utility

```
Program GRIB2HPAC
!**************************************************************************************
!       Purpose
!
!       This program will take the 2 files decoded by wgrib.exe and rearrange the data into an HPAC
!       upper air profile (.prf) file.  One of the files is the inventory file that describes the data
!       contained in the data file, while the other is the file containing the actual weather data.
!
!       Date                Programmers             Description of Change
!       ====                ==========              ====================
!       24 OCT 05           MAJ Kevin Pace          Original Code
!
!       07 NOV 06           MAJ Chris Jones         Modification of original code (see
!                                                            description below)
!
!  Code modified to be able to take the gridded binary (GRIB) file produced in RAMS v6.0, formatted by
!  REVU v2.5, to a resolution of 0.09 degrees (approximately 10 km resolution).  Modified also to accept
!  a forecast GRIB file, in which the original date and time group (dtg) does not vary, but the forecast
!  time does, and therefore must be added to the original dtg.
!**************************************************************************************
Use Kinds
Use Globals
Use LocationTools
Use TimeTools
Use LevelTools
Use WxTools
Use PrfWriter

Implicit None

Integer,      Allocatable:: DTG(:)     ! Date-Time-Groups in which Wx data is avail [YYYYMMDDHH]
Integer,      Allocatable:: Level(:)   ! Pressure levels for which Wx data is avail [mb]
Type(Loc),      Allocatable:: Location(:)! Locations for which Wx data is avail [Lon, Lat]
Type(WxPoint), Allocatable:: WXPT(:,:,:)! 3D array (Level, Location, Time) of Wx data points

!**************************************************************************************!
! Get Filenames of WGRIB-Decoded Inventory and Data Files

Write(*,*) 'Enter filename of inventory file that was decoded by WGRIB: '
Read(*,*) Inventory
Write(*,*) 'Enter filename of matching data file that was also decoded by WGRIB: '
Write(*,*) 'It is imperative that the two files were created by a single WGRIB decoding'
Read(*,*) DataFile
!  Uncomment the options below to run default data set
!Inventory = 'Gdesc.txt'
!Datafile = 'Gdata.txt'

!**************************************************************************************!
! Allocate and Initialize Location Array
Call GetLocationSize (Inventory)            !Find the number of reanalysis points
                                            !in this file.  Also returns flags for
```

```
                                                !separating data in data file eg "6 6"
Allocate (Location(1:LocSize))                  !Allocate the array
Location%Lat = -9999.0_dp           !Initialize the array to -9999, as HPAC understands this as
Location%Lon = -9999.0_dp           !the code for "no data"

Write(*,*) "There are ", LocSize, " locations covered in this file"
Write(*,*)

!***********************************************************************************!
! Fill Location Array with all lat/lon locations for which reanalysis data is available
! It will write to file for import into spreadsheet for the purpose of determining elevations

Call FillLocation (Location, Inventory)

Open (Unit=100, File='LatLon.txt')
Write(100,*) "Latitude          Longitude"
!Write(*,*) "Location Number         Longitude            Latitude"
Do i = 1, LocSize

!uncomment the options below to write to screen
!Write(*, 1000) i, Location(i)%Lon, Location(i)%Lat
!1000 Format (I6, 16x, F9.4,13x,F9.4)

        Write(100, 1000) Location(i)%Lat, Location(i)%Lon
        1000 Format (F9.5,13x,F9.4)

End Do
Close(100)

Write(*,*)

!************************************************************************************!
! Allocate and Initialize DTG Array

Call GetTimeSize (TimeSize, Inventory)      !Also counts the number of records in the reanalysis file
Allocate (DTG(1:TimeSize))
DTG = -9999._dp                             !Initialize character array

Write(*,*) "Number of Records:  ", Rec
Write(*,*) "There are ", TimeSize ,"DTGs that this file covers"

!************************************************************************************!
! Fill Array with DTGs that the reanalysis data covers.  Early -> Late (Just as Inventory File)

Call FillTimeArray (DTG, Inventory)

Write(*,*) DTG
Write(*,*)

!************************************************************************************!
! Allocate Layer Array

Call GetLevelSize (LevelSize, Inventory)
Allocate (Level(1:LevelSize))
```

```
Level = -9999.0_dp

! Fill Layer Array with Pressure Levels
Call FillLevelArray(Level, Inventory, LevelSize)

Write(*,*) Level
Write(*,*)

!*************************************************************************************!
! Allocate and Initialize WXPT Array (Array of TYPE: WxPoint)

Allocate (WXPT(1:LevelSize, 1:LocSize, 1:TimeSize))

WXPT%HGT    = -9999.0_dp                    !Initialize the Array
WXPT%T      = -9999.0_dp
WXPT%U      = -9999.0_dp
WXPT%V      = -9999.0_dp
WXPT%RH     = -9999.0_dp
WXPT%WndDir = -9999.0_dp
WXPT%WndSpd = -9999.0_dp

! Fill WXPT Array with data from data file from WGRIB
Call FillWXPTArray (WXPT, Level, Location, DTG, Inventory, DataFile)

!*************************************************************************************!
! Write HPAC .prf file
Call WritePRF (WxPT, DTG, Location, Level, Inventory)

End Program GRIB2HPAC

Module LocationTools
!************************************************************************************
!       Computes the locations of all reanalysis weather data within the spatial boundary
!
!       Date                Programmers                 Description of Change
!       ====                ==========                  ====================
!       24 OCT 05           MAJ Kevin Pace              Original Code
!       7 NOV 06            MAJ Chris Jones             Modification of original code (see
!                                                         description below)
!  The original code accounted for 2.5 degree resolution found in raw reanalysis data.  The code
!  was modified to account for the 0.09 degree resolution produced using RAMS software.
!************************************************************************************
Use Kinds
Use Globals
Implicit None

Contains

Subroutine GetLocationSize (Inventory)
!************************************************************************************
! Extracts out # of lat/lon locations that the RAMS file covers, which should be the HPAC spatial
! domain.  The first few lines of a typical RAMS inventory file look like:
!
!  rec 1:4:date 1952060100 HGT kpds5=7 kpds6=100 kpds7=1000 levels=(3,232) grid=255 1000 mb 60min fcst:
!  HGT=Geopotential height [gpm]
```

```
!  timerange 10 P1 0 P2 60 TimeU 0  nx 74 ny 60 GDS grid 0 num_in_ave 0 missing 0
!  center 7 subcenter 0 process 10 Table 2 scan: WE:SN winds(grid)
!  latlon: lat  34.303000 to 39.000000 by 0.090000  nxny 4440
!          long -119.249000 to -112.000000 by 0.090000, (74 x 60) scan 64 mode 136 bdsgrid 1
!  min/max data -58.5 67.2  num bits 11  BDS_Ref -585  DecScale 1 BinScale 0
!
!rec 2:6204:date 1952060100 HGT kpds5=7 kpds6=100 kpds7=925 levels=(3,157) grid=255 925 mb 60min fcst:
!  HGT=Geopotential height [gpm]
!  timerange 10 P1 0 P2 60 TimeU 0  nx 74 ny 60 GDS grid 0 num_in_ave 0 missing 0
!  center 7 subcenter 0 process 10 Table 2 scan: WE:SN winds(grid)
!  latlon: lat  34.303000 to 39.000000 by 0.090000  nxny 4440
!          long -119.249000 to -112.000000 by 0.090000, (74 x 60) scan 64 mode 136 bdsgrid 1
!  min/max data 653.3 747.2  num bits 10  BDS_Ref 6533  DecScale 1 BinScale 0
!
!*************************************************************************************

Use Kinds
Use Globals
Implicit None

Character(Len=20), Intent(In):: Inventory      !Name of the reanalysis inventory file
Character(Len = 200) :: Line6                  ! 6th Line of the Inventory File. Contains Grid numbers
Integer:: arrow                                ! Pointer used to index my way across a line of text
Real(dp):: TempLat                             ! Temporary holder for latitude
Real(dp):: TempLon                             ! Temporary holder for longitude
Character(Len=30) :: A                         ! Dummy Holder
Real(dp):: NLAT, SLAT, WLON, ELON              ! North/South Lat and E/W Lon boundaries
Real(dp):: Res                                 ! Reanalysis Resolution of global Lat/Lon matrix

ierror1 = 0

! Open File and check for errors on OPEN
OPEN (UNIT = 20, FILE=Inventory, STATUS='OLD', ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'error Opening Inventory File in GetLocSize Subroutine'

Do i = 1,5                                     ! Move pointer over the first 5 lines
        READ (20,*, IOSTAT = ierror1)
        If (ierror1 .NE. 0) EXIT
End Do

Read (20,'(a)', IOSTAT = ierror1) Line6        ! Read the 6th Line of the Inventory file
arrow = index(Line6,"(") + 1                   ! Find the ( before the Number of Lons
Read (Line6(arrow:),*) LonGrid                 ! Read the number of Lons in the grid
arrow = index(Line6,"x") + 1                   ! Find the x before the Number of Lats
Read (Line6(arrow:),*) LatGrid                 ! Read the number of Lats in the grid
Close (20)
OPEN (UNIT = 20, FILE=Inventory, STATUS='OLD', ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'error Opening Inventory File in FillLoc Subroutine'
Do i = 1,4                                     ! Move pointer over the first 4 lines
        READ (20,*, IOSTAT = ierror1)
        If (ierror1 .NE. 0) EXIT
End Do


Read(20, *) A, A, NLAT, A, SLAT, A, Res, A, LocSize    ! Read the 3rd, 5th, 7th and 9th items in line 5

Read(20, *) A, WLON, A, ELON                           ! Read the 2nd and 4th items in line 6
```

```
Close (20)

End Subroutine GetLocationSize


Subroutine FillLocation (Location, Inventory)

!*************************************************************************************
! Fills the Location array with Lats/Lons in the order that the data file lists values.
! For reanalysis and RAMS files, the first value listed is for the most NW location.  After that it moves
! across the Northern-most lat in an Eastward direction.  When it runs to the the most NE location
! it starts at the second most northern lat and the most western lon reading across in an Easterly
! direction.  It continues this 'typewriter' approach of assigning values when it reaches the most
! SE location.
!*************************************************************************************

Use Kinds
Use Globals
Implicit None

TYPE(Loc), Intent(InOut) :: Location(:)        ! Array of TYPE: Loc
Character(Len=20), Intent(In):: Inventory      ! Name of the reanalysis inventory file
Real(dp):: NLAT, SLAT, WLON, ELON, NX, NY     ! North/South Lat and E/W Lon boundaries
Real(dp):: Res                                 ! Reanalysis Resolution of global Lat/Lon matrix
Character(Len=30) :: A                         ! Dummy Holder
Integer :: Counter                             ! Loop Counter

ierror1 = 0

! Open File and check for errors on OPEN

OPEN (UNIT = 20, FILE=Inventory, STATUS='OLD', ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'error Opening Inventory File in FillLoc Subroutine'

Do i = 1,2                                     ! Move pointer over the first 2 lines
        READ (20,*, IOSTAT = ierror1)
        If (ierror1 .NE. 0) EXIT
End Do

Read(20, *) A, A, A, A, A, A, A, A, A, NX, A, NY    ! Read the 10th and 12th items in line 3

Close (20)

OPEN (UNIT = 20, FILE=Inventory, STATUS='OLD', ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'error Opening Inventory File in FillLoc Subroutine'

Do i = 1,4                                     ! Move pointer over the first 4 lines
        READ (20,*, IOSTAT = ierror1)
        If (ierror1 .NE. 0) EXIT
End Do

Read(20, *) A, A, NLAT, A, SLAT, A, Res   ! Read the 3rd, 5th, and 7th items in line 5
```

```
Read(20, *) A, WLON, A, ELON                ! Read the 2nd and 4th items in line 6

Close (20)

! Manipulate the Lats/Lons into integers, loop through the values, and fill in the location array
Counter = 1

! This loop only works for Northern latitudes (Latitude is a postive number) and
! Westerly Longitudes (Longitude is given a a negative number).  The Lat and Lon are
! calculated equidistantly by dividing the total lat or lon by the number of x and y values

Do i = 1, NX
        Do j = 1, NY
                Location(Counter)%Lat = Real(i,dp)* (SLAT - NLAT)/NX + NLAT
                Location(Counter)%Lon = Real(j,dp)* (ELON - WLON)/NY + WLON
                Counter = Counter + 1
        End Do
End Do

End Subroutine FillLocation

End Module LocationTools

Module TimeTools
!*************************************************************************************
!       Computes the locations of all reanalysis weather data within the spatial boundary
!
!       Date                    Programmers                     Description of Change
!       ====                    ==========
        ====================
!       25 OCT 05               MAJ Kevin Pace          Original Code
!       7 NOV 06                MAJ Chris Jones         Modification of original code (see
description below)
!
! The code was modified to accept the forecast time as the update for the date and time group (dtg)
! instead of a variable dtg from the GRIB file.
!*************************************************************************************

Use Kinds
Use Globals
Implicit None

Contains

Subroutine GetTimeSize (TimeSize, Inventory)
!************************************************************************************
! Extracts out # of unique Date-Time-Groups from the inventory file.
!  As seen below, the dtg does not update, but rather, at the end of the record line, a time of
!  forecast is given.  This value is made into a real value and added to the dtg to update the
!  record and allow analysis in a temporal domain.A typical inventory file
!  looks like:
!
!rec 1:4:date 1952060100 HGT kpds5=7 kpds6=100 kpds7=1000 levels=(3,232) grid=255 1000 mb 60min fcst:
!  HGT=Geopotential height [gpm]
!  timerange 10 P1 0 P2 60 TimeU 0  nx 74 ny 60 GDS grid 0 num_in_ave 0 missing 0
```

```
!  center 7 subcenter 0 process 10 Table 2 scan: WE:SN winds(grid)
!  latlon: lat  34.303000 to 39.000000 by 0.090000  nxny 4440
!           long -119.249000 to -112.000000 by 0.090000, (74 x 60) scan 64 mode 136 bdsgrid 1
!  min/max data -58.5 67.2  num bits 11  BDS_Ref -585  DecScale 1 BinScale 0
!
!rec 2:6204:date 1952060100 HGT kpds5=7 kpds6=100 kpds7=925 levels=(3,157) grid=255 925 mb 60min fcst:
!  HGT=Geopotential height [gpm]
!  timerange 10 P1 0 P2 60 TimeU 0  nx 74 ny 60 GDS grid 0 num_in_ave 0 missing 0
!  center 7 subcenter 0 process 10 Table 2 scan: WE:SN winds(grid)
!  latlon: lat  34.303000 to 39.000000 by 0.090000  nxny 4440
!           long -119.249000 to -112.000000 by 0.090000, (74 x 60) scan 64 mode 136 bdsgrid 1
!  min/max data 653.3 747.2  num bits 10  BDS_Ref 6533  DecScale 1 BinScale 0
!****************************************************************************************

Use Kinds
Use Globals
Implicit None

Integer, Intent(InOut) :: TimeSize              ! Size of Location Array
Character(Len=20), Intent(In):: Inventory      !Name of the reanalysis inventory file
Character(Len=3):: CheckRec                    ! First item of line.  Use to check if DTG is on this line
Character(Len=200) :: A,A1, A2, A3, A4, A5, A6, A7, A8, A9, A10       ! Dummy holders
Integer :: TimeStamp1, TimeStamp2              ! TimeStamp in Inv file.  2 were made for comparison
Integer :: Arrow                               ! Pointer for location in line
Character(len =10) :: Update                   ! Character reading of forecast update time
integer :: UpdateHr                            ! Hourly update variable
integer :: UpdateDay                           ! Daily update variable
integer :: k                                   ! Loop counter

UpdateDay = 0
ierror1 = 0

! Open File and check for errors on OPEN
OPEN (UNIT = 20, FILE=Inventory, STATUS='OLD' , ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'error Opening Inventory File in GetTimeSize Subroutine'

! Initialize variable to unlikely dtg
TimeStamp1 = 1800000000                        ! YYYYMMDDHH
TimeSize = 0
Rec = 0
Do
        ! Read through each line of Inventory File
        Read (20,*, IOSTAT = ierror1) CheckRec     ! Read first 3 characters of first object in line
        If (ierror1 .NE. 0) Then
                Write(*,*) "GetTimeSize:  No first object in line.  EOR is found"
                Exit
        End If

        If (CheckRec .EQ. "rec") Then         ! Is the line a record line (contains DTG and update time)
                Backspace 20
                Rec = Rec + 1                  ! Sum up all records while we are counting
  Read (20,*, IOSTAT = ierror1) CheckRec, A, TimeStamp2, A1, A2, A3, A4, A5, A6, A7, A8, A9,
Update, A10
                If (ierror1 .NE. 0) Then      ! Read in all necessary variable for updating
                        Write(*,*) "2. Error reading CheckRec in GetTimeSize Subroutine"
                        Exit
                End If
```

```
! If this record is the first timegroup, then the DTG does not need to be updated
If (Update .EQ. 'anl:') Then
            UpdateHr = 0._dp
            UpdateDay = 0._dp
 Else

! Trim character string of letters "min"
  Update = Update (1:LEN_TRIM(Update)-3)

! Write the resultant integer to file as a character
  Open(unit = 75, File='Scratch.txt')
            Write(75,*)Update
  Close (75)

! Read the value from file as a real number
  Open (unit = 75, File='Scratch.txt')
             Read(75,*) UpdateHr
  Close (75)

! Translate minutes into hours and days
  UpdateHr = UpdateHr/60
   If ((UpdateHr .ge. 24) .and. (UpdateHr .lt. 48)) then
              UpdateDay = 100
!******For Smoky ONLY:  Month changes, so uncomment the statement below*****!!!!!!!
!             UpdateDay = 7000
     UpdateHr = UpdateHr - 24
            End If
   If (UpdateHr .ge. 48) then
                        UpdateDay = 200
!******For Smoky ONLY:  Month changes, so uncomment the statement below*****!!!!!!!
!                       UpdateDay = 7100
                        UpdateHr = UpdateHr - 48
            End If
End If

! Add the forecast time to the original timestamp
  TimeStamp2 =  TimeStamp2 + UpdateHr + UpdateDay

                        If (TimeStamp2 .NE. TimeStamp1) Then      ! Is this a new DTG?
                                    TimeSize = TimeSize +1            ! Add one to the array size
                                    TimeStamp1 = TimeStamp2           ! Make new DTG the old DTG for future
                                                                      ! comparisons
                        End If
            End If
End Do

Close (20)

End Subroutine GetTimeSize


Subroutine FillTimeArray (DTG, Inventory)
!*********************************************************************************
```

```
! Fills the Location array with Lats/Lons in the order that the data file lists values.
! For RAMS files, the first value listed is for the most NW location.  After that it moves
! across the Northern-most lat in an Eastward direction.  When it runs to the the most NE location
! it starts at the second most northern lat and the most western lon reading across in an Easterly
! direction.  It continues this 'typewriter' approach of assigning values when it reaches the most
! SE location.
!*************************************************************************************

Use Kinds
Use Globals
Implicit None

Integer, Intent(InOut) :: DTG(:)                ! Array of Date-Time-Groups
Character(Len=20), Intent(In):: Inventory       ! Name of the reanalysis inventory file
Character(Len=3):: CheckRec                     ! First item of line.  Use to check if DTG is on this line
Character(Len=200) :: A,A1, A2, A3, A4, A5, A6, A7, A8, A9   ! Dummy holders
Integer :: TimeStamp1, TimeStamp2               ! TimeStamp in Inv file.  2 made for comparison
Integer :: Counter                              ! Counting integers
Character(len =10) :: Update                    ! Character reading of forecast update time
integer :: UpdateHr                             ! Hourly update variable
integer :: UpdateDay                            ! Daily update variable
integer :: k                                    ! Loop counter

UpdateDay = 0
Counter = 1
ierror1 = 0

! Open File and check for errors on OPEN
OPEN (UNIT = 20, FILE=Inventory, STATUS='OLD', ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'error Opening Inventory File in GetTimeSize Subroutine'

TimeStamp1 = 1800000000                         ! YYYYMMDDHH

Do
        ! Read through each line of Inventory File
        Read (20,*, IOSTAT = ierror1) CheckRec          ! Read first 3 characters of first object in line

        If (ierror1 .NE. 0) Then
                !Write(*,*) "GetTimeSize:  No first object in line.  EOR is found"
                Exit
        End If

        If (CheckRec .EQ. "rec") Then                   ! Is the line a record line (contains DTG)
                Backspace 20

  Read (20,*, IOSTAT = ierror1) CheckRec, A, TimeStamp2, A1, A2, A3, A4, A5, A6, A7, A8, A9, Update
        If (ierror1 .NE. 0) Then                        ! Read in all necessary variable for updating
                Write(*,*) "2. Error reading CheckRec in GetTimeSize Subroutine"
                Exit
        End If

! If this record is the first timegroup, then the DTG does not need to be updated
 If (Update .EQ. 'anl:') Then
        UpdateHr = 0._dp
```

```
            UpdateDay = 0._dp
 Else

! Trim character string of letters "min"
  Update = Update (1:LEN_TRIM(Update)-3)

! Write the resultant integer to file as a character
  Open(unit = 75, File='Scratch.txt')
            Write(75,*)Update
  Close (75)

! Read the value from file as a real number
  Open (unit = 75, File='Scratch.txt')
            Read(75,*) UpdateHr
  Close (75)

! Translate minutes into hours and days
  UpdateHr = UpdateHr/60
   If ((UpdateHr .ge. 24) .and. (UpdateHr .lt. 48)) then
              UpdateDay = 100
!******For Smoky ONLY:  Month changes, so uncomment the statement below*****!!!!!!!
!             UpdateDay = 7000
     UpdateHr = UpdateHr - 24
            End If
   If (UpdateHr .ge. 48) then
                        UpdateDay = 200
!******For Smoky ONLY:  Month changes, so uncomment the statement below*****!!!!!!!
!                       UpdateDay = 7100
                        UpdateHr = UpdateHr - 48
            End If
End If

! Add the forecast time to the original timestamp
  TimeStamp2 =  TimeStamp2 + UpdateHr + UpdateDay

                        If (TimeStamp2 .NE. TimeStamp1) Then      ! Is this a new DTG?
                                    DTG(Counter) = TimeStamp2                               ! Add one to the array size
                                    TimeStamp1 = TimeStamp2                                             ! Make new DTG
the old DTG for future comparisons
                                    Counter = Counter + 1
                        End If
            End If

End Do

Close (20)

End Subroutine FillTimeArray

End Module TimeTools

Module LevelTools
!*****************************************************************************************
!           Computes the locations of all reanalysis weather data within the spatial boundary
```

```
!
!       Date            Programmers         Description of Change
!       ====            ==========          ====================
!       25 OCT 05       MAJ Kevin Pace      Original Code
!       7 NOV 06        MAJ Chris Jones     Modified to fit RAMS data
!***********************************************************************************

Use Kinds
Use Globals
Implicit None

Contains

Subroutine GetLevelSize (LevelSize, Inventory)
!***********************************************************************************
! Extracts out # of unique pressure levels from the inventory file.  A typical inventory file from RAMS
! looks like (Pressure level is value after "kpds7=") the example below.  In this case,
! the first pressure level is 1000mb.  It is also towards the end of the first line:
!
!rec 1:4:date 1952060100 HGT kpds5=7 kpds6=100 kpds7=1000 levels=(3,232) grid=255 1000 mb 60min fcst:
!  HGT=Geopotential height [gpm]
!  timerange 10 P1 0 P2 60 TimeU 0  nx 74 ny 60 GDS grid 0 num_in_ave 0 missing 0
!  center 7 subcenter 0 process 10 Table 2 scan: WE:SN winds(grid)
!  latlon: lat  34.303000 to 39.000000 by 0.090000  nxny 4440
!          long -119.249000 to -112.000000 by 0.090000, (74 x 60) scan 64 mode 136 bdsgrid 1
!  min/max data -58.5 67.2  num bits 11  BDS_Ref -585  DecScale 1 BinScale 0
!
!rec 2:6204:date 1952060100 HGT kpds5=7 kpds6=100 kpds7=925 levels=(3,157) grid=255 925 mb 60min fcst:
!  HGT=Geopotential height [gpm]
!  timerange 10 P1 0 P2 60 TimeU 0  nx 74 ny 60 GDS grid 0 num_in_ave 0 missing 0
!  center 7 subcenter 0 process 10 Table 2 scan: WE:SN winds(grid)
!  latlon: lat  34.303000 to 39.000000 by 0.090000  nxny 4440
!          long -119.249000 to -112.000000 by 0.090000, (74 x 60) scan 64 mode 136 bdsgrid 1
!  min/max data 653.3 747.2  num bits 10  BDS_Ref 6533  DecScale 1 BinScale 0
!
!***********************************************************************************

Use Kinds
Use Globals
Implicit None

Integer, Intent(InOut) :: LevelSize               ! Size of Level Array
Character(Len=20), Intent(In):: Inventory         ! Name of the reanalysis inventory file
Character(Len=3):: CheckRec                       ! Used to check for a "rec" line in data file
Character(Len=5):: A, B, C,VarNew,VarOld  ! A-C dummy; Var is variable for that record eg HGT
Integer:: LvlSzTmp                                ! Pressure Level holders
Integer:: RecCounter, VarCounter                  ! Variables to ensure all records/variables are read

VarCounter = 0
!Result should be #DTGs * (# Variables +1) -> Hgt, UGRD, VGRD, TMP, RH, + Pressure
RecCounter = 0          !Result should be # Records in file
ierror1   = 0
LevelSize = 0
LvlSzTmp  = 1
VarOld = "Chris"        !Initialize VarOld to something that will never appear in Inventory File

! Open File and check for errors on OPEN
```

```
OPEN (UNIT = 20, FILE=Inventory, STATUS='OLD', ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'error Opening Inventory File in GetLevelSize Subroutine'

Do
        ! Read through each line of Inventory File
        Read (20,*, IOSTAT = ierror1) CheckRec    ! Read first 3 characters of first object in line
        If (ierror1 .NE. 0) Then
                !Write(*,*) "GetLevelSize:  No first object in line.  EOR is found"
                Exit
        End If

        If (CheckRec .EQ. "rec") Then                ! Is line a record line (contains pressure level)
                Backspace 20                         ! Back up to the "rec" line that we just read
                RecCounter = RecCounter +1
                Read (20,*, IOSTAT = ierror1) A,B,C,VarNew         ! Get first 4 objects of rec line
                If (ierror1 .NE. 0) Then
                        Write(*,*) "2. Error reading CheckRec in GetLevelSize Subroutine"
                        Exit
                End If



                If (VarNew .EQ. VarOld) Then                 ! Is this a new variable?
                        LvlSzTmp = LvlSzTmp + 1              ! Sum up levels for this particular variable

                Else
                        If(LvlSzTmp .GT. LevelSize) LevelSize = LvlSzTmp
                        LvlSzTmp = 1
                        VarOld = VarNew
                        VarCounter = VarCounter + 1
                End If

        End If

End Do

Close (20)

Write(*,*) "There are ", LevelSize, " pressure levels covered by this file"
Write(*,*) "The GetLevelSize Sub read", RecCounter, " records and ", VarCounter,"variables"

End Subroutine GetLevelSize


Subroutine FillLevelArray (Level, Inventory, LevelSize)
!************************************************************************************
! Fills the Location array with Lats/Lons in the order that the data file lists values.
! For reanalysis files, the first value listed is for the most NW location.  After that it moves
! across the Northern-most lat in an Eastward direction.  When it runs to the the most NE location
! it starts at the second most northern lat and the most western lon reading across in an Easterly
! direction.  It continues this 'typewriter' approach of assigning values when it reaches the most
! SE location.
!************************************************************************************
```

```
Use Kinds
Use Globals
Implicit None

Integer, Intent(InOut) :: Level(:)              ! Array of Pressure Levels [mb]
Character(Len=20), Intent(In):: Inventory       ! Name of the reanalysis inventory file
Integer, Intent(In):: LevelSize                 ! This is the size of the Level array
Character(Len=3):: CheckRec                     ! Used to check for a "rec" line in data file
Integer:: PrField                               ! Holds Pressure Level Object e.g. 995
Character(Len=5):: A,B,C,D,E,F,G,H,L            ! dummy variables - used as placeholders and debugging
Character(Len=5):: VarNew,VarOld                ! Var is variable for that record (eg HGT)
Integer:: Counter1                              ! # Times we have read in a value to Level Array
Integer:: LvlSzTmp                              ! # of levels we have read for the current variable


ierror1  = 0
VarOld   = "CHRIS"                 !Initialize VarOld to something that will never appear in Inventory File
LvlSzTmp = 1

! Open File and check for errors on OPEN
OPEN (UNIT = 20, FILE=Inventory, STATUS='OLD', ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'Error Opening Inventory File in FillLevelArray Subroutine'

Do        ! Read records until you find a variable with values at all pressure levels
        Read (20,*, IOSTAT = ierror1) CheckRec    ! Read first 3 characters of first object in line
        If (ierror1 .NE. 0) Then
                !Write(*,*) "GetLevelSize:  No first object in line.  EOR is found"
                Exit
        End If

        If (CheckRec .EQ. "rec") Then                 ! Is line a record line (contains pressure level)

                Backspace 20                          ! Back up to the "rec" line that we just read

                Read (20,*, IOSTAT = ierror1) A,B,C,VarNew        ! Get first 4 objects of rec line
                If (ierror1 .NE. 0) Then
                        Write(*,*) "2. Error reading CheckRec in GetLevelSize Subroutine"
                        Exit
                End If

                If (VarNew .EQ. VarOld) Then                  ! Same variable as the last record we read?
                        LvlSzTmp = LvlSzTmp + 1               ! Sum up levels for this particular variable

                        If(LvlSzTmp .EQ. LevelSize) Then ! See if levels for this variable = level size
                                Do i = 1, (LevelSize *8)   !If so, backup to record where variable starts
                                        BackSpace 20       ! and get out of this loop
                                End Do
                                Exit
                        End If
                Else                                  ! If not new variable, we will
                        LvlSzTmp = 1                  ! Start the level counter over and
                        VarOld = VarNew               ! Make comparison variable equal to new variable
                End If
```

```
    End If

End Do

Counter1=0

Do                  ! Read through records until we find a variable with "LevelSize" contiguous
                    ! records. The pointer should start at the first record of the first variable
                    ! that is defined at all levels.  For Pressure levels, its probable HGT

    Read (20,*, IOSTAT = ierror1) CheckRec    ! Read first 3 characters of first object in line
    If (ierror1 .NE. 0) Then
        Write(*,*) "FillLevelArray:  No first object in line.  EOR is found"
        Exit
    End If

    If (CheckRec .EQ. "rec") Then             ! Is line a record line (contains pressure level)

        Backspace 20                          ! Back up to the "rec" line that we just read
            ! Get first 10 objects of rec line (#4 is Variable, #10 is pressure in millibars
        Read (20,*, IOSTAT = ierror1) CheckRec,B,C,VarNew,D,E,F,G,H,L,PrField
        If (ierror1 .NE. 0) Then
            Write(*,*) "2. Error reading CheckRec in FillLevelArray Subroutine"
            Exit
        End If

        Counter1 = Counter1 + 1               ! Sum up levels for this particular variable
        Level(Counter1) = PrField

        If (Counter1 .EQ. LevelSize) Exit
    End If

End Do

Close (20)
Write(*,*) "FillLevelArray levels were determined by ", VarOld
Write(*,*) "This variable sequence ended on record ", B

End Subroutine FillLevelArray

End Module LevelTools

Module WxTools
!*************************************************************************************
! Fills WXPT array with values.  Values come from the data file as opposed to the inventory file.
!
!       Date            Programmers             Description of Change
!       ====            ==========              ====================
!       27 OCT 05       MAJ Kevin Pace          Original Code
!       07 NOV 06       MAJ Chris Jones         Modification of original code (see
!                                               description below)
!  The time and location calculators were updated to reflect RAMS output, and because of the 100-fold
!  increase in each dimension of the array, the windspeed and direction operation was moved inside
!  the loop to be incremented singly.
```

```
!**************************************************************************************

Use Kinds
Use Globals
Implicit None

Contains

Subroutine FillWxPTArray (WXPT, Level, Location, DTG, Inventory, DataFile)
!**************************************************************************************
! This Subroutine reads the WxPT data from the datafile using the Inventory file for an
! explanation of what each block of numbers mean.  For example, the first few lines of a
! typical datafile look like:
!  4 3
!  7
!  6
!  12
!  10
!  3
!  3
!  27
!  6
!  9
!  8
!  8
!  6
!  4 3
! This means that for the 4x3 matrix of locations, these are the values of what record 1 in
! in the Inventory file describe.  The first few lines of a typical reanalysis inventory file
! look like:
!
!rec 1:0:date 1952060100 HGT kpds5=7 kpds6=100 kpds7=1000 levels=(3,232) grid=255 1000 mb anl:
!  HGT=Geopotential height [gpm]
!  timerange 10 P1 0 P2 0 TimeU 1  nx 4 ny 3 GDS grid 0 num_in_ave 0 missing 0
!  center 7 subcenter 1 process 80 Table 2 scan: WE:NS winds(N/S)
!  latlon: lat  40.000000 to 35.000000 by 2.500000  nxny 12
!          long -120.000000 to -112.500000 by 2.500000, (4 x 3) scan 0 mode 128 bdsgrid 1
!  min/max data 7 66  num bits 6  BDS_Ref 7  DecScale 0 BinScale 0
!
!rec 2:92:date 1952060100 HGT kpds5=7 kpds6=100 kpds7=925 levels=(3,157) grid=255 925 mb anl:
!  HGT=Geopotential height [gpm]
!  timerange 10 P1 0 P2 0 TimeU 1  nx 4 ny 3 GDS grid 0 num_in_ave 0 missing 0
!  center 7 subcenter 1 process 80 Table 2 scan: WE:NS winds(N/S)
!  latlon: lat  40.000000 to 35.000000 by 2.500000  nxny 12
!          long -120.000000 to -112.500000 by 2.500000, (4 x 3) scan 0 mode 128 bdsgrid 1
!  min/max data 674 730  num bits 6  BDS_Ref 674  DecScale 0 BinScale 0
!
! So in the above example, the 12 values under "4 3" are the heights of the 1000mb pressure
! level.  The values are ordered in a sequence like a typewriter:  NW to SE lat/lon locations.
! So at location 40 lat/-120 lon the height of the 1000mb level is 7m and the height of the
! 1000mb pressure level at 35 lat/-112.5 lon is 6m.
! The only difference from a reanalysis file and RAMS file is the size (74 x 60), and the
! updated forecast timestamp.  Code is modified to reflect this difference.
!**************************************************************************************

Use Kinds
Use Globals
```

```
Implicit None

Type(WxPoint),Intent(InOut):: WxPT(:,:,:)  ! 3D array of weather data points
Integer,Intent(In):: Level(:)             ! Pressure levels for which Wx data is avail [mb]
Type(Loc),Intent(In):: Location(:)   ! Locations for which Wx data is avail [Lon, Lat]
Integer,Intent(In):: DTG(:)             ! Date-Time-Groups where Wx data is avail [YYYYMMDDHH]
Character(Len=20), Intent(In):: Inventory, DataFile    !Name of the reanalysis files
Character(Len=5):: CheckRec,Var   ! Key Fields from rec line of Inv File
Integer:: Lvl                             ! Key Fields from rec line of Inv File
Real(dp):: Time                           ! Key Fields from rec line of Inv File
Character(Len=5):: B,E,F,G,H,L,M,N   ! Dummy Variables between fields and for debugging
Real(dp):: Temp(1:LocSize+1)        ! Temporary Array holding sets of data from datafile
Character(Len=10)::Flag, CheckFlag    ! FLAG separates data groups in datafile
Integer:: DI, LI, k                       ! DTG index and Level Index for array searching
Character(len =10) :: Update           ! Character reading of forecast update time
integer :: UpdateHr                    ! Hourly update variable
integer :: UpdateDay                   ! Daily update variable

UpdateHr = 0
UpdateDay = 0
ierror1 = 0
ierror2 = 0

! Open Files and check for errors on OPEN
OPEN (UNIT = 20, FILE=Inventory, STATUS='OLD', ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'Error Opening Inventory File in FillWxPTArray Subroutine'
OPEN (UNIT = 30, FILE=DataFile,  STATUS='OLD', ACTION='READ', IOSTAT=ierror2)
If (ierror2 .NE. 0) Write(*,*) 'Error Opening Data File in FillWxPTArray Subroutine'


Do      i = 1,(rec*7) !Read through every record in the Inv and Data File and extract key fields of data
!********Get key fields from Inv File**************************************************
        Read (20,*, IOSTAT = ierror1) CheckRec    ! Read first 3 characters of first object in line
        If (ierror1 .NE. 0) Then
                Write(*,*) "FillWxPTArray:  No first object in line in Inv File.  EOR is found"
                Exit
        End If

        If (CheckRec .EQ. "rec") Then        ! Is line a record line (contains pressure level)
                Backspace 20                 ! Back up to the "rec" line that we just read

                ! Get Time, Variable, PressureLevel, and Update time
                Read (20,*, IOSTAT = ierror1) CheckRec,B,Time,Var,E,F,G,H,L,M,Lvl,N,Update

! If this record is the first timegroup, then the DTG does not need to be updated
If (Update .EQ. 'anl:') Then
        UpdateHr = 0._dp
        UpdateDay = 0._dp
 Else

! Trim character string of letters "min"
  Update = Update (1:LEN_TRIM(Update)-3)

! Write the resultant integer to file as a character
```

```
  Open(unit = 75, File='Scratch.txt')
             Write(75,*)Update
  Close (75)

! Read the value from file as a real number
  Open (unit = 75, File='Scratch.txt')
              Read(75,*) UpdateHr
  Close (75)

! Translate minutes into hours and days
  UpdateHr = UpdateHr/60
   If ((UpdateHr .ge. 24) .and. (UpdateHr .lt. 48)) then
              UpdateDay = 100
!******For Smoky ONLY:  Month changes, so uncomment the statement below*****!!!!!!!
!             UpdateDay = 7000
      UpdateHr = UpdateHr - 24
            End If
   If (UpdateHr .ge. 48) then
                       UpdateDay = 200
!******For Smoky ONLY:  Month changes, so uncomment the statement below*****!!!!!!!
!                      UpdateDay = 7100
                       UpdateHr = UpdateHr - 48
            End If
End If

! Add the forecast time to the original timestamp
  Time =  Time + UpdateHr + UpdateDay

            !******************************************************************************

            !*********Find index of "Time" in DTG array and index of "Level" in Level Array*******
                       Do j = 1, TimeSize
                                   If(DTG(j) .EQ. Time) Then
                                               DI = j
                                               Exit
                                   End If
                       End Do

                       Do j = 1, LevelSize
                                   If(Level(j) .EQ. Lvl) Then
                                               LI = j
                                               Exit
                                   End If
                       End Do


            !******************************************************************************
                       !*********Read the group of data from datafile that corresponds to the record in Inv File
                       Do
                       Read (30,'(a)', IOSTAT = ierror2) CheckFlag             !Read a line from DataFile
                       If (ierror2 .NE. 0) Then
                                   Write(*,*) "FillWxPTArray:  No first object in line of datafile.  EOR is found"
                                   Exit
                       End If
```

```
            If (i .EQ. 1) Flag = CheckFlag !First item of every data file is the flag (Do this only once)

            If (CheckFlag .EQ. Flag) Then                    ! Is line a value separator in the data file
                        Do j = 1, LocSize
                                    Read (30,*, IOSTAT = ierror1) Temp(j) !Store value in Temp Array
                        End Do
                        Exit
            End If
            End Do
        !*****************************************************************************
            !********Assign the datafile data set into the appropriate place in WxPT array
            SelectCase (Trim(Var))
                        Case("HGT")
                                                WxPT(LI,:,DI)%HGT = Temp(:)
                        Case("UGRD")
                                                WxPT(LI,:,DI)%U   = Temp(:)
                        Case("VGRD")
                                                WxPT(LI,:,DI)%V   = Temp(:)
                        Case("TMP")
                                                WxPT(LI,:,DI)%T   = Temp(:)
                        Case("RH")
                                                WxPT(LI,:,DI)%RH  = Temp(:)
            End Select

        !*****************************************************************************
        End If

End Do
        !*****************************************************************************
Close (20)
Close (30)

! Fill up the WxPT%WndSpd and WxPT%WndDir in the WxPT Array
Call UVConverter (WxPT)

End Subroutine FillWxPTArray

Subroutine UVConverter (WxPT)
!*********************************************************************************
! Converts the U- and V- wind speeds into a windspeed and direction.  Input:WXPT%U and WXPT%V
! output: WXPT%WndSpd and WXPT%WndDir
!*********************************************************************************
Use Kinds
Use Globals
Implicit None

Type(WxPoint),Intent(InOut):: WxPT(:,:,:)! 3D array of weather data points
Real(dp):: CartDeg          !Cartesian Degree described by U,V components of the wind
Integer :: Quadrant         !Quadrant in which the Cartesian Degree resides (I = Upper Right
                            !II = Upper Left, III = Lower Left, and IV = Lower Right)
Real(dp):: WndDir
!Compute WindDirection.  In Cartesian Coordinates positive angles are measured from the
!positive X-axis (0 degrees) in a CounterClockWise (CCW) direction.  In meteorology, the
```

```
!angles are positive from the positive Y-axis (called V (Northern Direction)) in a ClockWise
!Direction.
Do i = 1,TimeSize
        Do j = 1, LevelSize
                Do k = 1, LocSize

!Compute WindSpeed
                WxPT(j,k,i)%WndSpd = SQRT(WxPT(j,k,i)%V**2 + WxPT(j,k,i)%U**2)
                !First we get the angles in normal Cartesian values
                !This is Degrees from -180 to 180 (0 is East(U), and angles are positive going CCW)
                !ATAN2D takes a Y,X (or V,U) pair as arguements
                        CartDeg =  ATAN2D(WxPT(j,k,i)%V,WxPT(j,k,i)%U)

                        !Transform Cartesian angle (-180 to 180) to Cartesian angle (0 to 360)
                        If(CartDeg .GE. 0._dp .AND. CartDeg .LE. 180._dp) Then
                                CartDeg = CartDeg
                        Else If(CartDeg .LT.  0._dp .AND. CartDeg .GT. -180._dp) Then
                                CartDeg = CartDeg + 360._dp
                        Else If(CartDeg .EQ.  -180._dp) Then
                                CartDeg = 180._dp
                        Else
                                Write(*,*) "UV Converter Cartesian: Angle input is not between -180
and 180"
                        End If


                        !Find the quadrant of this angle
                        If(CartDeg .GE. 0._dp .AND. CartDeg .LE. 90._dp)                Then
                                Quadrant = 1
                        Else If(CartDeg .GT.  90._dp .AND. CartDeg .LE. 180._dp) Then
                                Quadrant = 2
                        Else If(CartDeg .GT. 180._dp .AND. CartDeg .LE. 270._dp) Then
                                Quadrant = 3
                        Else If(CartDeg .GT. 270._dp .AND. CartDeg .LT. 360._dp) Then
                                Quadrant = 4
                        Else If(CartDeg .EQ.  360._dp) Then
                                CartDeg = 0.0_dp
                                Quadrant = 1
                        Else
                                Write(*,*) "UV Converter Quadrant: Angle input not between 0 and
360"
                        End If

                        ! Turn Cartesian Angle (0-359 going CCW from +X axis)
                        ! into Azimuthal Angle (0-360 going CW from +Y axis)

                        SelectCase (Quadrant)
                                Case(1)
                                        WxPT(j,k,i)%WndDir =  90._dp - CartDeg
                                Case(2)
                                        WxPT(j,k,i)%WndDir = 450._dp - CartDeg
                                Case(3)
                                        WxPT(j,k,i)%WndDir = 450._dp - CartDeg
                                Case(4)
```

```
                                        WxPT(j,k,i)%WndDir = 450._dp - CartDeg
                                Case Default
                                        Write(*,*) "UV Converter WndDir: The angle was not in
Quadrant I-IV"
                                End Select

                        ! Now convert this angle to where the wind is coming from NOT GOING TO!
                        If (WxPT(j,k,i)%WndDir .EQ. 0._dp ) Then
                                WxPT(j,k,i)%WndDir = 180._dp
                        Else If (WxPT(j,k,i)%WndDir .GT. 0._dp .AND. WxPT(j,k,i)%WndDir .LT.
180._dp ) Then
                                WxPT(j,k,i)%WndDir = WxPT(j,k,i)%WndDir + 180._dp
                        Else If (WxPT(j,k,i)%WndDir .EQ. 180) Then
                                WxPT(j,k,i)%WndDir = 0._dp
                        Else If (WxPT(j,k,i)%WndDir .GT. 180._dp .AND. WxPT(j,k,i)%WndDir .LE.
360._dp) Then
                                WxPT(j,k,i)%WndDir = WxPT(j,k,i)%WndDir - 180._dp
                        Else
                                Write(*,*) "UV Converter:  Angle Reversal not working.  Input angle
not 0-360!"
                        End If
                End Do
        End Do
End Do


End Subroutine UVConverter

End Module WxTools

Module PrfWriter
!*********************************************************************************
! Writes a textfile with a .prf extension.  This file contains weather data in a format in which HPAC can
!ingest it.
!

!       Date                    Programmers                     Description of Change
!       ====                    ==========                      ====================
!       29 OCT 05               MAJ Kevin Pace                  Original Code
!       7 NOV 06                MAJ Chris Jones                 Modification of original code (see
!                                                               description below)
!
!       Code modified to update the times, and to incorporate the fine resolution of latitudes and
!       longitudes to match with elevations from a generated spreadsheet.
!*********************************************************************************

Use Kinds
Use Globals
Implicit None

Contains

Subroutine WritePRF (WxPT, DTG, Location, Level, Inventory)
!*********************************************************************************
```

```
!	This Subroutine takes the newly-filled WxPT array and writes the data into a format
!	in which FORTRAN can understand.  This format is explained in the HPAC 4.03 user manual
!	starting on page 573.  The basic gist is copied here for a quick explanation:
!
!	Profile File
!	A sample PRF file is shown below.
!
!	# CREATOR: WXEDITOR
!	# DATE: 2001-04-17 20:58:42 GMT
!	# SOURCE: obs
!	# REFERENCE: agl
!	# TYPE: OBSERVATION
!	# ANALYSIS: 2001 04 17 12.00
!	# START: 2001 04 17 12.00
!	# END: 001 04 17 15.00
!	# TIMEREFERENCE: UTC
!	# MODE: profile all
!	PROFILE
!	8 6
!	ID YYMMDD HOUR LAT LON ELEV ZI HFLUX
!	HOURS N E M M W/M2
!	Z WDIR WSPD P T H
!	M DEG M/S MB C %
!	HPAC 4.04 User's Manual
!	574
!	-9999
!	ID: 722650 010417 12.00 31.95 -102.22 872 112 -28.68
!	2 360 5.1 960 2.6 97
!	680 20 19.0 925 3.8 100
!	1369 45 14.9 850 4.2 100
!	2933 55 12.9 700 -2.9 94
!
!	Header lines begin with the # character in the first column. All header lines are at the
!	beginning of the PRF file. As shown above, the header lines describe the data type
!	(Observation, Forecast, or Analysis), the time reference (i.e., UTC or LOCAL), which
!	application wrote the file and when it was written. For Forecast files, an Analysis header
!	line will appear defining the date and time of the model analysis.
!	The keyword entry PROFILE indicates that this is an upper air observations file.
!	The first number 6 indicates there are six Fixed Data columns in the ID line of the PRF file. The
!	Fixed Data columns contain data that refer to the observing station. The second number 6
!	indicates there are six Profile Data columns. Profile Data columns contain the multi-level, upper
!	air observations.
!	The first two lines list the Fixed Data variable names and the units for each fixed data variable
!	respectively. The Fixed Data are given once for each report. A summary of the Fixed Data
!	variable names and units typically used in the PRF files is given in the table below.
!
!	Fixed Data Variable Description	Fixed Data Variable Name	Fixed Data Variable Units
!	Station ID			ID				None
!	Year-Month-Day			YYMMDD				None
!	Hour				HOUR				HOURS
!	Latitude			LAT				N
!	Longitude			LON				E
!	Station Elevation		ELEV				M
!
```

```
!       The last two lines list the Profile Data variable names and the units for each Profile Data variable
!       respectively.The Profile Data are given for each level in the report. A summary of the Profile Data
!       variable names and units typically used in the PRF files is given in the table below.
!
!       Profile Data Variable          Profile Data                        Profile   Name
!       Description                    Variable Name                       Variable Units
!
!       Altitude                       Z                                   M
!       Wind Direction                 WDIR (or DIR)                       DEG
!       Wind Speed                     WSPD (or SPEED or SPD)              M/S
!       Pressure                       P                                   MB
!       Temperature                    T                                   K
!       Humidity                       H (or HUMID or Q)                   % x 100
!
!
!       The number -9999 is the indicator used for missing data.
!       The output file contains the data values in column order. All observations for a
!       particular station, date, and time are grouped together. Within a group, the observations
!       are listed in order of ascending height. When observations are available for multiple
!       stations or multiple times the output file will contain multiple sections that are similar
!       to the above example. Each of these sections will begin with a unique ID: line.
!
!**************************************************************************************!

Use Kinds
Use Globals
USE DFPORT
Implicit None

Type(WxPoint),Intent(In)   :: WxPT(:,:,:)      ! 3D array of weather data points
Integer,  Intent(In)       :: Level(:)         ! Pressure levels for which Wx data is avail [mb]
Type(Loc),Intent(In)       :: Location(:)      ! Locations for which Wx data is avail [Lon, Lat]
Integer,  Intent(In)       :: DTG(:)           ! Date-Time-Groups where Wx data is avail
[YYYYMMDDHH]
Character(Len=20), Intent(In):: Inventory
Character(Len=20)          :: OutputFile       ! Name of prf file that will be created
Character(Len=3)           :: Initials         ! Name of person creating file
Integer   :: Year, Month, Day, Elev            ! DTG index and Level Index for array searching
Character(Len=24):: CurrentTime
Integer:: TimeArray(8)                         ! Array containing time information
Character(Len =10)::Analysis, StartTime, EndTime
Integer :: ID1, ID2, LonGrid, LatGrid, Arrow           ! Used for finding LonGrid and LatGrid
Character(Len=200):: Line6                             ! Used for finding LonGrid and LatGrid
Character(Len = 6):: IDNumber                          ! ID Number
Character(Len = 2)::  F3, L3                           ! First 3 numbers, Last 3 Numbers of IDNumber
Character(Len=15):: SfcFile                            ! Name of .txt file containing surface elevation data
SfcFile = "New Surface.txt"

ierror1 = 0

! Get user input
Write(*,*) 'Enter name of HPAC .prf file to be created (exampl: george.prf): '
!Read(*,*)  OutputFile
```

```
! Uncomment below to hardcode an output file
OutputFile = "JonnieBoy1962.prf"

Write(*,*) 'Enter your initials (limited to 3 letters): '
!Read(*,*)  Initials

! Uncomment below to hardcode an output file
Initials = "CPJ"    !Initials of Christopher Patrick Jones

!********Get LatGrid and LonGrid for writing to "ID:" field **********************************!
! Open inventory file
OPEN (UNIT = 20, FILE=Inventory, STATUS='OLD', ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'error Opening Inventory File in GetLocSize Subroutine'

Do i = 1,5                              ! Move pointer over the first 5 lines
        READ (20,*, IOSTAT = ierror1)
        If (ierror1 .NE. 0) EXIT
End Do

Read (20,'(a)', IOSTAT = ierror1) Line6          ! Read the 6th Line of the Inventory file
arrow = index(Line6,"(") + 1                     ! Find the ( before the Number of Lons
Read (Line6(arrow:),*) LonGrid                   ! Read the number of Lons in the grid
arrow = index(Line6,"x") + 1                     ! Find the x before the Number of Lats
Read (Line6(arrow:),*) LatGrid                   ! Read the number of Lats in the grid

Close (20)

!***********************************************************************************!
! Open output file
OPEN (UNIT = 40, FILE=OutputFile, STATUS='NEW', ACTION='WRITE', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'WritePRF Subroutine: Error Creating PRF file'

Write(40, 5000) Initials
5000 Format ("# CREATOR:", T19, A3)

CurrentTime = FDate()
Write(40,5010) CurrentTime
5010 Format ("# DATE:", T19, A24, 1x, "Local")

Write(40,5020) "GRIB"
5020 Format ("# SOURCE:", T19, A4)

Write(40,5030) "no"
5030 Format ("# EDITED:", T19, A2)

Write(40,5040) "msl"
5040 Format ("# REFERENCE:", T19, A3)

Write(40,5050) "forecast"
5050 Format ("# TYPE:", T19, A8)

Write(Analysis, '(i10)') (DTG(1))
Write(40,5060) Analysis(1:4), Analysis(5:6), Analysis(7:8),Analysis(9:10)
5060 Format ("# ANALYSIS:", T19, A4, 1x, A2, 1x, A2, 1x, A2, ".00")
```

```
Write(StartTime, '(i10)') (DTG(1))
Write(40,5070) StartTime(1:4), StartTime(5:6), StartTime(7:8),StartTime(9:10)
5070 Format ("# START:", T19, A4, 1x, A2, 1x, A2, 1x, A2, ".00")

Write(EndTime, '(i10)') (DTG(TimeSize))
Write(40,5080) EndTime(1:4), EndTime(5:6), EndTime(7:8),EndTime(9:10)
5080 Format ("# END:", T19, A4, 1x, A2, 1x, A2, 1x, A2, ".00")

Write(40,5090) "UTC"
5090 Format ("# TIMEREFERENCE:", T19, A3)

Write(40,5100) "Profile All"
5100 Format ("# MODE:", T19, A11)

Write(40,5110) "PROFILE"
5110 Format (A7)

Write(40, 5120) 6, 6
5120 Format (I1, 1x, I1)

Write(40, 5130) "ID      ", "YYYYMMDD  ", "HOUR    ", "LAT     ", "LON     ", "ELEV    "
5130 Format (A8, A8, A8, A8, A8, A8)

Write(40, 5140) "HOURS   ", "N       ", "E       ", "M       "
5140 Format (T17, A8, A8, A8, A8)

Write(40, 5150) "Z       ", "WDIR    ", "WSPD    ", "P       ", "T       ", "HUMID   "
5150 Format (A8, A8, A8, A8, A8, A8)

Write(40, 5160) "M       ", "DEG     ", "M/S     ", "MB      ", "K       ", "%       "
5160 Format (A8, A8, A8, A8, A8, A8)

Write(40, 5170) -9999
5170 Format (I5)

!Step Through Time Blocks
Do i = 1, TimeSize

Write(StartTime, '(i10)') (DTG(i))

! Open surface file here (once each timesize) for comparison in elevation subroutine
OPEN (UNIT = 90, FILE=SfcFile, STATUS='Old', ACTION='READ', IOSTAT=ierror1)
If (ierror1 .NE. 0) Write(*,*) 'Elevation Subroutine: Error opening surface elevation data file'

Read (90,*)                ! Read over 1st line in data file (its header data)

ID1 = 0
ID2 = 1

        !Step Through Levels
        Do j = 1, LocSize
                Call Elevation(Location(j)%Lat,Location(j)%Lon,Elev)
```

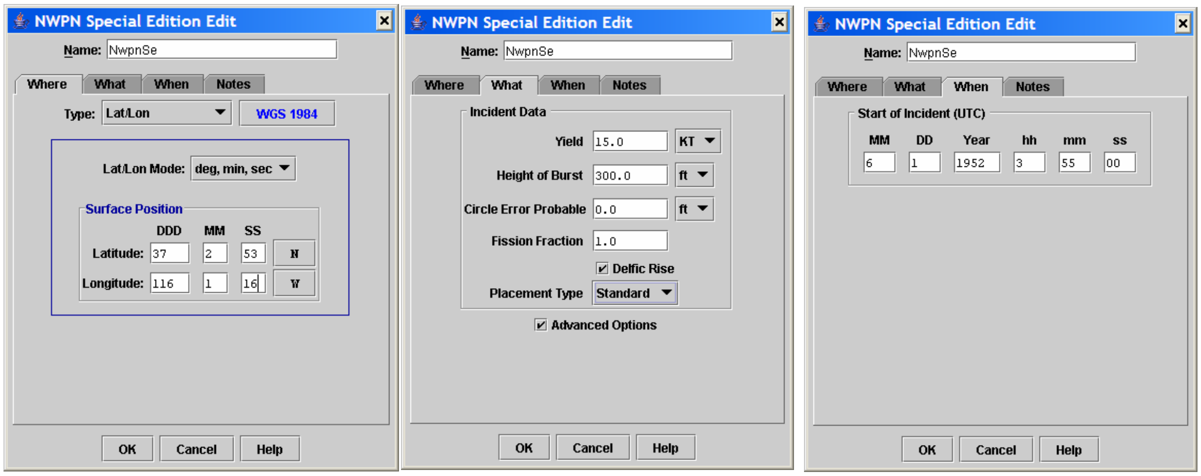
```
	!*********This block of code constructs the ID # for the .prf file*********************
		IDNumber = "000000"
		ID1 = ID1 +1			!Gets the ID numbering sequence
		If(ID1 .EQ. LonGrid + 1) Then
			ID1 = 1
			ID2 = ID2 +1
		End If

		Write(F3, '(I2)') ID1
		Write(L3, '(I2)') ID2

		If (ID1 .GE. 10) Then
			IDNumber(2:3) = F3(1:2)
		Else
			IDNumber(3:3) = F3(2:2)
		End If

		If (ID2 .GE. 10) Then
			IDNumber(5:6) = L3(1:2)
		Else
			IDNumber(6:6) = L3(2:2)
		End If

	!*******************************************************************************
		Write(40, 5180) "ID: ",IDNumber, StartTime(1:8) , StartTime(9:10), Location(j)%Lat, &
		& Location(j)%Lon, Elev
		5180 Format (A4, T5, A6, T14, A8, T23, A2, ".00", T30, F7.4, T38, F9.4,T50, I5)

		Do k = 1, LevelSize
			Write(40, 5190) Int(WxPT(k,j,i)%HGT), Int(WxPT(k,j,i)%WndDir), &
			& WxPT(k,j,i)%WndSpd, Int(Level(k)),WxPT(k,j,i)%T, Int(WxPT(k,j,i)%RH)
			5190 Format (3x, I5, T10, I3, T19, F5.1, T30, I4, T43, F5.1, T52, I5)

		End Do

	End Do
Close (90)
End Do

Close (40)

End Subroutine WritePRF


Subroutine Elevation (Lat, Lon, Elev)
!*********************************************************************************
!	This Subroutine takes a Latitude and Longitude and returns the surface elevation.  It does
!	this by looking up the elevation from a data file (New Surface.txt) which was created
!	by saving an Excel File as a tab-delimited text file.  The data for this file comes from Google
!	Earth, and is limited to 4440 locations.  The locations range from (39.00,-119.25) to
!	(33.03,-112.00) in a 0.09 degree resolution, as produced in the nested grid using the RAMS v6.0
!	software.
!
!	Partial New Surface.txt Contents:
```

```
!
!	Latitude	Longitude	Elevation (ft)	Elevation (m)
!	34.3665	-119.1282	899	274.0152
!	34.3665	-119.0074	313	95.4024
!	34.3665	-118.8866	914	278.5872
!	34.3665	-118.7657	2506	763.8288
!	34.3665	-118.6449	1865	568.452
!	34.3665	-118.5241	1388	423.0624
!	…………………………………………………………………………
!	34.3665	-115.6245	742	226.1616
!	34.3665	-115.5037	581	177.0888
!	34.3665	-115.3829	593	180.7464
!	34.3665	-115.2620	1156	352.3488
!	34.3665	-115.1412	1661	506.2728
!	34.3665	-115.0204	1024	312.1152
!	34.3665	-114.8996	2138	651.6624
!	34.3665	-114.7788	2502	762.6096
!	34.3665	-114.6580	1273	388.0104
!	34.3665	-114.5371	1317	401.4216
!	34.3665	-114.4163	1790	545.592
!	34.3665	-114.2955	888	270.6624
!	34.3665	-114.1747	665	202.692
!	34.3665	-114.0539	1754	534.6192
!	34.3665	-113.9331	1438	438.3024
!	34.3665	-113.8122	1803	549.5544
!	34.3665	-113.6914	2294	699.2112
!	34.3665	-113.5706	1997	608.6856
!	34.3665	-113.4498	2324	708.3552
!	34.3665	-113.3290	2786	849.1728
!	34.3665	-113.2082	1992	607.1616
!	34.3665	-113.0873	2442	744.3216
!	34.3665	-112.9665	3621	1103.6808
!	34.3665	-112.8457	4132	1259.4336
!	34.3665	-112.7249	4266	1300.2768
!	34.3665	-112.6041	4612	1405.7376
!	34.3665	-112.4833	5077	1547.4696
!	34.3665	-112.3624	5750	1752.6
!	34.3665	-112.2416	4518	1377.0864
!	34.3665	-112.1208	3722	1134.4656
!	34.3665	-112.0000	4313	1314.6024
!	34.4300	-119.1282	1512	460.8576
!	34.4300	-119.0074	3550	1082.04
!
!*********************************************************************************

Use Kinds
Use Globals
Implicit None

Real(dp),Intent(In) :: Lat		! Degrees of North Latitude
Real(dp),Intent(In) :: Lon		! Degrees of Eastern Longitude
Integer,Intent(InOut):: Elev		! Surface Elevation in meters
Real(dp):: TempLat, TempLon		! Lats and Lons read from data file
Integer:: Dummy1			! Elevation (in Feet) from .dat file
```

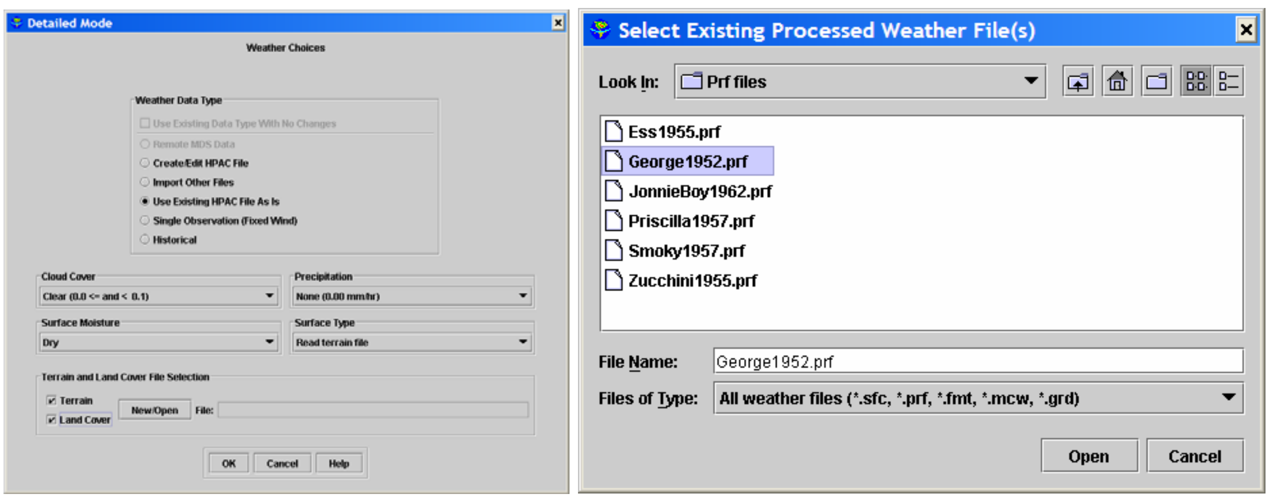
```
Real(dp):: TempElev                    ! Elevation (in meters) from .dat file
Real(dp):: diffLat, diffLon            !Tolerance markers to check for matching lat/lon
integer:: flag
Real(dp):: Tol

ierror1 = 0

! set tolerance
Tol = 0.001_dp

Do      ! Sequentially read through the records

Read (90,*, IOSTAT = ierror2) TempLat, TempLon, Dummy1, TempElev        !Read .txt file record
        If (ierror2 .NE. 0) Then
                Write(*,*) 'Elevation Subroutine: Error reading a record in Elevation data file'
                Exit
        End If

        diffLat = abs (Lat - templat)
        diffLon = abs (Lon - templon)

        If( (diffLat .LE. Tol) .AND. (diffLon .LE. Tol) ) Then
                Elev = TempElev         ! Get Elevation
                Exit                    ! Exit and pass Elev to WritePRF Sub
        Else
        End If

End Do

! reset tolerance markers so no erroneous data is loaded
difflat = 10._dp
diffLon = 10._dp

End Subroutine Elevation

End Module PrfWriter

Module Globals
! Module that contains global variables used throughout the program

Use Kinds
Implicit None

Integer:: ierror1, ierror2                      ! Error Flag
Integer:: i, j, k                               ! Loop Counters
Character(len=20):: Inventory, DataFile         ! Filenames for the 2 files decoded by wgrib.exe
Integer:: rec                   ! Number of records in the Inventory (sets of data in data file)
Integer:: LonGrid, LatGrid, LocSize, TimeSize, LevelSize        ! Computed for the allocation of arrays

Type :: WxPoint                 ! Contains Wx values for a given location (lat/lon), press level, and time
        Real(dp) :: HGT         ! Geopotential height at bottom of the layer [m]
        Real(dp) :: T           ! Air Temperature [K]
        Real(dp) :: U           ! E-W Wind Component (Wind is TO this direction; positive = East) [m/s]
        Real(dp) :: V           ! N-S Wind Component (Wind is TO this direction; positive = North) [m/s]
```

```
        Real(dp) :: RH     ! Relative Humidity [%]
        Real(dp) :: WndDir !Wind Azimuth (Clockwise from North; wind FROM this direction) [unitless]
        Real(dp) :: WndSpd  !Wind Speed of the Wind Azimuth [m/s]
End Type WxPoint

Type :: Loc                    ! Location consists of a Latitude and Longitude
        Real(dp) :: Lat
        Real(dp) :: Lon
End Type Loc

End Module Globals

Module Kinds
        Implicit None
        Public
!*************************************************************************************!
!       Date                Programmers              Description of Change       !
!       ====                ==========               ====================
!       7 NOV 06            MAJ Chris Jones          Original Code
!*************************************************************************************!
        Integer,Parameter:: sp = Selected_Real_Kind(p=6)
        Integer,Parameter:: dp = Selected_Real_Kind(p=14)
End Module Kinds
```

Appendix D: Input weather file to HPAC



Initial definition of event (George in this case)



Editing the weather to input upper air file

Appendix E: MOE and NAD values for tests

GEORGE			
4x4 No Terrain (120 to 112.5W, 35 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.488	0.912	0.364
0.02	0.507	0.864	0.361
0.08	0.248	0.241	0.755
0.2	0.254	0.270	0.738
0.8	0.306	0.246	0.727
2	0.285	0.118	0.833
3x4 No Terrain (117.5 to 112.5W, 35 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.490	0.852	0.378
0.02	0.492	0.787	0.394
0.08	0.240	0.227	0.767
0.2	0.268	0.298	0.717
0.8	0.289	0.249	0.732
2	0.159	0.071	0.902
3x4 900 point (117.5 to 112.5W, 35 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.506	0.982	0.332
0.02	0.546	0.963	0.303
0.08	0.309	0.292	0.700
0.2	0.240	0.287	0.738
0.8	0.290	0.247	0.733
2	0.260	0.115	0.841
3x4 3500 point (117.5 to 112.5W, 35 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.507	0.972	0.334
0.02	0.542	0.945	0.311
0.08	0.247	0.236	0.759
0.2	0.229	0.281	0.748
0.8	0.290	0.256	0.728
2	0.258	0.113	0.842
3x4 35000 point (117.5 to 112.5W, 35 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.465	0.977	0.370
0.02	0.505	0.948	0.341
0.08	0.223	0.238	0.770
0.2	0.224	0.248	0.764
0.8	0.279	0.252	0.735
2	0.306	0.132	0.816

ESS			
3x3 No Terrain (117.5 to 112.5W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.252	0.736	0.625
0.02	0.295	0.797	0.570
0.08	0.434	0.739	0.453
0.2	0.528	0.734	0.386
0.8	0.849	0.497	0.373
2	0.820	0.304	0.557
3x2 No Terrain (117.5 to 112.5W, 35 to 37.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.313	0.838	0.544
0.02	0.305	0.909	0.543
0.08	0.337	0.682	0.548
0.2	0.327	0.505	0.603
0.8	0.477	0.290	0.639
2	0.615	0.231	0.664
3x2 900 point (117.5 to 112.5W, 35 to 37.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.395	0.993	0.434
0.02	0.396	0.988	0.435
0.08	0.448	0.860	0.411
0.2	0.474	0.740	0.422
0.8	0.824	0.543	0.346
2	0.930	0.365	0.476
3x2 3500 point (117.5 to 112.5W, 35 to 37.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.338	0.978	0.497
0.02	0.337	0.982	0.498
0.08	0.357	0.844	0.498
0.2	0.385	0.693	0.505
0.8	0.706	0.481	0.428
2	0.762	0.300	0.570
3x2 35000 point (117.5 to 112.5W, 35 to 37.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.281	0.854	0.577
0.02	0.296	0.974	0.546
0.08	0.359	0.947	0.479
0.2	0.428	0.849	0.431
0.8	0.924	0.653	0.235
2	0.963	0.379	0.456

ZUCCHINI			
3x3 No Terrain (117.5 to 112W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.343	0.490	0.597
0.02	0.272	0.349	0.694
0.08	0.022	0.024	0.977
0.2	0.026	0.030	0.972
0.8	0.069	0.037	0.952
2	0.099	0.042	0.941
4x4 No Terrain (116 to 110W, 35 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.030	0.041	0.965
0.02	0.002	0.003	0.997
0.08	0.004	0.004	0.996
0.2	0.007	0.009	0.992
0.8	0.032	0.019	0.976
2	0.063	0.024	0.965
6x6 No Terrain (122.5 to 110W, 30 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.234	0.607	0.662
0.02	0.206	0.450	0.718
0.08	0.109	0.154	0.872
0.2	0.034	0.045	0.962
0.8	0.061	0.033	0.957
2	0.094	0.041	0.942
6x6 900 point (122.5 to 110W, 30 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.231	0.310	0.735
0.02	0.176	0.218	0.805
0.08	0.019	0.035	0.975
0.2	0.022	0.032	0.974
0.8	0.056	0.034	0.958
2	0.081	0.034	0.952
6x6 3500 point (122.5 to 110W, 30 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.275	0.312	0.708
0.02	0.114	0.123	0.882
0.08	0.012	0.013	0.988
0.2	0.013	0.015	0.986
0.8	0.045	0.027	0.966
2	0.081	0.036	0.950
6x6 35000 point (122.5 to 110W, 30 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.008	0.311	0.356	0.668
0.02	0.198	0.211	0.796

0.08	0.015	0.020	0.983
0.2	0.016	0.018	0.983
0.8	0.050	0.030	0.963
2	0.094	0.044	0.940

PRISCILLA			
3x4 No Terrain (120 to 112.5W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.02	0.011	0.063	0.981
0.1	0.031	0.134	0.950
0.2	0.047	0.172	0.926
1	0.100	0.271	0.854
3x2 No Terrain (117.5 to 112.5W, 35 to 37.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.02	0.291	0.193	0.768
0.1	0.126	0.024	0.960
0.2	0.171	0.026	0.955
1	0.377	0.026	0.952
3x2 900 point (117.5 to 112.5W, 35 to 37.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.02	0.016	0.089	0.972
0.1	0.038	0.167	0.938
0.2	0.051	0.178	0.921
1	0.097	0.268	0.857
3x2 3500 point (117.5 to 112.5W, 35 to 37.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.02	0.025	0.163	0.956
0.1	0.055	0.244	0.910
0.2	0.075	0.265	0.883
1	0.135	0.360	0.804
3x2 35000 point (117.5 to 112.5W, 35 to 37.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.02	0.016	0.089	0.972
0.1	0.038	0.167	0.938
0.2	0.051	0.178	0.921
1	0.097	0.268	0.857

SMOKY			
6x6 No Terrain (122.5 to 110W, 30 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.02	0.070	0.322	0.885
0.1	0.003	0.019	0.995
0.2	0.000	0.000	1.000
1	0.000	0.001	1.000
2	0.000	0.002	1.000
10	0.001	0.011	0.998
20	0.006	0.025	0.990
3x3 No Terrain (117.5 to 112.5W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.02	0.061	0.173	0.910
0.1	0.002	0.011	0.997
0.2	0.000	0.000	1.000
1	0.000	0.001	1.000
2	0.000	0.002	1.000
10	0.001	0.011	0.998
20	0.000	0.000	1.000
3x3 900 point (117.5 to 112.5W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.02	0.002	0.004	0.998
0.1	0.001	0.009	0.998
0.2	0.000	0.000	1.000
1	0.000	0.001	1.000
2	0.000	0.002	1.000
10	0.000	0.000	1.000
20	0.000	0.000	1.000
3x3 3500 point (117.5 to 112.5W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.02	0.001	0.004	0.998
0.1	0.001	0.007	0.998
0.2	0.000	0.000	1.000
1	0.000	0.001	1.000
2	0.000	0.002	1.000
10	0.000	0.000	1.000
20	0.000	0.000	1.000
3x3 35000 point (117.5 to 112.5W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.02	0.138	0.187	0.842
0.1	0.001	0.009	0.998
0.2	0.000	0.000	1.000
1	0.000	0.001	1.000
2	0.000	0.002	1.000
10	0.001	0.011	0.998
20	0.000	0.000	1.000

JOHNIE BOY			
4x4 No Terrain (120 to 112.5W, 35 to 42.5N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.01	0.003	0.002	0.997
0.05	0.004	0.002	0.998
0.1	0.003	0.001	0.998
0.5	0.007	0.015	0.991
1	0.003	0.005	0.996
10	0.000	0.000	1.000
3x3 No Terrain (117.5 to 112.5W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.01	0.002	0.002	0.998
0.05	0.002	0.001	0.999
0.1	0.002	0.001	0.999
0.5	0.006	0.012	0.992
1	0.003	0.005	0.996
10	0.000	0.000	1.000
3x3 900 point (117.5 to 112.5W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.01	0.000	0.001	0.999
0.05	0.001	0.001	0.999
0.1	0.000	0.000	0.999
0.5	0.002	0.004	0.997
1	0.003	0.004	0.996
10	0.000	0.000	1.000
3x3 3500 point (117.5 to 112.5W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.01	0.001	0.001	0.999
0.05	0.001	0.001	0.999
0.1	0.001	0.000	0.999
0.5	0.002	0.005	0.997
1	0.003	0.004	0.997
10	0.000	0.000	1.000
3x3 35000 point (117.5 to 112.5W, 35 to 40N)			
Dose Rate [r/hr]	MOE x	MOE y	NAD
0.01	0.001	0.001	0.999
0.05	0.002	0.001	0.999
0.1	0.002	0.000	0.999
0.5	0.002	0.005	0.997
1	0.003	0.004	0.996
10	0.000	0.000	1.000

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Vita

Major Christopher P. Jones graduated from Westwood High School in Austin, Texas. He entered undergraduate studies at Florida Institute of Technology located in Melbourne, Florida where he graduated with a Bachelor of Science in Earth and Space Science. He was commissioned into the US Army Corps of Engineers through FIT's Panther Battalion.

After the basic course at Fort Leonard Wood (FLW), MO, he served as an S-4, line platoon leader, A&O platoon leader, Support Platoon Leader, and Company XO in his first assignment with the 16^{th}, then the 54^{th} Combat Engineer Battalion in Bamberg, Germany. Following this assignment, he returned to FLW for his advance course and CASSS, simultaneously graduating from Missouri School of Mines in the University of Missouri with a masters of science in geology and geophysics. Following this schooling, he was assigned to the 555^{th} Engineer Group and then the 6^{th} MP Group (CID) at Fort Lewis, Washington. He proceeded from this assignment to Dallas, Texas, where he served as a senior observer/controller and team leader with the 75^{th} Training Support Battalion. He entered the Graduate School of Engineering and Management, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio. Upon graduation, he will serve as a Nuclear Research Officer at DTRA in Kirtland AFB, New Mexico.

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14. ABSTRACT
Reanalysis weather data is obtained for dates surrounding historical nuclear tests and processed through Regional Atmospheric Modeling System (RAMS) software to produce a high-resolution weather forecast. Output from RAMS is visualized to check for validity and input into Hazard Prediction and Assessment Capability (HPAC) software and modeled predictions are compared to historical observation data. Simulations are conducted using constant high resolution weather and varying terrain resolution. The HPAC prediction is numerically compared to historical observation data. The result of this research culminated in the knowledge that early-time, low-altitude wind data was neglected by HPAC's incorporation of the Defense Land Fallout Interpretive Code (DELFIC) Cloud Rise Module, resulting in HPAC predictions being inaccurate for early fallout deposition.

15. SUBJECT TERMS
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