

Air Force Institute of Technology

AFIT Scholar

Theses and Dissertations

Student Graduate Works

3-10-2005

In-line Particulate Transport and Dispersion Modeling Using the Regional Atmospheric Modeling System (RAMS)

John W. Englert

Follow this and additional works at: <https://scholar.afit.edu/etd>



Part of the [Atmospheric Sciences Commons](#), and the [Nuclear Commons](#)

Recommended Citation

Englert, John W., "In-line Particulate Transport and Dispersion Modeling Using the Regional Atmospheric Modeling System (RAMS)" (2005). *Theses and Dissertations*. 3743.

<https://scholar.afit.edu/etd/3743>

This Thesis is brought to you for free and open access by the Student Graduate Works at AFIT Scholar. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of AFIT Scholar. For more information, please contact richard.mansfield@afit.edu.



**IN-LINE PARTICULATE TRANSPORT AND DISPERSION MODELING USING
THE REGIONAL ATMOSPHERIC MODELING SYSTEM (RAMS)**

THESIS

John W. Englert, Captain, USAF

AFIT/GNE/ENP/05-03

**DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY**

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States Government.

AFIT/GNE/ENP/05-03

IN-LINE PARTICULATE TRANSPORT AND DISPERSION MODELING USING
THE REGIONAL ATMOSPHERIC MODELING SYSTEM (RAMS)

THESIS

Presented to the Faculty

Department of Engineering Physics

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science (Nuclear Science)

John W. Englert, B.S.

Captain, USAF


March 2005

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

IN-LINE PARTICULATE TRANSPORT AND DISPERSION MODELING USING
THE REGIONAL ATMOSPHERIC MODELING SYSTEM (RAMS)

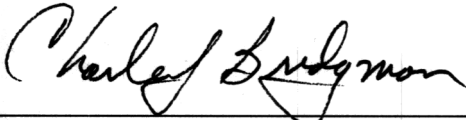
John W. Englert, BS
Captain, USAF

Approved:



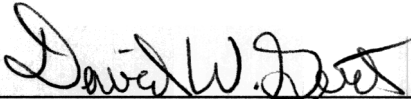
Steven T. Fiorino (Chairman)

10 MAR 05
date



Charles J. Bridgman (Member)

10 March 2005
date



David W. Gerts (Member)

9 Mar 05
date

Abstract

There are a number of analytical and semi-empirical models that describe the behavior of particulate matter in the atmosphere. Many of these require modification for all types of weather, dry versus wet deposition, and overall effects can be quite non-linear. Rainfall (rate, drop size, etc.), snowfall (rate, flake size, etc.), humidity, pressure, temperature, and combination of these greatly affect particle settling and washout rates. To that end, a method for tracking released constituents using the Regional Atmospheric Modeling System (RAMS) microphysics package is developed by modifying one of the hydrometeor categories (hail) in the microphysics package. The RAMS microphysics package allows the investigator to change the formulation of the parameterization scheme of the model for different applications, such as a regional-scale numerical study versus a small continental cumulus simulation. In this study, four test simulations are conducted, two with precipitation and two during dry conditions, each with two different mean particle sizes. Modified RAMS simulations using the larger mean particle size have similar deposition patterns to the Hazard Prediction and Assessment Capability (HPAC) version 4.04 simulations using location time and meteorological data. Advantages to using RAMS for particulate tracking as opposed to using a non-forecasting dispersion model include more realistic plume and fallout patterns and continuous feedback into the numerical forecast of the tracked particulate effects.

Acknowledgements

I would like to thank my advisor, Lieutenant Colonel Steven Fiorino, without whose motivation, patience and constructive criticism I would not have completed my research. I'd also like to thank the members of my committee, Dr. Charles J. Bridgman and Captain David Gerts, for their insight, suggestions and feedback.

Of course I must thank Dr. Craig Tremback and Dr. Robert Walko from Atmospheric Meteorological and Environmental Technologies of Boulder, Colorado. They provided much needed advice for the installation and operation of RAMS through many emails and the RAMS Forum set up on the ATMET website.

I wish to thank my classmates in the nuclear engineering program for their daily, unspoken inspiration. Knowing that others were going through the same difficulties made the effort bearable and worthwhile. It has been a pleasure and a learning experience working beside them.

John W. Englert

Table of Contents

	Page
<i>Abstract</i>	<i>iv</i>
<i>Acknowledgements</i>	<i>v</i>
<i>List of Figures</i>	<i>viii</i>
<i>List of Tables</i>	<i>x</i>
I. Introduction.....	1
1.1. Motivation.....	1
1.2. Background.....	1
1.3. Problem Statement.....	2
1.4. General Approach.....	2
1.5. Thesis Overview.....	3
II. Background.....	4
2.1. Background Overview.....	4
2.2. Modeling Particulate Transport and Dispersion.....	4
2.3. Aerosol Effects.....	6
2.4. RAMS Description.....	11
III. Methodology.....	13
3.1. Methodology Chapter Overview.....	13
3.2. Modification of Hail Hydrometeor Category.....	13
3.3. Code Modification: Model Initialization.....	14
3.4. RAMS Deposition Simulations.....	15
3.5. Deposition Scenarios.....	17
3.6. HPAC Comparison Run.....	21
IV. Results.....	22
4.1. Results Overview.....	22
4.2. Wet Deposition Results.....	22
4.3. Dry Deposition Results.....	32
4.4. HPAC Simulations.....	37
4.5. Discussion of Results.....	39

V. Conclusions.....	42
5.1. RAMS as a Transport and Dispersion Model.....	42
5.2. Future Research Opportunities	45
Appendix A. Glossary of Acronyms	47
Appendix B. Skew-T Plots.....	48
Appendix C. RAMS Source Code Modifications	51
Appendix D. Sample RAMSIN File.....	58
References.....	70
Vita	71

List of Figures

Figure	Page
1. Aerosol-Cloud-Climate interactions.....	6
2. Cloud droplet formation and aerosol size and number concentration	7
3. Cloud influence on aerosol populations	8
4. RAMS domain for wet deposition scenarios using three grids	19
5. RAMS domain for dry deposition scenarios using three grids.....	19
6. RAMS domain with the four-grid set up.....	20
7. 30-min mod-hail deposition [kg/m^2], wet deposition, 200- μm mean diameter.....	23
8. 1-hour mod-hail deposition [kg/m^2], wet deposition, 200- μm mean diameter.....	24
9. 6-hour mod-hail deposition [kg/m^2], wet deposition, 200- μm mean diameter.....	24
10. 30-min accumulated rainfall [mm], wet deposition, 200- μm mean diameter	25
11. 1-hour accumulated rainfall [mm], wet deposition, 200- μm mean diameter	25
12. 6-hour accumulated rainfall [mm], wet deposition, 200- μm mean diameter	26
13. 12-hour mod-hail deposition [kg/m^2], wet deposition, 200- μm mean diameter.....	26
14. 30-min 925mb winds [m/s], wet deposition, 200- μm mean diameter	27
15. 12-hour 925mb winds [m/s], wet deposition, 200- μm mean diameter	27
16. 30-min 700mb winds [m/s], wet deposition, 200- μm mean diameter	28
17. 12-hour 700mb winds [m/s], wet deposition, 200- μm mean diameter.....	28
18. 12-hour mod-hail deposition [kg/m^2], wet deposition, 20- μm mean diameter.....	29
19. 12-hour accumulated rainfall for 200- μm and 20- μm mean particles.....	30
20. Mod-hail deposition 30-min to 12-hours: three-grid scheme	31
21. Mod-hail deposition 30-min to 12-hours: four-grid scheme	31
22. 6-hour mod-hail dry deposition [kg/m^2], 200- μm mean diameter	33

23.	12-hour mod-hail dry deposition [kg/m ²], 200- μ m mean diameter	33
24.	Mod-hail mixing ratio [g/kg] 120 - 180 seconds.....	34
25.	Mod-hail deposition 4 to 12-hours: winds are nearly calm from the NW	34
26.	30-min 925mb winds [m/s], dry deposition, 200- μ m mean diameter	35
27.	12-hour 925mb winds [m/s], dry deposition, 200- μ m mean diameter	35
28.	30-min 700mb winds [m/s], dry deposition, 200- μ m mean diameter	36
29.	12-hour 700mb winds [m/s], dry deposition, 200- μ m mean diameter	36
30.	HPAC dose rate (12-hour) for 6-DEC-04 (contours are .01, 0.1, 1.0, and 10 rad/hr)	38
31.	HPAC dose rate (12-hour) for 7-OCT-04 (contours are .01, 0.1, 1.0, and 10 rad/hr)	39

List of Tables

Table	Page
1. Hail-to-Soil changes.....	14
2. Namlist descriptions for RAMSIN files.....	16
3. Grid settings for 3-grid simulations.....	18
4. Grid settings for 4-grid simulations.....	21

IN-LINE PARTICULATE TRANSPORT AND DISPERSION MODELING USING THE REGIONAL ATMOSPHERIC MODELING SYSTEM (RAMS)

I. Introduction

1.1. Motivation

The United States Air Force Technical Applications Center (AFTAC) is charged with observing global environmental conditions to detect and identify activities peculiar to nuclear weapons testing. A global array of seismic, atmospheric, and other environmental sensors makes up the U.S. Atomic Energy Detection System (USAEDS). By means of USAEDS and a full complement of world-class analytical laboratories, AFTAC monitors signatory nations' compliance with international nuclear test ban treaties. In a role supporting this mission, AFTAC meteorologists generate routine and special atmospheric pollutant transport simulations. The simulations can, from a given source, gauge how much pollutant will arrive where and when.

1.2. Background

AFTAC meteorologists have proposed comparing transport and deposition models with the goal of developing better forecasting tools. There are several models available for running transport and diffusion simulations. The Defense Threat Reduction Agency (DTRA) developed the Hazard Prediction and Assessment Capability (HPAC). The National Oceanic and Atmospheric Administration (NOAA) Air Research Laboratory (ARL) has developed the Hybrid Single Particle Integrated Transport model

(HYSPLIT) model. These Models were developed independently and against a different set of requirements.

1.3. Problem Statement

There are a number of analytical and semi-empirical models that describe the behavior of particulate matter in the atmosphere. Many of these require modification for all types of weather, dry versus wet deposition, and overall effects can be quite non-linear. Rainfall (rate, drop size, etc.), snowfall (rate, flake size, etc.), humidity, pressure, temperature, and combination of these greatly affect particle settling and washout rates. To that end, a method for tracking released constituents using a widely available scalable atmospheric modeling system is developed by modifying one of the hydrometeor categories (hail) in the microphysics package to simulate nuclear fallout particles.

1.4. General Approach

The purpose of this work is to test the concept of using a Numerical Weather Prediction (NWP) model to track airborne particulates while providing for a feedback mechanism, due to the presence of the particulates of interest, back to the model. There are alternatives to modifying the microphysics package that would allow a user of RAMS to track a substance through the atmosphere. A scalar tracer can be placed into the model and advected by RAMS; but the presence of this tracer doesn't affect the RAMS forecast. Another method is to make use of the Cloud Condensation Nuclei (CCN) and Ice Freezing Nuclei (IFN) parameterizations. The concentration and size distribution of CCN and IFN can be changed, which may change the formation of clouds and possibly the amount of precipitation, but RAMS currently doesn't wash out the CCN or IFN.

Modifications to the Regional Atmospheric Modeling System (RAMS) microphysics package source code are performed so that a hydrometeor category simulates silicon dioxide (quartz), which is common in most soil. Outputs from the modified RAMS microphysics package are compared to HPAC model predictions, with a set of controlled hypothetical release scenarios, modifying for two types of weather to demonstrate both dry and wet deposition.

1.5. Thesis Overview

This document consists of five chapters and four appendices. Chapter II presents a discussion of particulate transport and dispersion as well as a description of parameterization of cloud microphysical processes. Chapter II also provides a description of the RAMS model and its microphysics package and the HPAC model. Chapter III outlines the methodology for modifying the RAMS microphysics package and using a hydrometeor category (hail) to perform transport and dispersion simulations. Chapter IV presents the results of this study, four test simulations, two with precipitation and two during dry conditions, each with two different mean particle sizes. The RAMS simulations are then compared to HPAC version 4.04 simulations using the same location, time and meteorological data. A discussion of this proof-of-concept and future research opportunities are in Chapter V.

II. Background

2.1. Background Overview

Effective modeling of particulate transport and dispersion (T&D) plus deposition requires a detailed accounting the interaction of those particulates with the atmosphere. This chapter starts with a brief review of transport and dispersion (T&D) modeling techniques used by both the DoD and civilian agencies. Next is a discussion of the interaction between aerosols and some of the cloud microphysical processes. Finally a description of RAMS and its microphysics package, which is modified to function as a T&D model, is provided. These topics are included to establish the framework for the deposition simulations as described in Sections 3.4 and 3.5.

2.2. Modeling Particulate Transport and Dispersion

T&D models are used for a variety of civilian and military applications ranging from assessing hazards due to a chlorine gas release to a forensic analysis to determine the origin of a radioisotope that has been deposited on the ground. These models employ various computation techniques to determine concentrations of released gases or particulates as a function of time and space from the source point. All of these models are non-forecasting. Therefore, they require the use of meteorological data: climatology, current observations, or the output of a prognostic atmospheric numerical model (e.g. RAMS) can be used to create the necessary wind fields and other atmospheric data. The HPAC and HYbrid PArticle and Concentration Transport (HYPACT) models are discussed in this section to describe some of the computation techniques used by T&D models. HPAC is mentioned because of its use in this study to provide a gauge of the

effectiveness of the modified RAMS as a T&D model. HYPACT is mentioned because it is a hybrid of two different computation methods and it is developed by the same developers of RAMS and it is designed specifically to use meteorological data fields predicted by RAMS.

2.2.1. HPAC. The HPAC software predicts the effects of hazardous nuclear, biological, and chemical (NBC) material releases into the atmosphere and its collateral effects on the civilian and military populations. This counter-proliferation and counterforce tool assists war fighters with targets containing weapons of mass destruction (WMD) and in emergency response to hazardous material releases. HPAC employs integrated source term models, high-resolution weather data, and particulate transport algorithms to model hazard areas and human collateral effects in minutes.

HPAC includes an atmospheric transport model called the Second-order Closure Integrated Puff (SCIPUFF) model. SCIPUFF calculates how the released material disperses through the environment. SCIPUFF calculations take into account turbulence and diffusion due to a variety of factors including the weather and terrain.

HPAC includes an integrated database of historical weather, terrain elevation, land cover, and map data. These data provide a stand-alone capability to run HPAC. Furthermore, HPAC's integrated environmental data readers let HPAC use weather data files that are downloaded from a Meteorological Data Server (MDS) or other external data sources. These external data may be more accurate in time and space, thus producing more accurate output. (DTRA 2003)

2.2.2. *HYPACT*. HYPACT, developed by the ASTER Division of Mission Research Corporation combines the features of grid-based Eulerian dispersion methodologies with Lagrangian particle dispersion modeling.

The HYPACT Lagrangian dispersion scheme is flexible; species can include gases, and a spectrum of aerosol sizes. The 2-D or 3-D wind and turbulence fields are provided by RAMS for forecast applications, or an observational network for diagnostic applications. A Lagrangian model functions well for regimes in which the assumptions underlying Gaussian plume-based models are violated, such as highly sheared flows, recirculating coastal and mountain/valley wind systems, urban heat islands, plume fumigation and bifurcation. The advantage is greatest near a source region for tracers when the source is small and irresolvable on the Eulerian grid (Walko 2001).

2.3. *Aerosol Effects*

Aerosols play an integral role in formation of clouds and determining the earth's climate as shown in Figure 1. A brief overview of the interplay between cloud processes and the presence of aerosols is provided to construct one piece of the framework for using a NWP model to do T&D modeling.

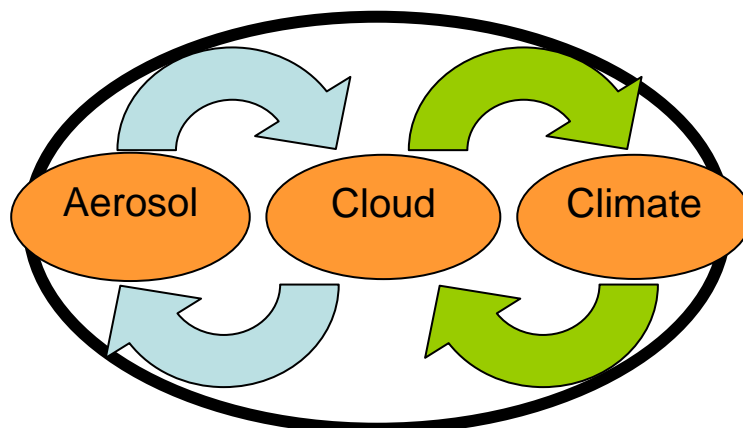


Figure 1 Aerosol-Cloud-Climate interactions

2.3.1. *Aerosols and Developing Clouds.* Dr. Peter Hobbs gives an excellent explanation on the role of aerosols in cloud formation in his book, *Aerosol-Cloud-Climate Interactions*. A parcel of air is lifted and cooled increasing the relative humidity. After it passes its saturation level, supersaturation increases and particles in the air are activated as Cloud Condensation Nuclei (CCN), which in turn allows condensation and the formation of cloud droplets. The concentration and size spectrum of aerosols in clouds can directly affect concentration and size spectra of cloud droplets and precipitation. Figure 2 depicts two particle size groups with different number concentrations. A smaller concentration of larger aerosols may start the formation of cloud droplets with a wide size spectrum. Droplets of different diameters will have different vertical velocities, increasing the likelihood that the larger droplets will grow in size through collision with smaller droplets, eventually becoming large enough to fall as rain. A higher concentration of small aerosols may form more cloud droplets with a narrower size spectrum, reducing the relative velocities between cloud droplets and decreasing the chances for collisions. The smallest particles may just form haze that evaporates as the supersaturation level falls (Hobbs 1993).

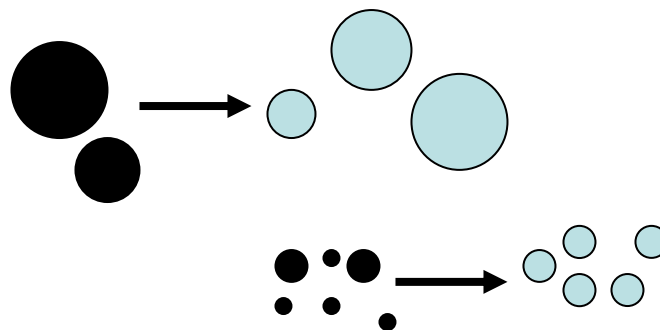


Figure 2 Cloud droplet formation and aerosol size and number concentration

2.3.2. *Clouds Affect Aerosols.* A lot of research has been conducted on the influence of clouds on atmospheric aerosols. These influences on aerosol populations can be categorized into four processes: vertical transport, scavenging processes, chemical changes in cloud drops, and particle formation near clouds (Hegg 2001). Two of these processes, vertical transport and scavenging, are discussed further in this section because of the manner in which RAMS is used to do T&D simulation.

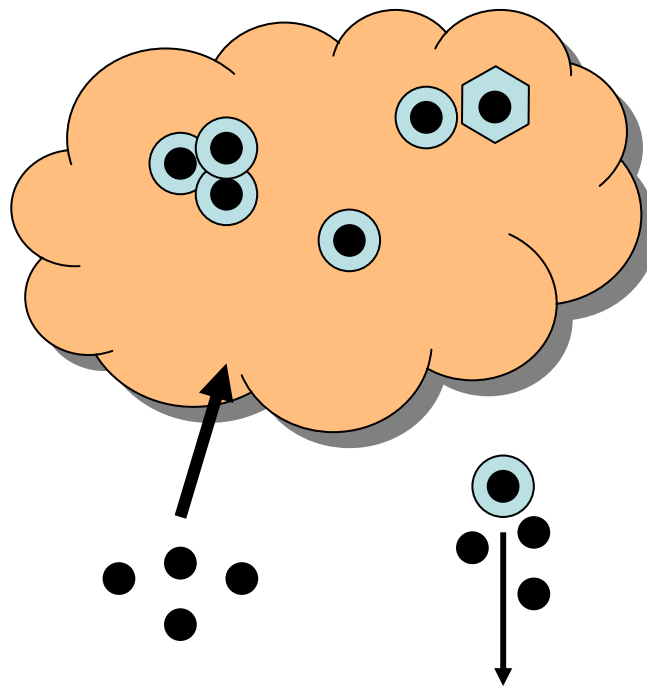


Figure 3 Cloud influence on aerosol populations

Figure 3 depicts two of the mechanisms that work on aerosols. Vertical transport as a mechanism for altering aerosols is where convective clouds move aerosols out of the boundary layer and into the free troposphere. Particles that are transported out of the

boundary layer can now be acted on by processes in the cloud even before aged based processes, such as radioactive decay, can occur. Particles in the cloud have a chance to be activated as CCN which is referred to as nucleation scavenging. Even particles that are insoluble may work well as nuclei for ice formation. Particles that don't make it into the cloud can still be removed through below cloud scavenging if there is precipitation present (Hegg 2001).

2.3.3. *Modeling Interactions of Weather and Aerosols.* There are many methods that have been employed in modifying models and studying the resulting changes in precipitation and how that may affect atmospheric pollutant transport simulations. Some studies have been centered on actual weather events such as a major storms or manmade catastrophes like the Chernobyl accident.

As discussed above, the size distribution and concentration of aerosols in the atmosphere can have significant effects on the nucleation of ice and liquid water, this may in turn affect other microphysical and dynamical characteristics of convective storm systems. Cloud resolving NWP models such as RAMS have been used for the purpose of modeling the sensitivity of predicted weather to the presence of aerosols. One investigation was of the impacts of Saharan dust on Florida storm characteristics. The results of the study demonstrated that Saharan dust does have a significant impact, not only on the microphysical characteristics of convective storms over Florida, but also on the dynamics, accumulated precipitation and precipitation efficiencies of such storms. (Van den Heever 2004)

Section 2.2 mentioned that T&D models use scavenging coefficients to parameterize of the transfer rate of particles into raindrops to account for wet deposition.

Precipitation scavenging coefficients are used widely in pollution studies and are derived from the parameterization of the aerosols and raindrop populations and their interactions (Mircea 2000). There are many aspects of precipitation scavenging coefficients that can be modified for sensitivity tests. One example of modifying modeling parameters was a test of the sensitivity of Cesium-137 wet deposition following the Chernobyl accident by changing the location of in-cloud scavenging through adjustments to the cloud base location from 80% relative humidity to 75% relative humidity (Kinser 2001).

Some studies explore the sensitivity of wet deposition to aerosol and raindrop size distributions. a study of the influence of measured aerosol and size distributions concluded that the polydisperse scavenging coefficients are strongly dependent on aerosol parameterization and type: urban, marine, rural and remote continental, but that they are not influenced significantly by the parameterization of the raindrop size distribution, especially for rain with intensity less than 50mmh^{-1} . For example, the polydisperse scavenging coefficient of urban aerosol was one order of magnitude higher than that of rural aerosol and two orders of magnitude higher than those of remote continental and marine aerosol. There is also almost one order of magnitude difference between the rural aerosol and the remote continental or marine aerosol (Mircea 00).

For another study, the National Atmospheric Release Advisory Center (NARAC) model was modified to include an assumption regarding rain rate and convective systems. Because it wasn't possible to directly simulate aerosol participation in the in-cloud processes, a conditional statement was included that said that if rain rate was greater than 25mmh^{-1} , then a particle greater than or equal to $0.2\text{-}\mu\text{m}$ would be assumed to be lifted

into the cloud and scavenged as if it were a 10 micron particle located below the cloud. This assumption established the condition for nucleation scavenging (Loosmore 2003).

2.4. RAMS Description

The Mission Research Corporation's RAMS (Regional Atmospheric Modeling System) is a highly versatile numerical code developed by scientists at Colorado State University for simulating and forecasting meteorological phenomena, and for depicting the results. Its major components are:

1. An atmospheric model which performs the actual simulations
2. A data analysis package which prepares initial data for the atmospheric model from observed meteorological data
3. A post-processing model visualization and analysis package which interfaces atmospheric model output with a variety of visualization software utilities.

The atmospheric model is constructed around the full set of primitive dynamical equations which govern atmospheric motions, and supplements these equations with optional parameterizations for turbulent diffusion, solar and terrestrial radiation, moist processes including the formation and interaction of clouds and precipitating liquid and ice hydrometeors, sensible and latent heat exchange between the atmosphere, multiple soil layers, a vegetation canopy, surface water, the kinematic effects of terrain, and cumulus convection. RAMS is fundamentally a limited-area model, but may be configured to cover an area as large as a planetary hemisphere for simulating mesoscale and large scale atmospheric systems. There is no lower limit to the domain size or to the mesh cell size of the model's finite difference grid: micro scale phenomena such as

tornadoes and boundary layer eddies, as well as sub-micro scale turbulent flow over buildings and in a wind tunnel, have been simulated with this code. Two-way interactive grid nesting in RAMS allows local fine mesh grids to resolve compact atmospheric systems such as thunderstorms, while simultaneously modeling the large scale environment of the systems on a coarser grid. (Walko 1995)

The RAMS microphysics package was developed in order to have the flexibility to change the formulation of the parameterization scheme of the RAMS model for different applications. The microphysics package provides an investigator with a large degree of flexibility in selecting a microphysics parameterization that is optimized for the specific application in mind, such as a regional-scale numerical study versus a small continental cumulus simulation.

The code for the module was developed in such a way that the microphysics package may be called from any dynamics model. The RAMS microphysics package is a bulk type module, where the various water categories may be represented by continuous specified size distributions. The module is passed the entire dynamics model's set of variables; it then calculates the total concentration and mixing ratio tendencies for all the categories of hydrometeors, which are passed back to the dynamics model (Flatau 1989).

A new microphysical parameterization scheme was developed which added several new features. The new scheme included the use of the generalized gamma distribution as the basis function for all hydrometeor categories, the use of a heat budget equation for hydrometeor classes that allows for heat storage and mixed phase hydrometeors and the addition of separate graupel and hail categories (Walko 1995).

III. Methodology

3.1. Methodology Chapter Overview

The RAMS version 4.4 was used to study particulate transport with wet and dry deposition. This chapter explains how RAMS with its microphysics package is modified to enable inline modeling of particulate transport and deposition. Section 3.2 describes the selection and modification of the hail hydrometeor category code in the RAMS microphysics modules. Section 3.3 explains how the meteorology fields are incorporated into the RAMS model. Section 3.4 describes the set up for the wet deposition RAMS runs. Section 3.5 describes the set up for the dry deposition RAMS runs. Section 3.6 covers the HPAC runs that were used for comparing to RAMS surface deposition. The results of the RAMS model runs are discussed in chapter 4.

3.2. Modification of Hail Hydrometeor Category

The RAMS model was chosen because of its availability and the microphysics source code accommodates modification of the microphysical processes. The hail hydrometeor category was selected for modification to simulate nuclear fallout particles. In order to make hail emulate the soil that has condensed out of the rising cloud from a nuclear explosion, the code was modified so that hail has similar physical properties of that soil: density, aerodynamic shape, and thermal properties (melting point). In addition to the physical properties, subroutines that decide if hail should change into rain due to liquid water content were changed to prevent the loss of the modified hail. Table 1 lists the hydrometeor properties and processes that were changed in RAMS. The code modifications can be found in Appendix C.

Table 1 Hail-to-Soil changes

Properties	RAMS Process	Change
Thermal	RAMS handles the melting or freezing of water with a change of internal energy through a thermal flux	The subroutine that calculates internal energy was changed to emulate SiO ₂ (quartz). The melting point for hail was increased by setting the internal energy at which melting occurs to a higher point.
Liquid water content	A hydrometeor category can grow in size through several different processes such as collision coalescence	This remains the same
Conversion from one hydro category to another	If the liquid water fraction of hail becomes greater than 95% then the hail mixing ratio is converted to rain	The subroutine that makes this conversion was changed so that modified hail remains identified as the modified hail even if nearly all the mass is liquid water

3.3. Code Modification: Model Initialization

RAMS is useful as a research tool because it allows the user to set up initial conditions to create a scenario of interest such as the development of a thunderstorm. The *ruser* module is used to initialize the model with these conditions. Modified hail is used as the particulate to be tracked by the RAMS model. To do this a concentration of modified hail is injected into the simulation at the beginning. A subroutine, *force_hail*, was added to *ruser* so that when called, increased the modified hail to air mixing ratio [g/kg] by an amount so that the total mass of inserted would be roughly equal to the mass of soil lofted ($.3t/T$) into the air by a 10-kiloton surface explosion (Bridgman 2001). A subroutine, *force_bubble*, was added to *ruser* to increase the potential temperature of the same volume of air that contained the initial modified hail mass by 50-K. This was done to emulate the cloud rise from the explosion.

3.4. RAMS Deposition Simulations

In this section a method is presented for assessing the modified hail category for simulating transport plus wet and dry deposition of particulates. Simulations are performed for two different weather conditions: one which is raining and the other dry. Model runs for each weather condition are then run two different times, using a different modified hail mean diameter.

3.4.1. Incorporation of Meteorological Data Fields. For simulations using observational data, RAMS needs data analyses for initial conditions, large scale lateral boundary tendencies, and the four-dimensional data assimilation scheme. Various observational datasets are combined and processed with a mesoscale isentropic data analyses package (Tremback, 1990) which has been termed RAMS/ISAN (Isentropic Analysis package). The meteorological input fields for RAMS simulations are 1.0 degree 6-hourly analysis updates from National Center for Atmospheric Research/National Centers for Environmental Prediction (NCAR/NCEP), which are downloaded from the URL: <http://dss.ucar.edu/datasets/ds083.2/data/> . The data files are also compatible with the Mesoscale Model 5th Generation (MM5) and the Weather Research and Forecasting Model (WRF). Use of the GDAS final (FNL) analysis requires the application of a GRIB-to-RALPH format converter, *fdgrib*, which is available from the same software download site as the RAMS source code. These data are accessed over the area of interest and interpolated onto the RAMS polar-stereographic grids, creating a polar-stereographic/pressure coordinate dataset. Then, the data are interpolated vertically to the isentropic vertical coordinate and the terrain-following, σ_z coordinate.

3.4.2. *Set-up and Running RAMS.* This section describes the procedure for setting up the RAMS atmospheric model and the RAMS ISAN (ISentropic ANalysis) package. Specifying values for each of the variables in the atmospheric model namelists is the principal way that a user sets up the desired model configuration and selects the many options available for a particular model run. The namelists have the appearance of a standard FORTRAN namelist. Table 2 shows the namelist and descriptions. Settings for the deposition simulations and the RAMSIN files can be found in Appendix D.

Table 2 Namlist descriptions for RAMSIN files

Namelist	Description
MODEL_GRIDS	set up the simulation time and space domain and grid parameters
MODEL_FILE_INFO	describes how often analysis and history files are written
MODEL_OPTIONS	<p>Hydrometeor category parameters for the microphysics package:</p> <ul style="list-style-type: none"> • Mean diameter • Number concentration per kilogram of air • Shape parameter of the gamma distribution A value of one indicates the Marshall-Palmer, or exponential distribution, in which number concentration decreases monotonically with diameter. Larger values indicate more general gamma distributions, in which the size distribution peaks at a positive diameter. Setting the namelist variable GNU to higher integer values narrows the distribution of the spectrum • Y-intercept of the number concentration Number concentration per unit diameter increment, (<i>i.e.</i>, number per m³ per m), evaluated at zero diameter
MODEL_SOUND	specified the sounding to be used in initializing a simulation
MODEL_PRINT	Used to specify selected data from the model to be written to the standard output file generated with a model run
ISAN	Specify if an ISAN stage is to be run and which observational data to be used

Now that the parameters for a RAMS simulation are set, the next step is to run the model. A surface run is done by setting the RAMSIN file to MAKESFC, which builds the terrain files built from topography files that are available from ATMET at the URL <http://bridge.atmet.org/users/data.php> . Next an isentropic analysis run is performed by setting the RAMSIN file to MAKEVFILE. Finally the simulation is run with RAMSIN set to INITIAL or HISTORY depending if the simulation is starting from the beginning or where another model run ended.

3.4.3. Exporting Simulation Results. The RAMS Evaluation and Visualization Utilities (REVU) is the standard supported package for generating graphical representations and reformatting RAMS model output. REVU's function is to read the analysis files written from a RAMS simulation, select user-specified fields and cross sections from the file data, and plot the field cross sections, or output the selected data in one of several available formats (e.g. Dump, Vis5D, GrADS, GRIB). The REVU_IN file contains the namelist input that instructs REVU which variables, cross sections, and format to output.

3.5. Deposition Scenarios

All depositions simulations are conducted with the particulate concentrations and warm air bubble initialized at the same location, Wilmington, OH. Wilmington was chosen because upper air RAOB's are launched nearby and the soundings can be easily compared to simulation results. There are two wet deposition scenarios, one with mean modified hail diameter of 200- μm and the other for 20- μm . There are also two dry deposition simulations, one with mean modified hail diameter of 200- μm and the other

with 20- μ m. Upper air reanalysis is processed in 6-hour increments by the ISAN starting at simulation beginning.

Simulations were first conducted using three grids, two nested, with the coarsest grid 105.6-km across. Table 3 lists the setting for the 3-grid simulations. Figure 4 and Figure 5 show the simulation domain and the location of the nested grids for the wet and deposition scenarios. Grids 2 and 3 of the wet deposition scenario are located at the SW section of grid 1 to accommodate the strong winds coming from the SW, see Appendix B for skew-T plots that correlate with simulation times.

The thermal bubble and increased modified hail mixing ratio are inserted at the beginning of the simulation, located at the center of grid 3, filling a 1200 x 1200 x 1400 meter box at approximately 2000 meters above the ground.

Table 3 Grid settings for 3-grid simulations

	Wet Deposition			Dry Deposition		
Date	2004 12 06			2004 10 06		
Time	0600 UTC			1200 UTC		
Duration	24 hours			24 hours		
Grid	1	2	3	1	2	3
Center Lat	39.7	39.5	39.5	39.5	39.5	39.5
Center Lon	-83.6	-83.8	-83.8	-83.8	-83.8	-83.8
X-spacing [m]	4800	1200	300	4800	1200	300
# Grid points	22	22	10	22	22	10
Y-spacing [m]	4800	1200	300	4800	1200	300
# Grid points	22	22	10	22	22	10
Z-spacing	30 grid points starting at 100 m, increasing by a factor of 1.15 until spacing reaches 1200 m					

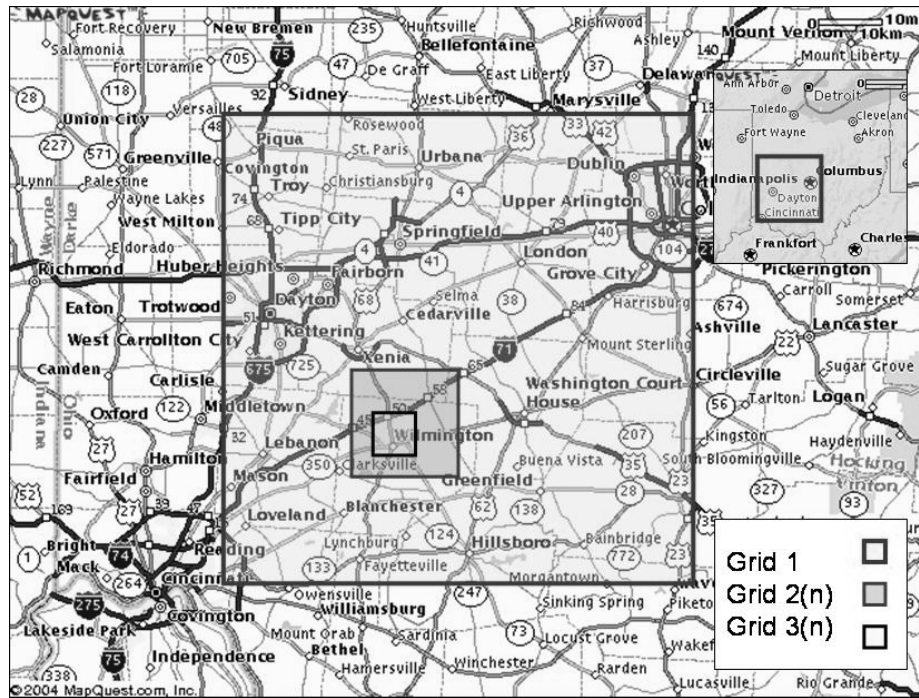


Figure 4 RAMS domain for wet deposition scenarios using three grids

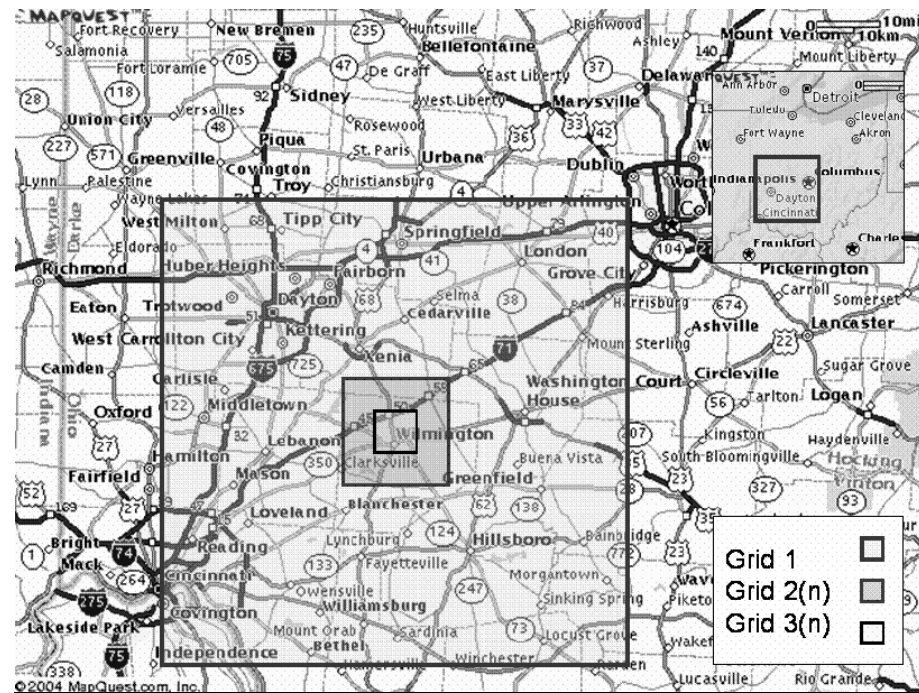


Figure 5 RAMS domain for dry deposition scenarios using three grids

The four deposition scenarios were also run with an expanded simulation domain to provide RAMS with more meteorological data. The domain size was increased to 480-km by adding larger and courser grid. The settings for the larger domain are listed in Table 4. Figure 6 depicts the location of the four grids for the expanded simulation domain. All four grids are centered on Wilmington for both the wet and dry deposition scenarios.

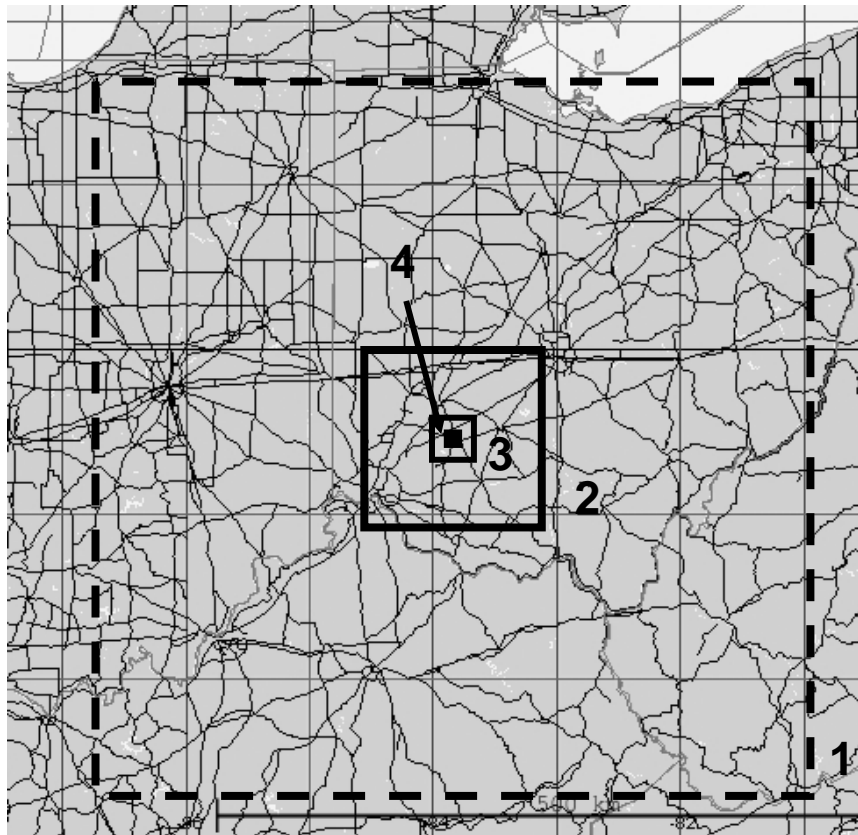


Figure 6 RAMS domain with the four-grid set up

Table 4 Grid settings for 4-grid simulations

	Wet Deposition				Dry Deposition			
Date	2004 12 06				2004 10 06			
Time	0600 UTC				1200 UTC			
Duration	12 hours				12 hours			
Grid	1	2	3	4	1	2	3	4
Center Lat	39.42	39.42	39.42	39.42	39.42	39.42	39.42	39.42
Center Lon	-83.82	-83.82	-83.82	-83.82	-83.82	-83.82	-83.82	-83.82
X-spacing [m]	19200	4800	1200	300	19200	4800	1200	300
# Grid points	25	22	22	10	25	22	22	10
Y-spacing [m]	19200	4800	1200	300	19200	4800	1200	300
# Grid points	25	22	22	10	25	22	22	10
Z-spacing	30 grid points starting at 100 m, increasing by a factor of 1.15 until spacing reaches 1200 m							

3.6. HPAC Comparison Run

The purpose of modifying the hail hydrometeor category in RAMS is to gauge the utility of using a meteorological model to perform particulate transport and dispersion and study the effects of wet deposition. To evaluate the use of a forecast model, DTRA's Hazard Prediction and Assessment Capability (HPAC) version 4.04 is used for a model-versus-model comparison. Only a rough comparison of contours is performed as opposed to a full Measure-of-Effectiveness (Warner 2001). Two HPAC runs are performed, one with precipitation and one without. Each run correlates to the same dates and times as the RAMS wet and dry simulations. The DTRA unclassified weather server is used to obtain meteorological input files for the HPAC runs.

IV. Results

4.1. Results Overview

The hail hydrometeor category was modified to simulate the soil component of nuclear fallout particles so that RAMS could be used to perform T&D simulations of those particles. This chapter explores the results of the two deposition scenarios. Section 4.2 presents the result for the wet deposition scenarios using two different mean particle diameters. Section 4.3 presents results for the dry deposition scenarios with two different mean particle diameters. Section 4.4 shows the results from HPAC simulations. Dose rate contours for a 10-KT surface detonation are plotted for the same location and times as the two different RAMS deposition scenarios. A discussion of the results is found in Section 4.5.

4.2. Wet Deposition Results

The results of the wet deposition runs are explored in this section. Simulations are conducted for two different mean particle diameters, 200- μm and 20- μm . The deposition from the larger mean diameter particles produces a V-shaped pattern starting from injection point and headed toward the northeast, following the direction of prevailing winds. The deposition pattern from the smaller particles, which develops just below the injection point, doesn't form until a front is brought through the simulation domain by RAMS. The simulation that uses the larger mean modified hail diameter produces more accumulated rain than when the mean diameter is smaller.

4.2.1. Large Particle Simulation. The accumulated modified hail, Figure 7, along with total rainfall, Figure 10, after 30-minutes, starts out below where the modified

hail was injected into grid 3 at the beginning of the simulation. As simulation time progresses, the accumulated modified hail, Figure 8 and Figure 9, is accompanied by a similar pattern of rainfall, Figure 11 and Figure 12. More rain then moves in from the southwest and progresses across the model domain as RAMS moves a front through. The mass of modified hail that is deposited on the ground is several orders of magnitude greater than the mass injected. Two possibilities for the increase in modified hail mass are the modified hail injected at the start of the simulation collected liquid water on the way to the ground or the simulation created modified hail that didn't melt. Most likely in this case the second explanation is dominant as seen in Figure 13.

The 925mb and 700mb level winds are plotted for simulation times of 30-minutes and 12-hours. RAMS simulates a front moving through causing the 925mb winds, Figure 14 and Figure 15 as well as the 700mb winds, Figure 16 and Figure 17 to change.

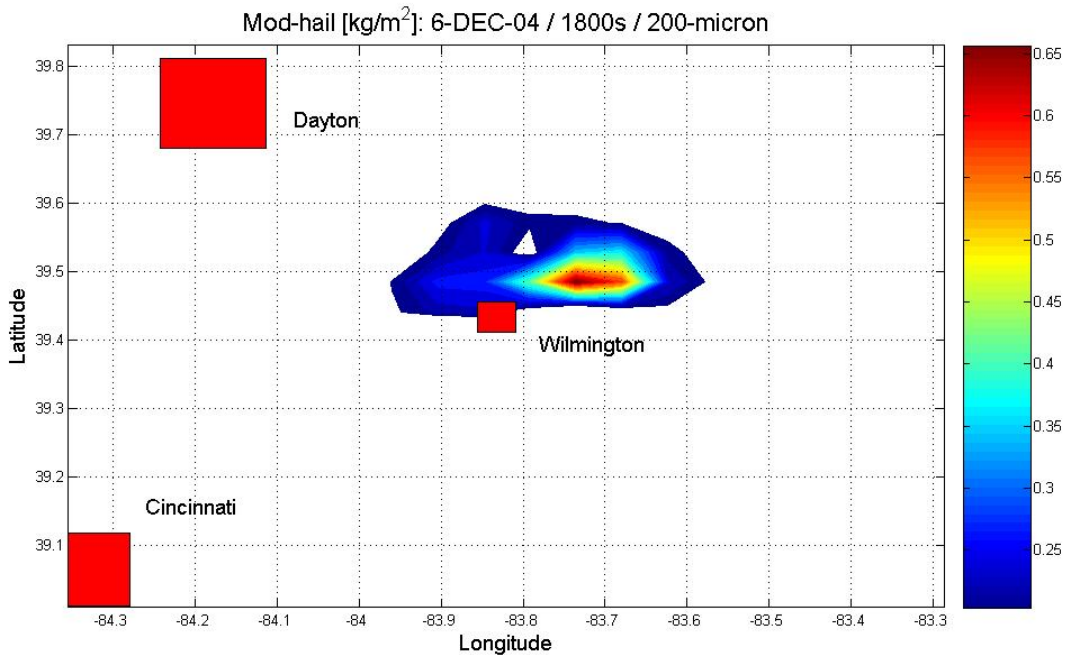


Figure 7 30-min mod-hail deposition [kg/m²], wet deposition, 200- μ m mean diameter

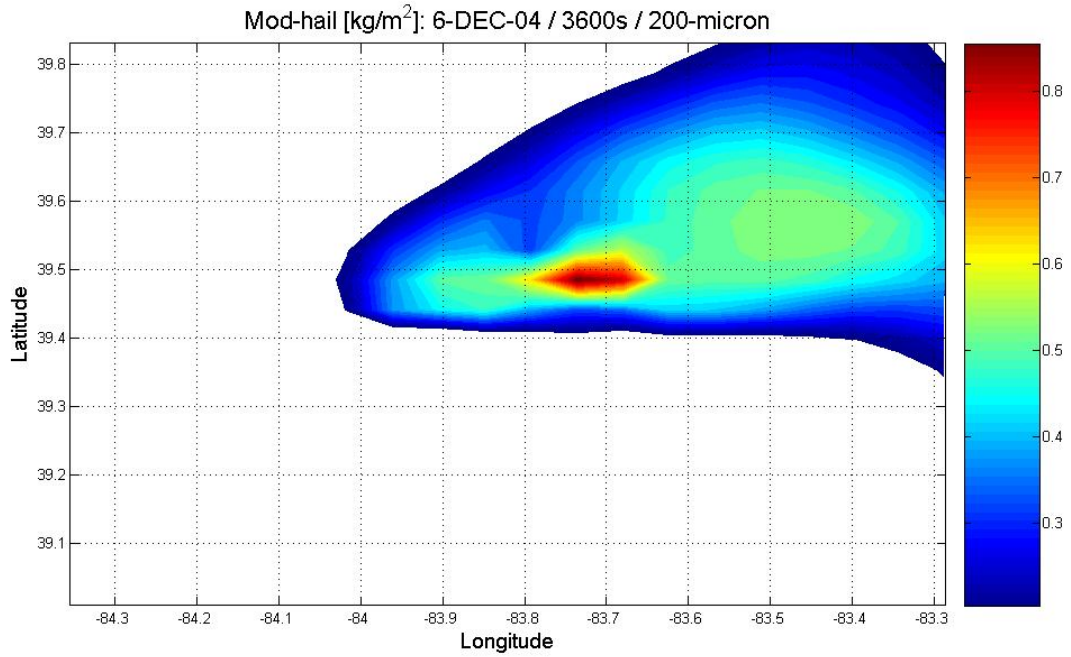


Figure 8 1-hour mod-hail deposition [kg/m^2], wet deposition, 200- μm mean diameter

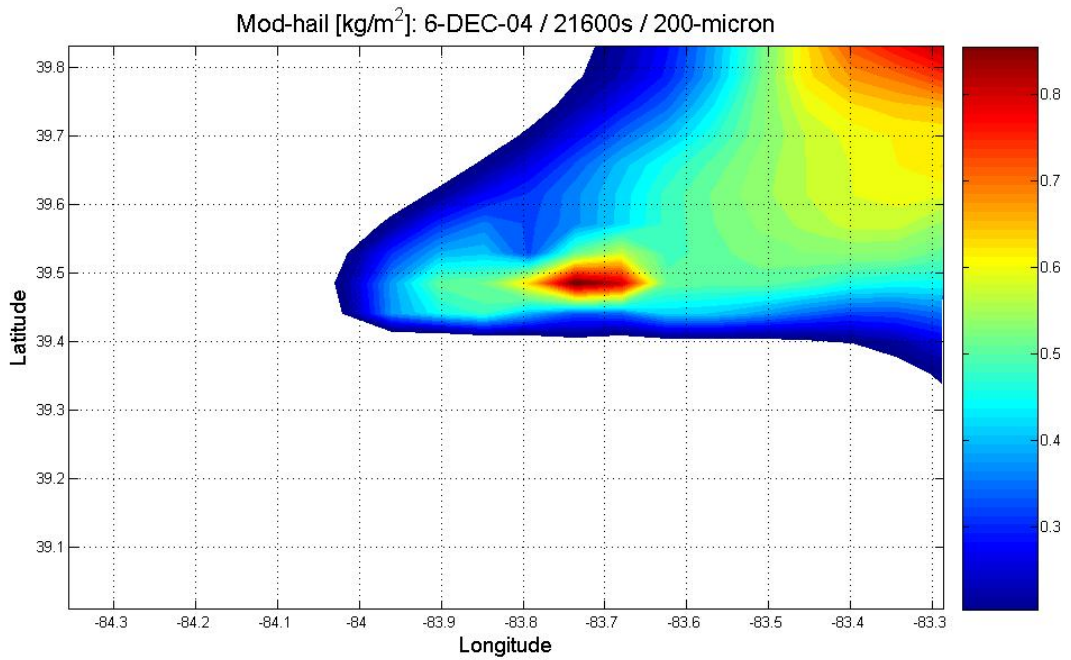


Figure 9 6-hour mod-hail deposition [kg/m^2], wet deposition, 200- μm mean diameter

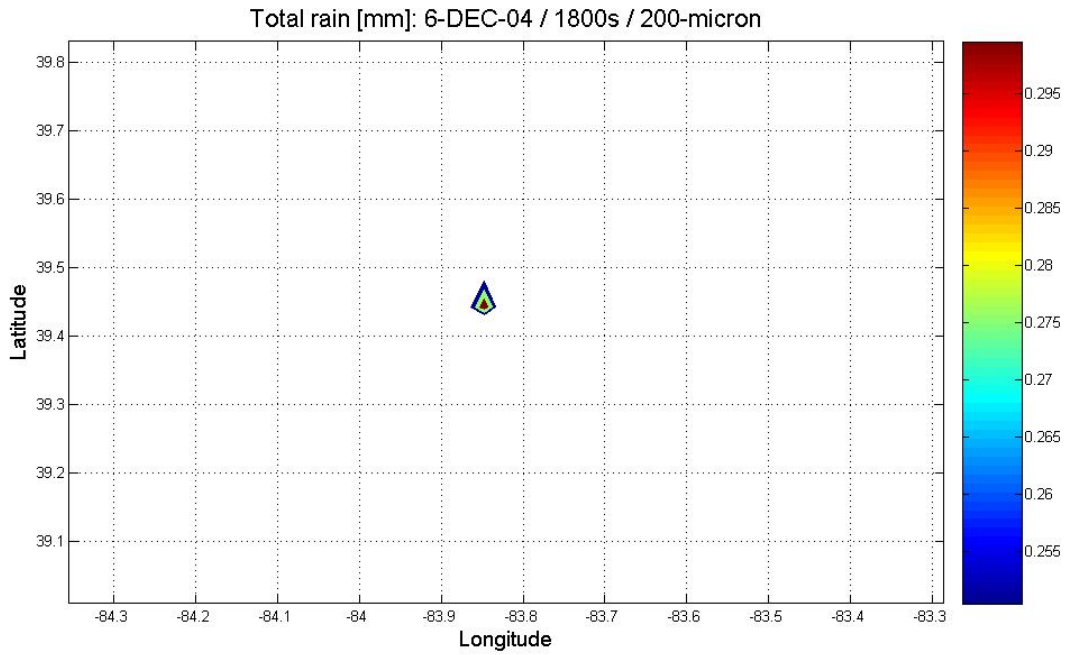


Figure 10 30-min accumulated rainfall [mm], wet deposition, 200- μ m mean diameter

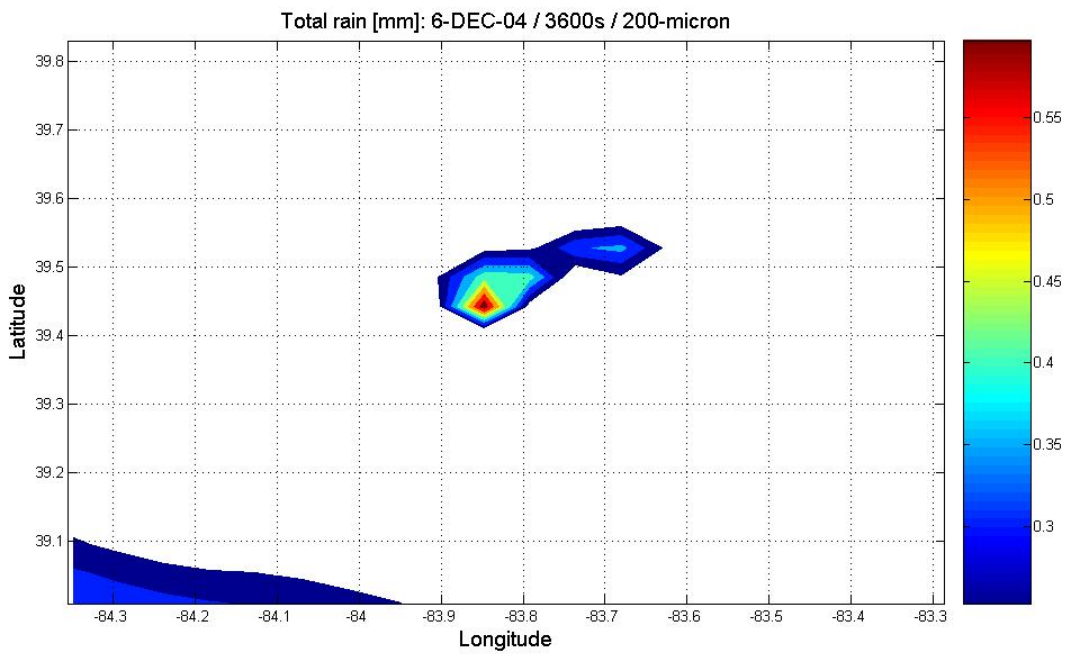


Figure 11 1-hour accumulated rainfall [mm], wet deposition, 200- μ m mean diameter

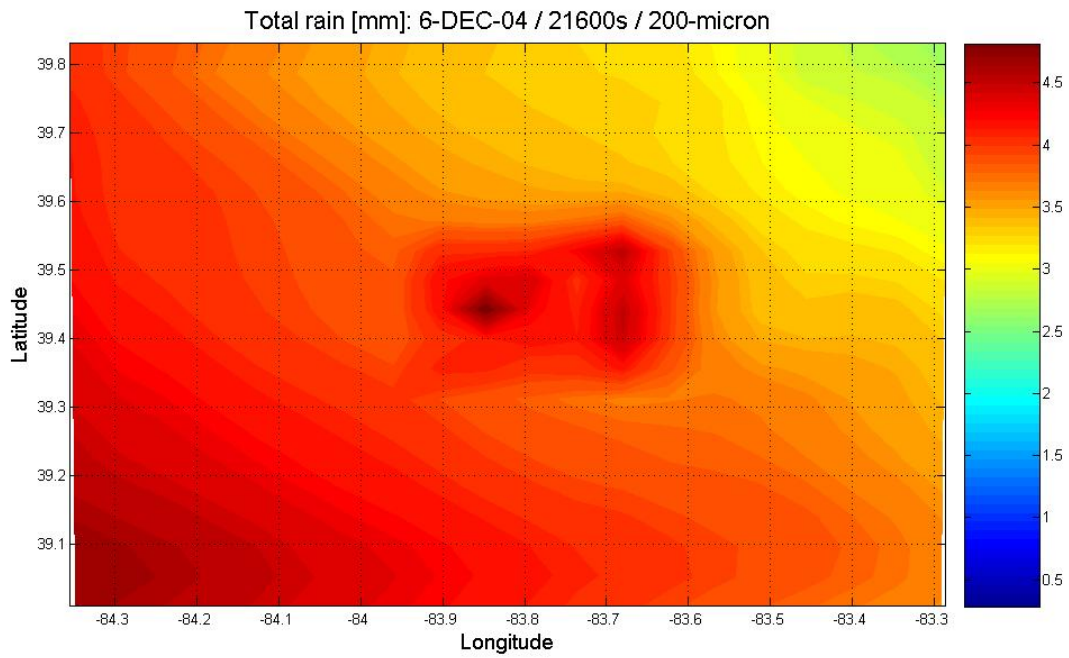


Figure 12 6-hour accumulated rainfall [mm], wet deposition, 200- μ m mean diameter

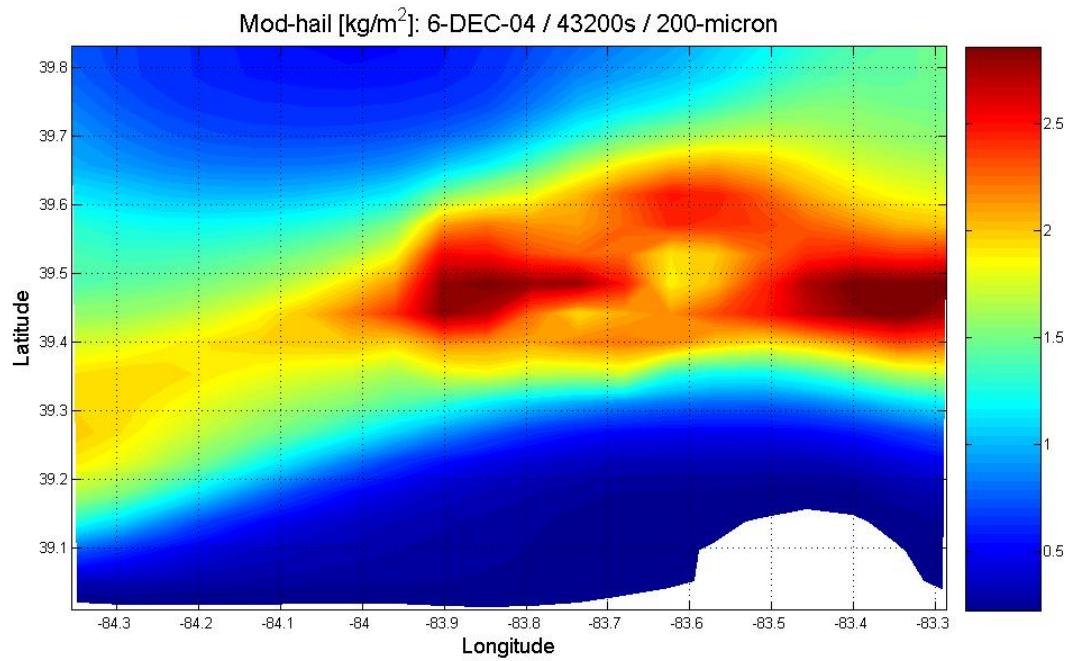


Figure 13 12-hour mod-hail deposition [kg/m²], wet deposition, 200- μ m mean diameter

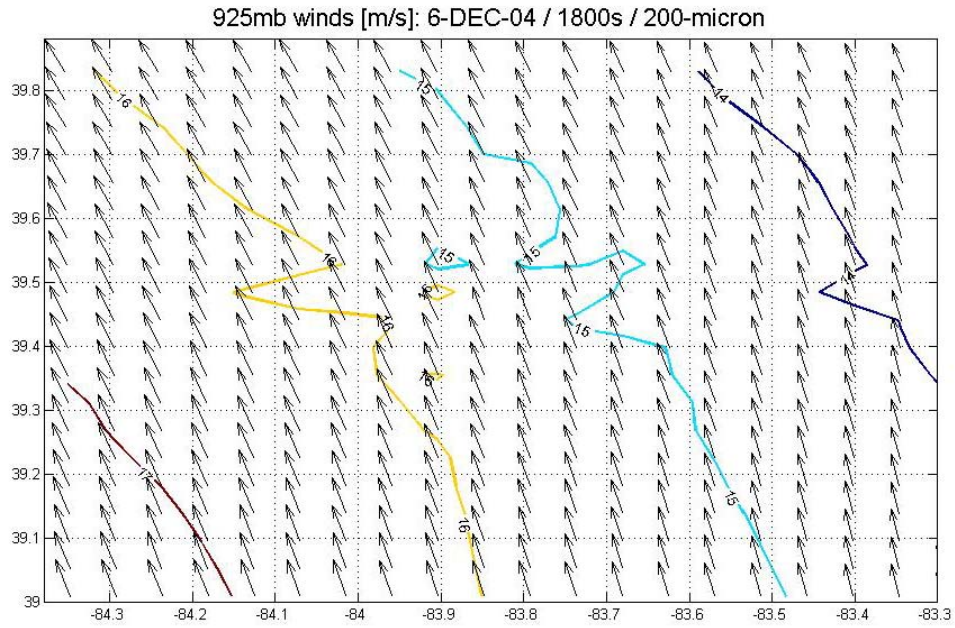


Figure 14 30-min 925mb winds [m/s], wet deposition, 200- μ m mean diameter

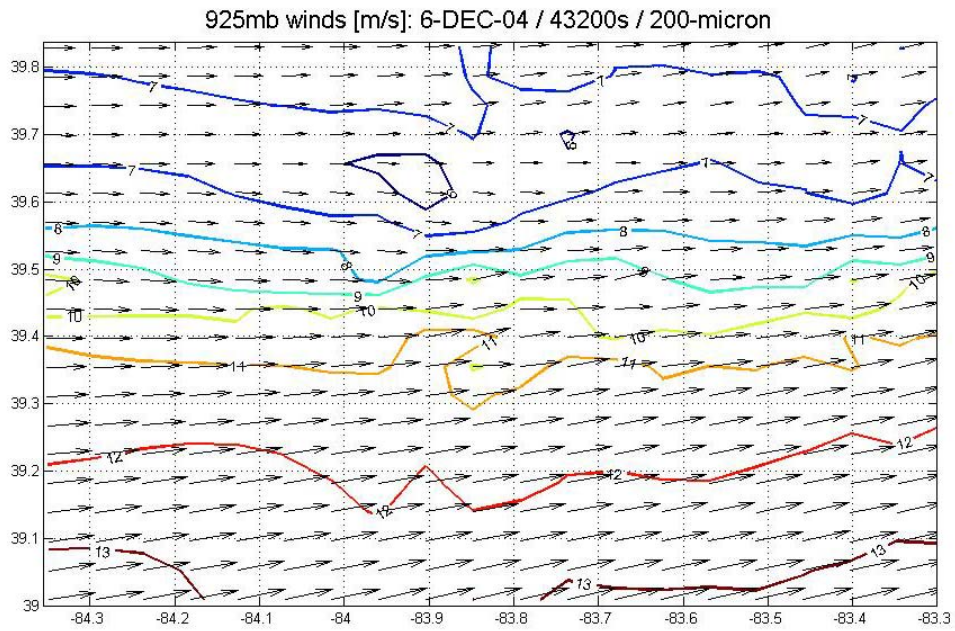


Figure 15 12-hour 925mb winds [m/s], wet deposition, 200- μ m mean diameter

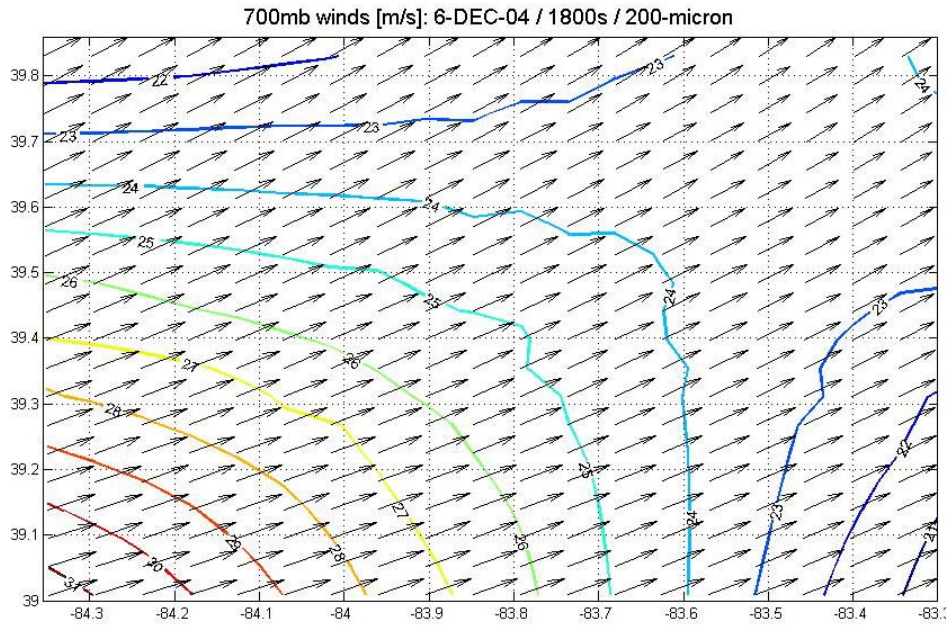


Figure 16 30-min 700mb winds [m/s], wet deposition, 200- μ m mean diameter

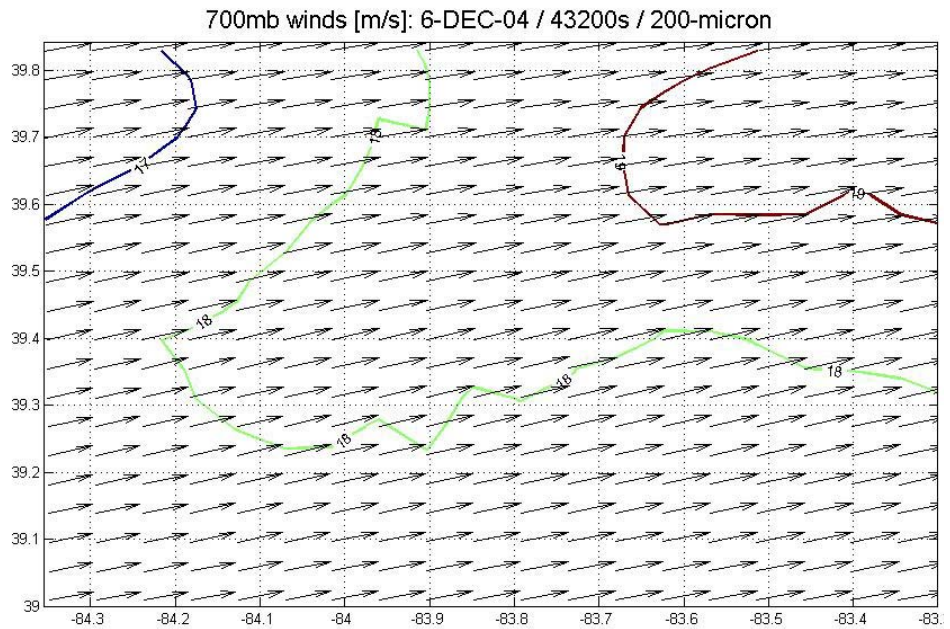


Figure 17 12-hour 700mb winds [m/s], wet deposition, 200- μ m mean diameter

4.2.2. *Small Mean Diameter Simulation.* The second wet deposition scenario starts with a mean modified hail diameter of 20- μm . Particles of this size settle very slowly so any deposition, a few milligrams per square meter, is most likely due to the modified hail interacting with cloud droplets, Figure 18.

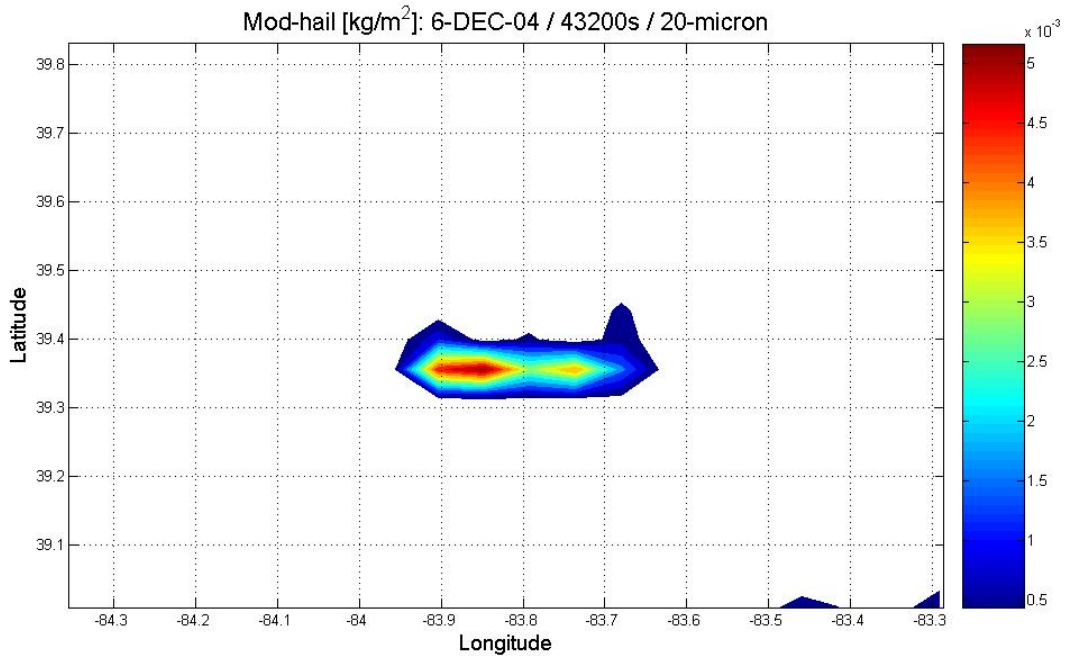


Figure 18 12-hour mod-hail deposition [kg/m²], wet deposition, 20- μm mean diameter

Changing the mean diameter of the modified hail appears to have an affect on the amount of rain predicted by RAMS. Measurable rain appears much later in this simulation than for the larger particle simulation. Figure 19 shows the 12-hour accumulated rain for the large particle and small particle simulations. The total rain over the whole grid for the large particle simulation is greater than for the small particle simulation. One possible explanation is that due to the smaller diameter modified hail, which results in a greater number concentration, RAMS is determining that more cloud

droplets of a smaller diameter are formed. This could result in fewer rain hydrometeors from becoming large enough to fall to the ground.

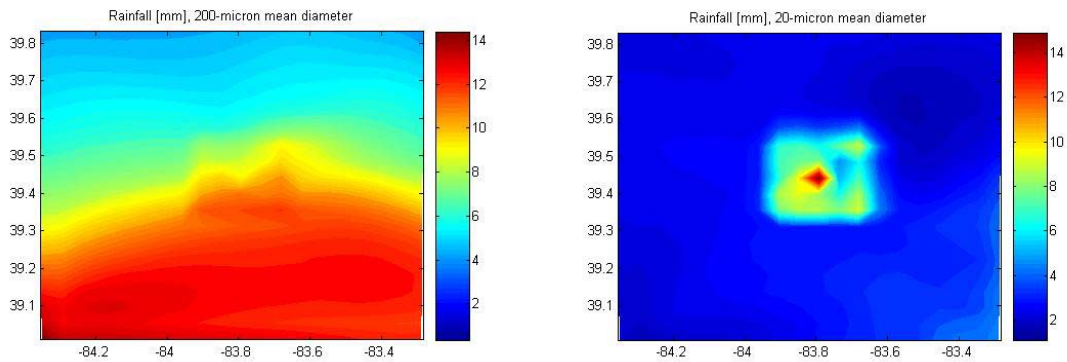


Figure 19 12-hour accumulated rainfall for 200- μm and 20- μm mean particles

4.2.3. Four-Grid vs. Three-Grid Schemes. Figure 20 is the deposition plots from the three-grid simulation. These plots as well as the plots in Figure 21 are from the same size grid, but with four grids RAMS makes calculations using information coming from the next courser grid. In both schemes, RAMS appears to be bringing a front through the domain, but there are differences in the deposition patterns.

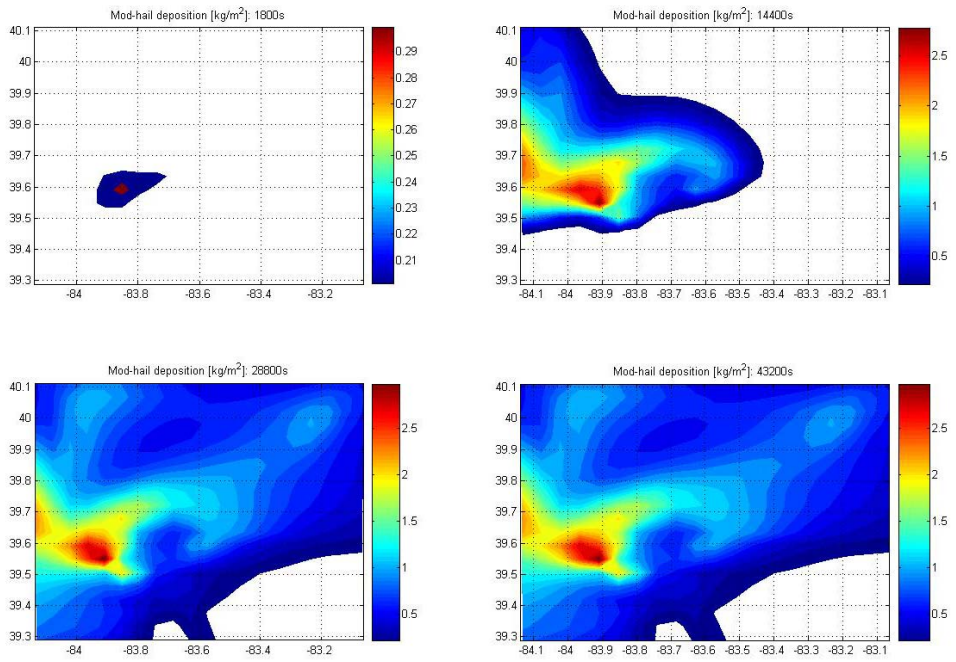


Figure 20 Mod-hail deposition 30-min to 12-hours: three-grid scheme

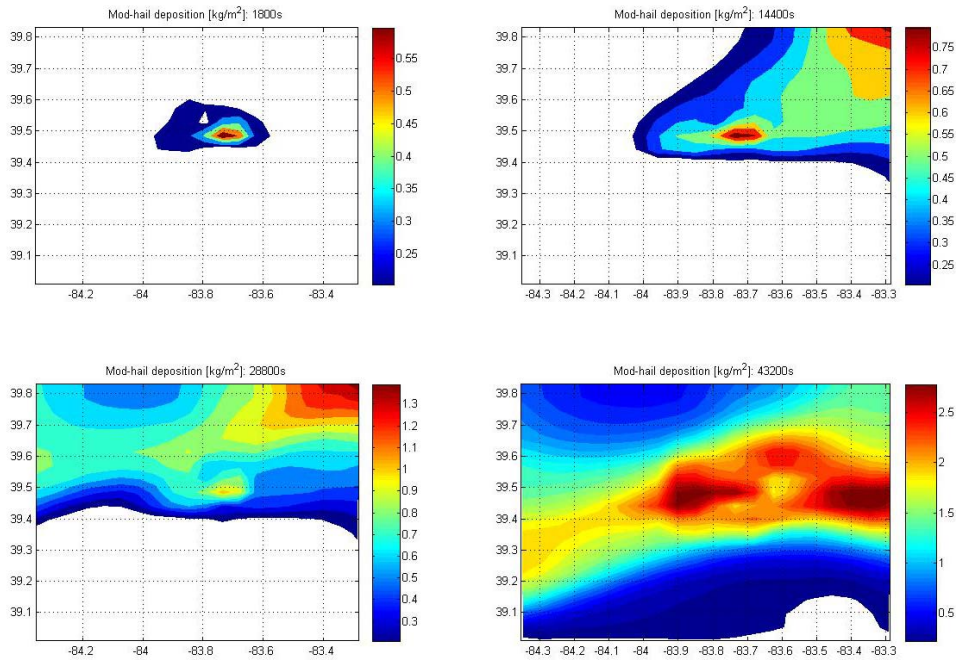


Figure 21 Mod-hail deposition 30-min to 12-hours: four-grid scheme

4.3. *Dry Deposition Results*

The results of the dry deposition runs are explored in this section. Simulations are conducted for two different mean particle diameters, 200- μm and 20- μm . The deposition from the larger mean diameter particles produces an oval-shaped pattern starting from injection point and headed toward the southeast, following the direction of the nearly calm winds. The smaller modified hail never accumulates on the ground during the 12-hour simulation due to the slow settling rates for the small particles.

4.3.1. Large particle Dry Deposition. The deposition of modified hail is mainly directly underneath the injection location as shown in Figure 22. Figure 23 shows modified hail that has been deposited along the northern and southeastern boundaries of the grid. This deposition away from the main area began earlier in the simulation, Figure 25, and is due to modified hail that is lofted above 8-km and accumulates on the ground away from the injection point, Figure 24.

Wind fields for the 925mb and 700mb levels are plotted for simulation times of 30-minutes and 12-hours. The effects of the thermal bubble can be seen in the center of the 925mb wind fields, Figure 26 through Figure 27 as well as the 700mb winds, Figure 28 through Figure 29.

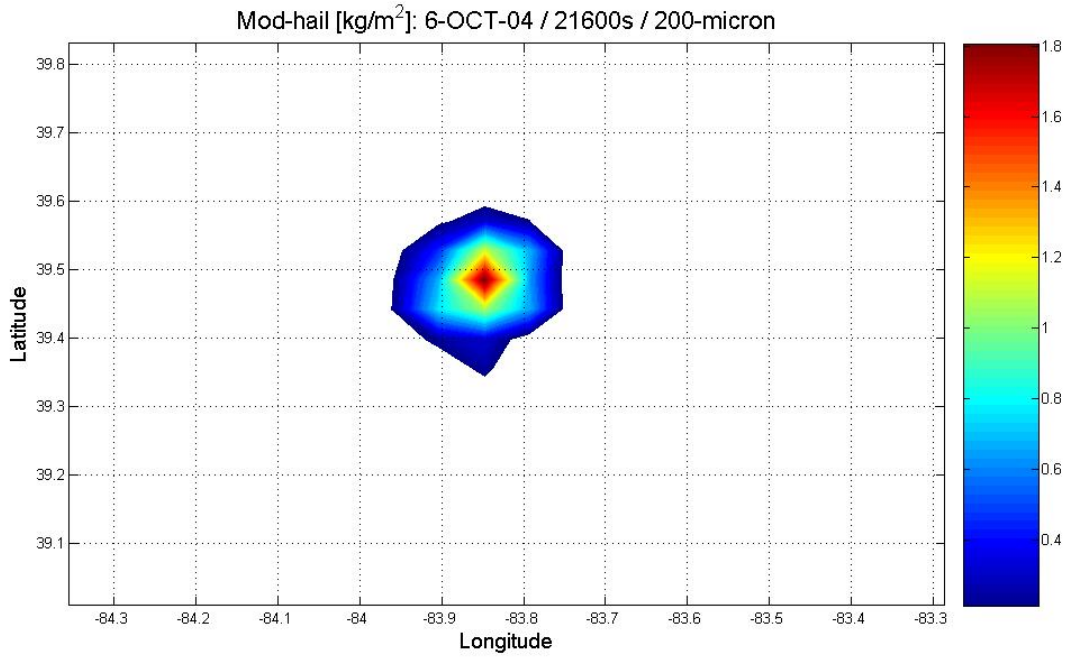


Figure 22 6-hour mod-hail dry deposition [kg/m²], 200-µm mean diameter

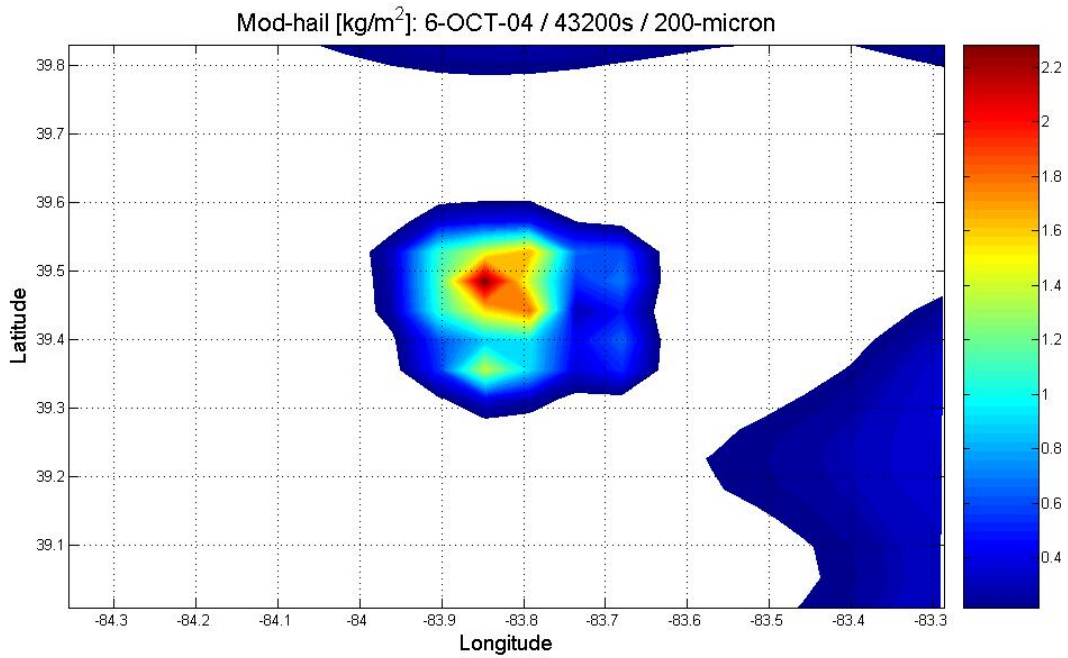


Figure 23 12-hour mod-hail dry deposition [kg/m²], 200-µm mean diameter

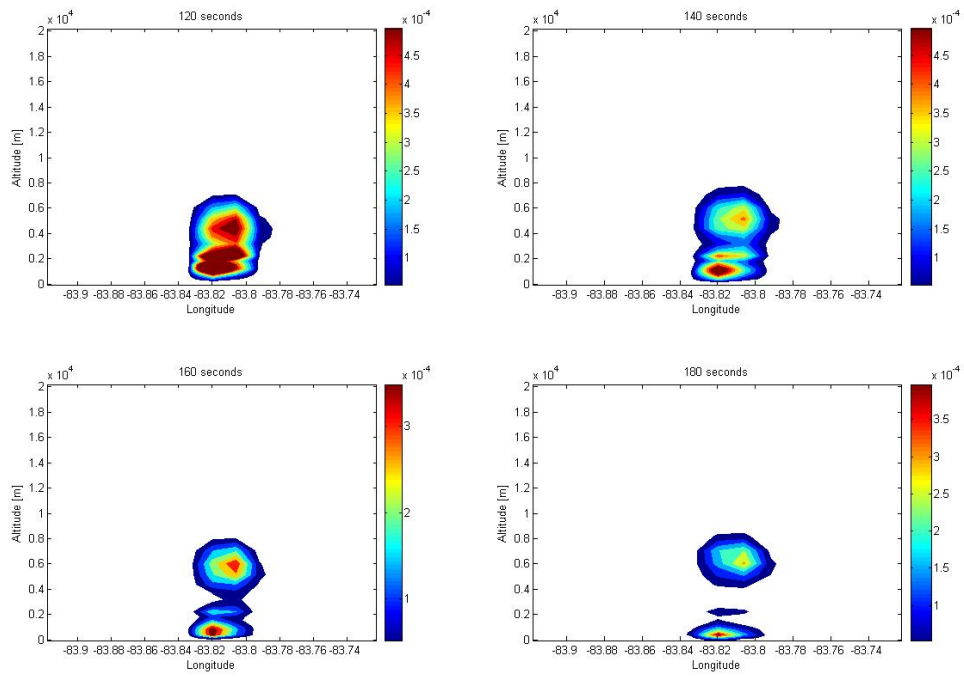


Figure 24 Mod-hail mixing ratio [g/kg] 120 - 180 seconds

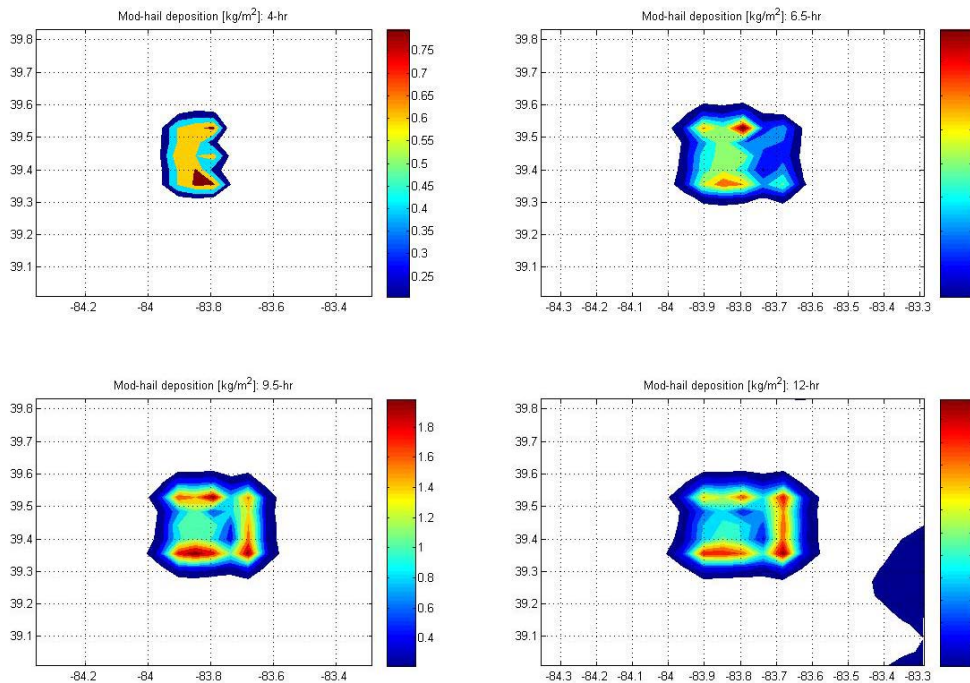


Figure 25 Mod-hail deposition 4 to 12-hours: winds are nearly calm from the NW

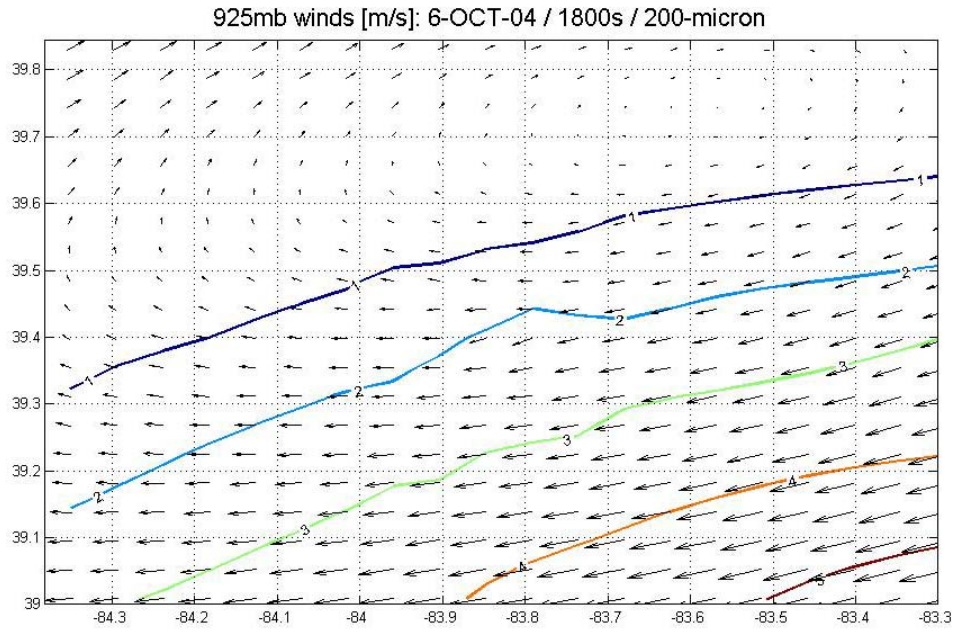


Figure 26 30-min 925mb winds [m/s], dry deposition, 200- μ m mean diameter

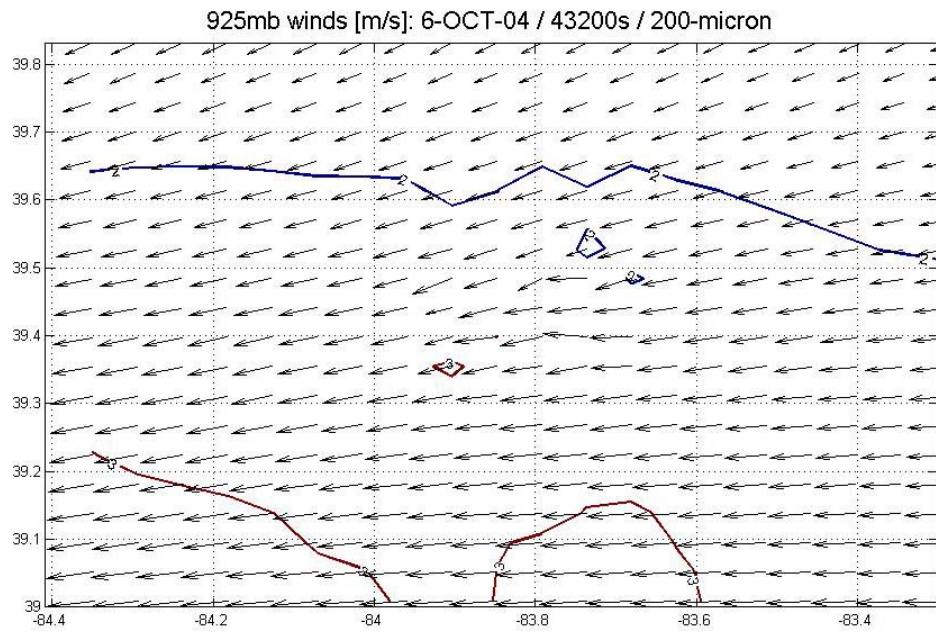


Figure 27 12-hour 925mb winds [m/s], dry deposition, 200- μ m mean diameter

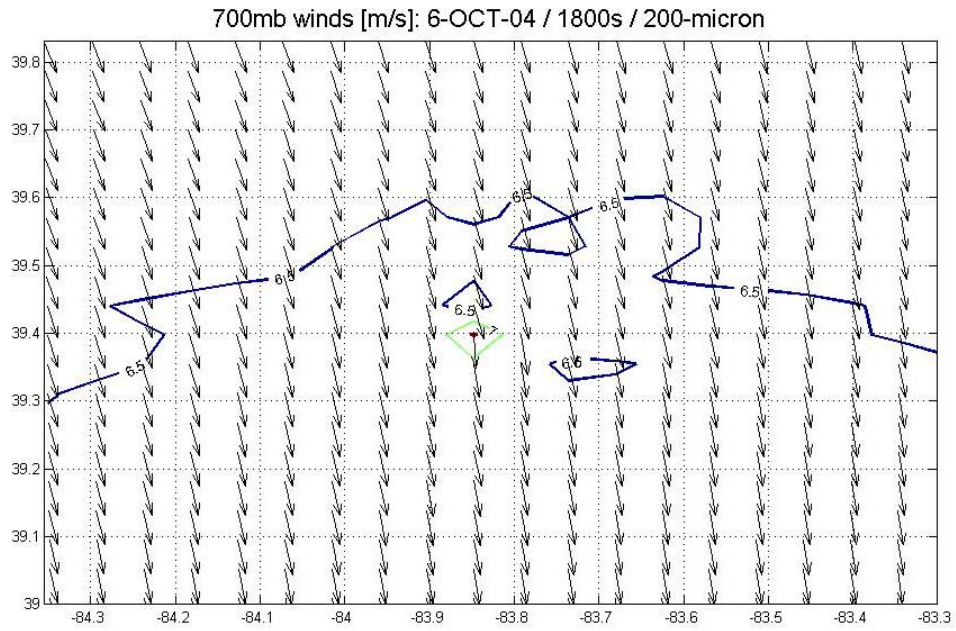


Figure 28 30-min 700mb winds [m/s], dry deposition, 200- μ m mean diameter

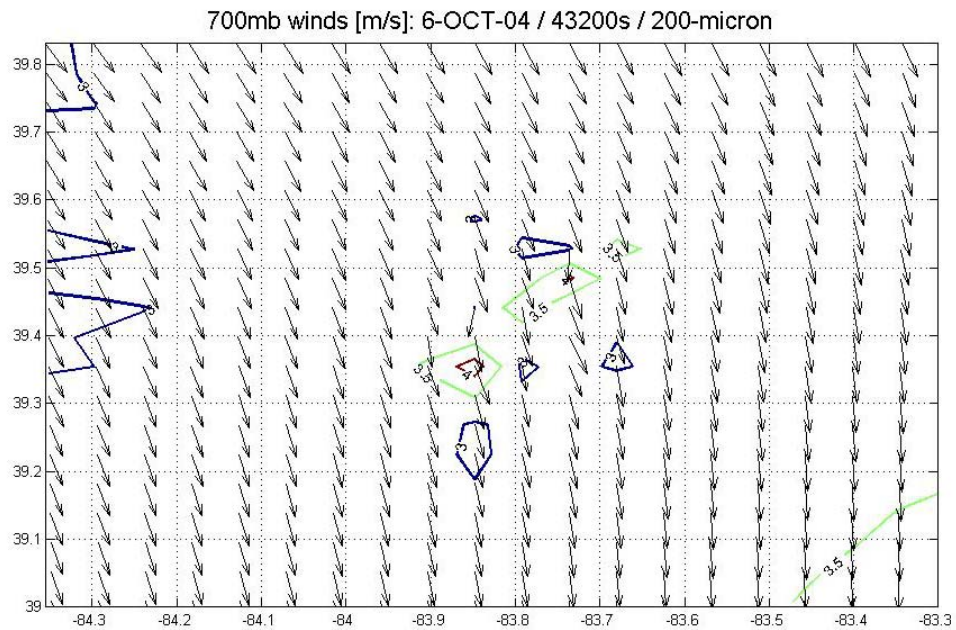


Figure 29 12-hour 700mb winds [m/s], dry deposition, 200- μ m mean diameter

4.3.2. *Small Particle Dry Deposition.* With this scenario, there isn't any deposition during the 24-hour simulation. The reason for this may be the long settling time for the smaller particles. RAMS calculates a mean-diameter-weighted fall speed for the hydrometeors. A 20-micron particle settles at about 3-cms^{-1} . At that speed, the first particles wouldn't be deposited for at least 16-hours, assuming there aren't any winds to keep the particles lofted into the air. Keep in mind that there are winds due to the 50K thermal bubble injected at the beginning of the simulation.

4.4. *HPAC Simulations*

Modifying the hail hydrometeor category for the purpose of using a forecast model to conduct T&D simulations is a proof-of-concept study. In order to gauge the feasibility of the concept, the HPAC model is used for evaluating the RAMS output. HPAC plots are integrated dose or dose rate, so only the location and shape of the contours are used since they reflect direction and speed of the winds during the simulation.

Applying a model-to-model comparison using HPAC helps to characterize the performance of the RAMS modifications and use that information to guide expanded studies of the use of a NWP model to perform T&D simulations. Although the RAMS deposition plots don't have the classic cigar shape of the HPAC plots, the RAMS-large diameter plots are similar in location and direction as HPAC. This suggests that the wind fields from the meteorological data imported by HPAC and the forecasted wind fields predicted by RAMS are similar.

4.3.1. *HPAC Simulation with Precipitation Activated.* Figure 30 is a 12-hour dose rate plot from an HPAC run that uses the same location and time domain as the RAMS wet deposition simulation.

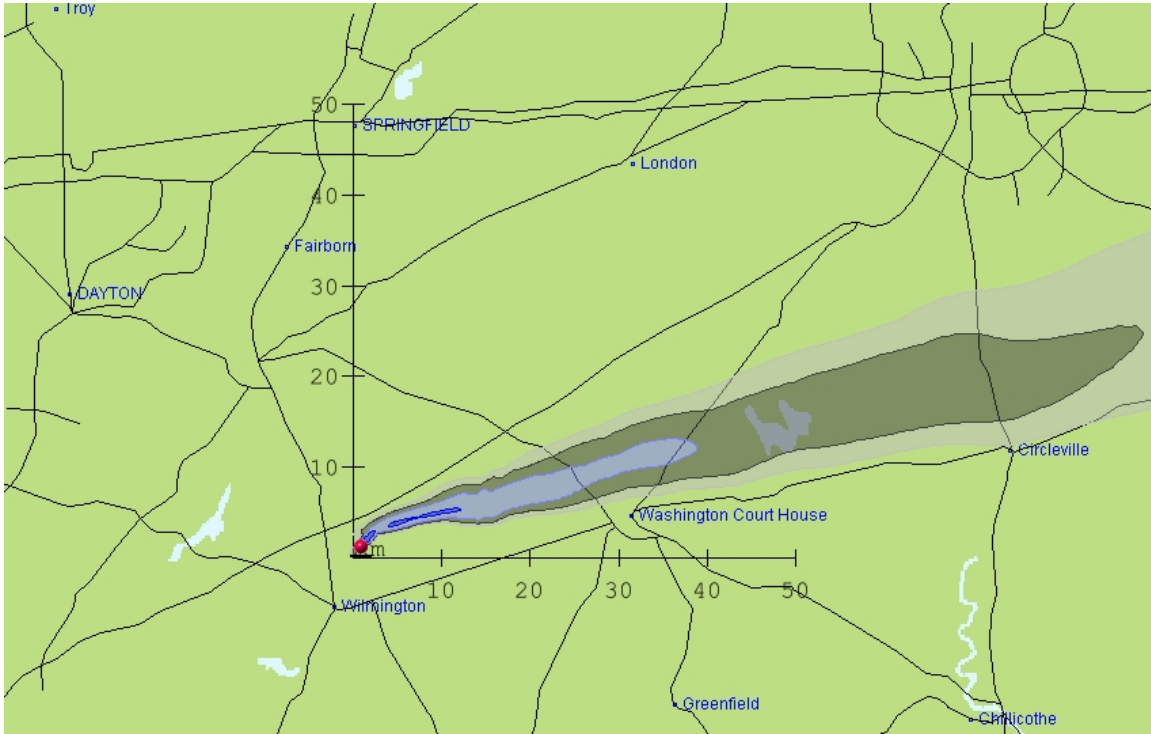


Figure 30 HPAC dose rate (12-hour) for 6-DEC-04 (contours are .01, 0.1, 1.0, and 10 rad/hr)

4.3.2. *HPAC Simulation with No Precipitation Activated.* Figure 31 is a 24-hour dose rate plot from an HPAC run that uses the same location and time domain as the RAMS dry deposition simulation. The winds for that 24-hour period were nearly calm, resulting in a higher dose rates near the point of detonation. The RAMS modified hail deposition plots are oriented the same direction; however it doesn't show the same cigar shape that one normally sees from HPAC. This is due in part because RAMS immediately starts to disperse the concentration of modified hail in the air, where HPAC takes some time for the puffs to separate and spread apart.

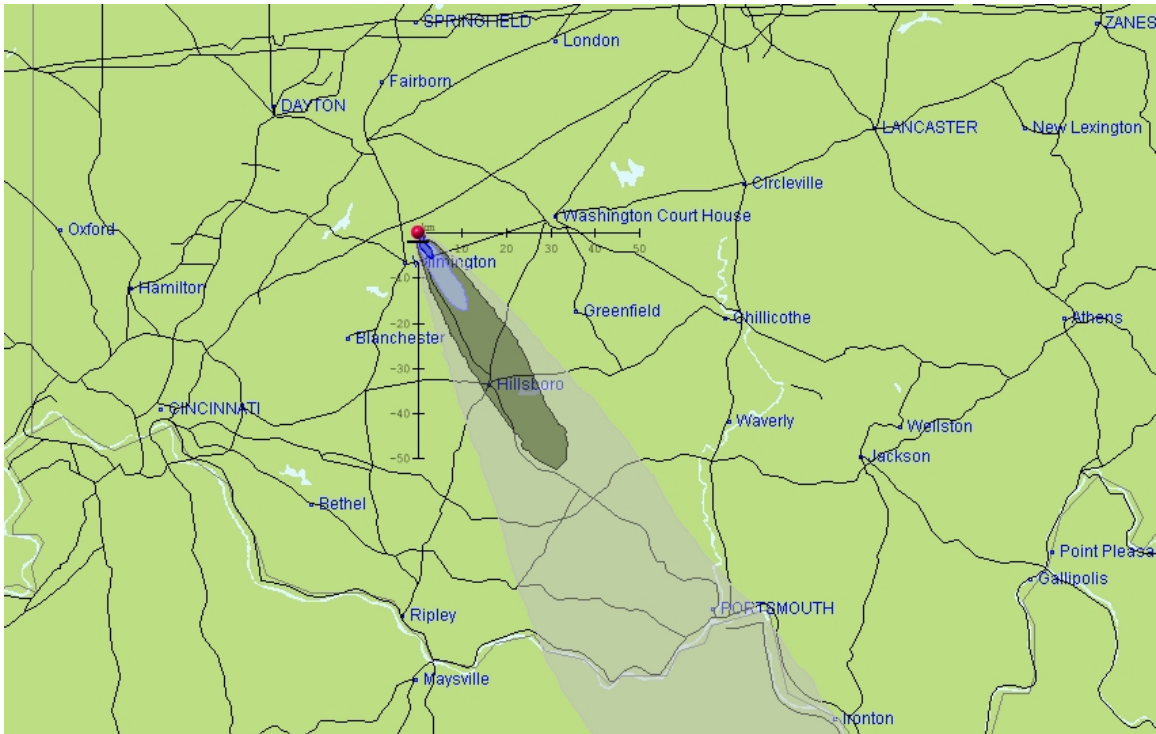


Figure 31 HPAC dose rate (12-hour) for 7-OCT-04 (contours are .01, 0.1, 1.0, and 10 rad/hr)

4.5. Discussion of Results

4.4.1. *Modifying the Hail Hydrometeor Category.* Hail was chosen for modification to simulate soil because it is already a solid and there are only a few paths from hail back to the other hydrometeors. Making changes to the code so that hail would simulate soil (quartz) was aided by the structure of the bulk microphysics package. The creators of RAMS have proceeded down a development path that enables researchers to make changes for different applications. An issue with modifying the properties of hail is that there may still be some processes in the code that aren't that intuitive how they affect the interaction of hail with the other hydrometeors, therefore weren't addressed during code modification. Modifications that weren't done for this study could be a part of future studies that are discussed in Section 5.2

4.4.2. *Use of the Hail Hydrometeor Category as a Soil Particulate.* The manner in which a particulate is affected by the weather and conversely how the presence of that particulate affects the weather are important to parameterize when using a forecast model to do T&D studies. Using hail as simulated quartz is an effective way to gain insight into the processes in a numerical weather model that would govern the behavior of fallout or some other particulate. For example, changing the size distribution of the simulated quartz from 200 to 20- μm , for the wet deposition simulations, results in a change in the amount and the location of rainfall. Fine particles of soil that condense out of the rising mushroom cloud may increase in size and mass by acting as an ice freezing nuclei (IFN) high up in a cloud then through collection of liquid water as they fall. This small particle, which would have taken days to settle to the ground, is now a contributor to the local fallout.

There are of course limitations to the use of a modified hydrometeor category (hail) to take the place of a particulate. Any process in the model that creates hail may add additional modified hail concentration to the simulation. This may be happening during the 200-micrometer mean diameter, wet deposition run. It's not clear if the mass of the accumulated modified hail is due to collection of liquid water on the modified hail as it falls toward the ground or in fact new modified hail is being created by RAMS as it moves a front through the simulation domain. Along with preventing the modified hail from melting, since quartz doesn't melt at 273K, changes to the code had to be made to make sure that the initial amount of modified hail injected into the model wasn't lost, no matter what the fraction of the modified hail's mass was liquid water. The unchanged microphysics code converts hail to rain if the liquid fraction is above 95 percent. By

changing this, any modified hail that forms from a simulated storm system, no matter if it melts, remains as modified hail and accumulates on the ground. These issues can be addressed through the development of a new category with a separate continuity equation.

V. Conclusions

5.1. RAMS as a Transport and Dispersion Model

The primary reason for exploring the use of a numerical weather prediction model such as RAMS is to provide for feedback due to the presence of the particulates of interest back to the model. Using the modified hail hydrometeor category as the simulated nuclear fallout particles established a solid foundation for achieving this in-line T&D modeling. The physical properties of the hail category were modified to emulate the quartz component of soil while still utilizing the microphysical parameterization of the hail hydrometeor. Using RAMS in this manner accounted for processes that aren't taken into account in non-forecasting T&D models such as HPAC. This resulted in significant differences between the RAMS modified hail deposition plots and the HPAC dose rate plots.

This chapter discusses the advantages of using a NWP to do T&D modeling as well as some of the problems encountered with this preliminary effort using the modified RAMS model. There is also a discussion of future research and development opportunities for in-line T&D modeling with RAMS.

5.1.1. Advantages of Using a NWP Model. This author believes there are many advantages to using a NWP model to perform T&D simulations. The advantages can be put into three groups: use of meteorological data, flexibility for sensitivity studies, and the inline interaction of the particulates in the simulation.

The first advantage is that a NWP makes greater use of the meteorological data that is available today. RAMS has the ability to use RAOB's, surface observations,

gridded upper-air analysis, soil moisture data, or any combination of the above. Most T&D models must parameterize environmental properties such as the soil moisture content based on monthly averages.

The second advantage is related to doing scientific studies. For example, cloud microphysical parameters can be adjusted by the user for the purpose of doing sensitivity studies of rain drop number concentration affects on in-cloud and below-cloud scavenging efficiency of fallout.

The third, and probably most important, advantage of using NWP for T&D modeling is the ability to account for the interaction between the particulate and weather; providing a feedback to the NWP model due to the presence of the particulate.

A look at the wet deposition simulation with the larger particles highlights this. The cloud rise from a nuclear detonation is roughly simulated by increasing the potential temperature around the injected modified hail. The square shape of the thermal bubble and uniform distribution of the modified quartz is not necessarily close to what would be found in an actual mushroom cloud however, it highlights some of the effects that aren't taken into account by a model such as HPAC. For example, RAMS shows the horizontal winds from the northwest butting up against the rising thermal bubble, which changes the nearby wind field. This causes an increase in the rain rate to the west of the modified hail cloud, which washes some of the modified hail out before it can be advected to the east due to the winds. This phenomenon would not be captured by a model such as HPAC because it starts with a stabilized cloud and gridded meteorological data field that is fixed from the start of the simulation.

The wet deposition simulations highlight a significant difference between a NWP and a non-forecast T&D model and that is the treatment of precipitation. Models such as HPAC compute a scavenging coefficient based on the precipitation rate. The Meteorological Data Server (MDS) for HPAC does not yet include precipitation information. This information would only be available if an HPAC user had weather data from another source, therefore if the MDS is used and precipitation is to be considered, the user must select a precipitation rate from the weather choices dialog box. This sets a single precipitation rate for the entire domain. RAMS predicts a spatially non-homogenous precipitation field that also varies with time, providing for a more realistic scavenging of particulates from the atmosphere. RAMS also predicts vertical velocities so particles can be lofted into clouds due to convective motion and then become deposited due to in-cloud nucleation scavenging.

In the case of this study, using one of the hydrometeor categories takes precipitation forecasting and particulate scavenging a step further, allowing for the feedback into the numerical forecast of the tracked particulate's effects. The presence of particulates (modified hail) in a cloud can change the precipitation rate, which causes some of the particulates to be washed out, which then reduces the amount that can settle out further away from the incident. This effect can be seen by looking at the accumulated rain patterns for the two different mean particle sizes. The two scenarios started with the same analysis data and the same mass of injected modified hail, but the larger particle resulted in substantially more rain.

5.1.2. Disadvantages of Using RAMS. There are several disadvantages to using a NWP for T&D modeling. The first is the time expense of NWP computation. In

the case of HPAC the forecasting or reanalysis is done ahead of time so the user is not aware of the expense. Another disadvantage of RAMS is the way RAMS tracks the hydrometeor categories from grid to grid through the model domain. RAMS has difficulties resolving concentrations of a particulate that occupy a small space until enough time has passed that the particulate fills several grids. This is being addressed by HYPACT-RAMS, which starts out with Lagrangian particle dispersion modeling then moves to a grid-based Eulerian dispersion (Walko 1995). In fact, the developer of the HYPACT T&D model, ATMET, currently has plans to integrate HYPACT with RAMS as an inline T&D model. Another issue is the fall speed of the modified hail. RAMS sometimes slows down the larger and denser particles since they may fall through multiple vertical grid points between time steps. This would probably only be reflected in fallout pattern near ground zero because that is where the largest particles are deposited.

5.2. Future Research Opportunities

Using the modified hail as a simulated nuclear fallout particle is the initial step toward developing additional modules for RAMS or other NWP models to perform inline T&D simulations. Continued research down this path can be split into three types: 1) creation of one or more aerosol categories along with an aerosol continuity equation and new particle size distribution functions, 2) source term and chemical and radiological processes, and 3) model verification and validation.

The formation of the various hydrometeors in clouds and the resulting precipitation, depend strongly on the presence and types of aerosols in the atmosphere.

The addition of an aerosol category for the purpose tracking particulates in the atmosphere and accurately modeling the effects of various aerosols would enable a T&D simulation to make use of the forecast capabilities of a NWP model. Sensitivity studies have already been conducted where CCN, giant CCN (GCCN) and ice forming nuclei (IFN) concentrations are varied to test the effects on thunderstorm formation. The addition of an aerosol category would enable a researcher to vary the way the model predicts the aerosols' tendencies through the namelist just like was done with the modified hail category. It would also be helpful if a user could select a new category from various log-normal size distributions since aerosol size distribution varies depending on the source.

Along with a new category and continuity equation, a source term would have to be developed that could be user selected, i.e. a chemical weapon or cesium-137 salt dispersed from a terrorist's radiological dispersion device. The particulates from these various sources are governed by different chemical and radiological processes. Incorporating first-order processes would improve the fidelity of a NWP model.

Finally any model should be verified with field data and validated for the scenario that it is to be used. Even before any work is done on a separate aerosol category, RAMS with the modified hail could be compared to controlled release scenarios.

Appendix A. Glossary of Acronyms

ARL - Air Research Laboratory

ATMET - Atmospheric Meteorological and Environmental Technologies

CCN - Cloud Condensation Nuclei

DTRA - Defense Threat Reduction Agency

GCCN - Giant Cloud Condensation Nuclei

GrADS - Grid Analysis and Display System

GRIB - Gridded Binary data files

HPAC - Hazard Prediction and Assessment Capability

HYPACT - HYbrid PArticle and Concentration Transport

IFN - Ice Freezing Nuclei

ISAN - Isentropic Analysis package

MDS - Meteorological Data Server

MM5 - Mesoscale Model 5th Generation

NARAC - National Atmospheric Release Advisory Center

NCAR - National Center for Atmospheric Research

NCEP - National Centers for Environmental Prediction

NOAA - National Oceanic and Atmospheric Administration

NWP - Numerical Weather Prediction

RAMS - Regional Atmospheric Modeling System

RAOB - RAwinsonde OBservation

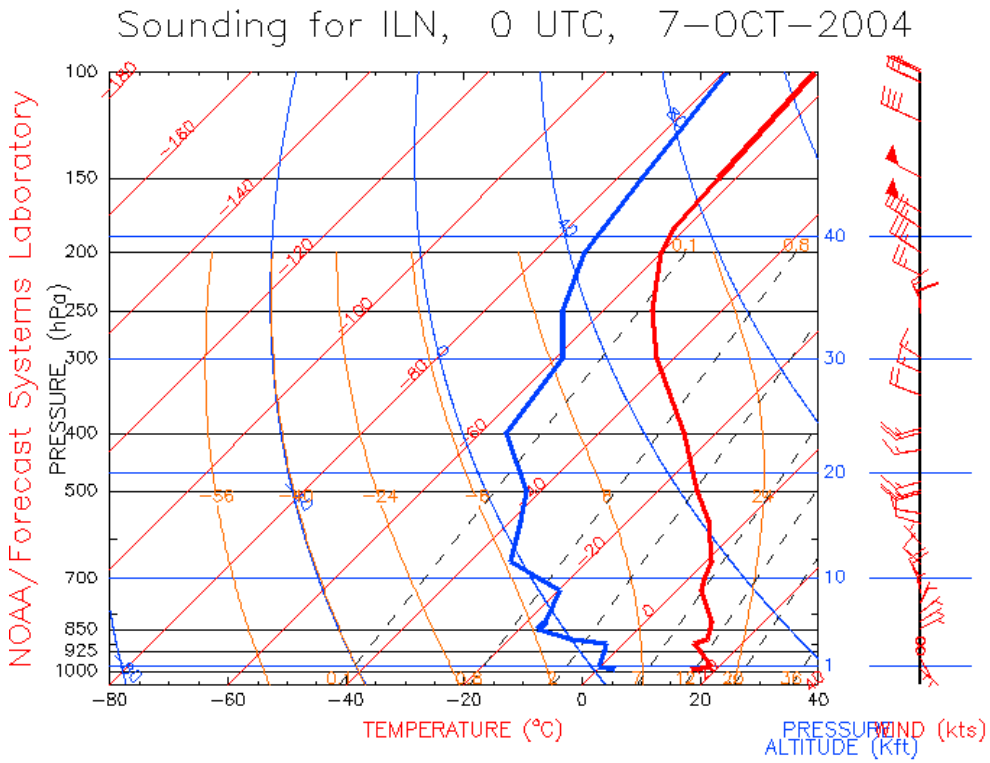
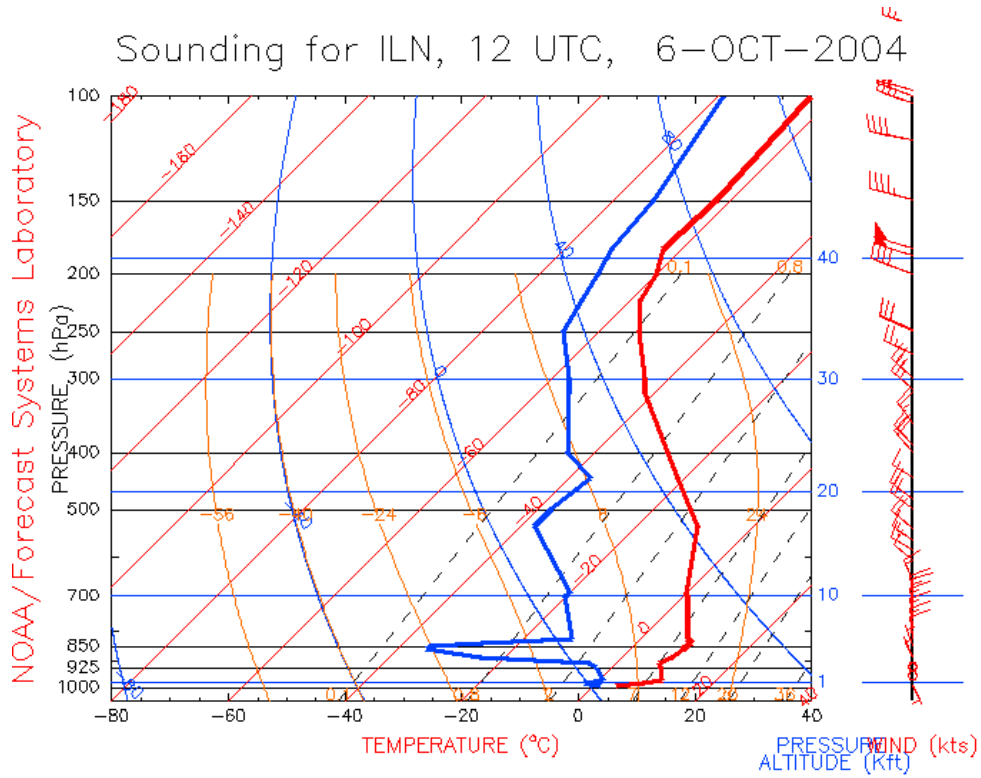
REVV - RAMS Evaluation and Visualization Utilities

SCIPUFF - Second-order Closure Integrated Puff

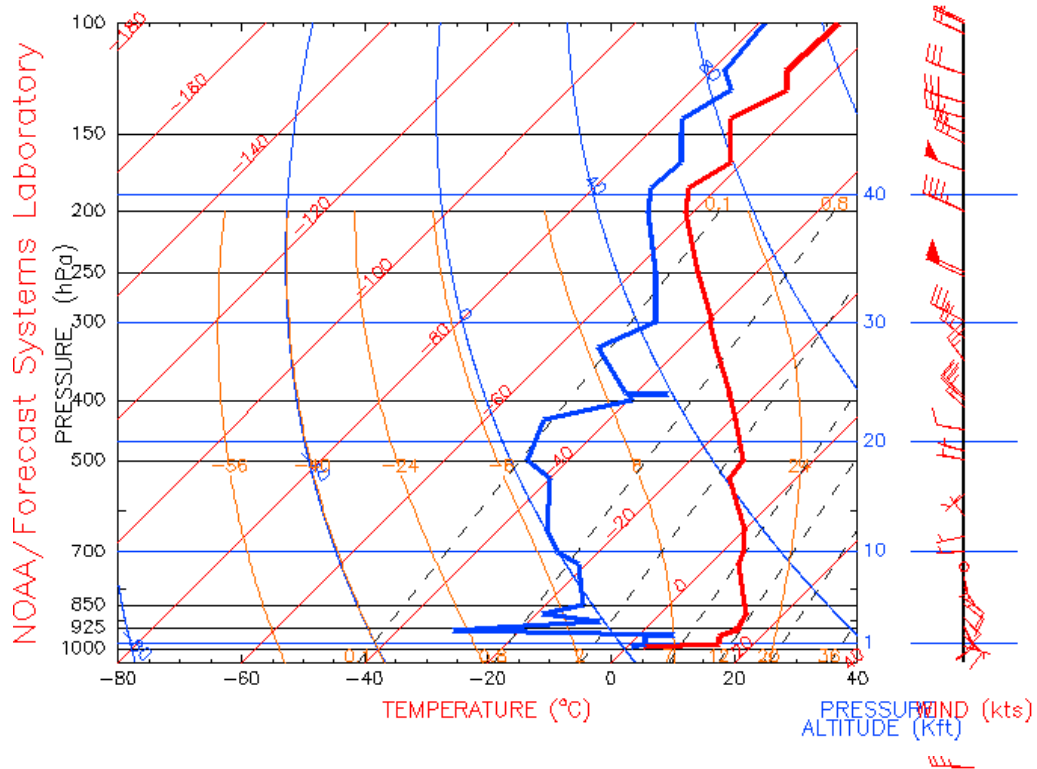
T&D - Transport and Dispersion

WRF - Weather Research and Forecasting Model

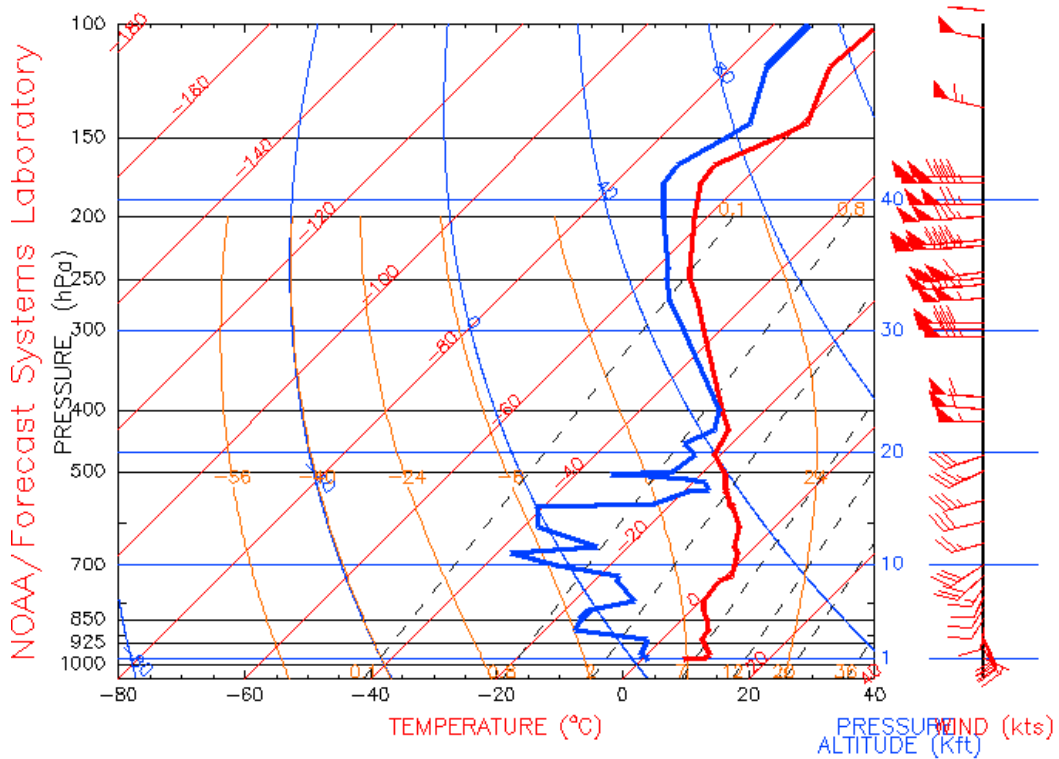
Appendix B. Skew-T Plots



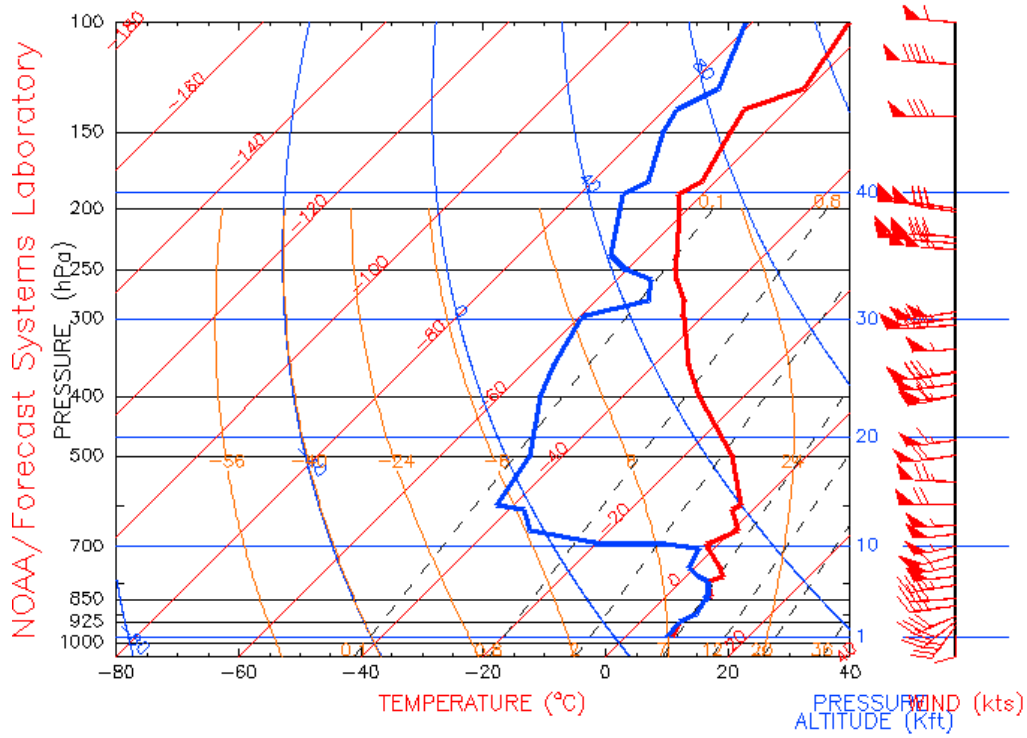
Sounding for ILN, 12 UTC, 7-OCT-2004



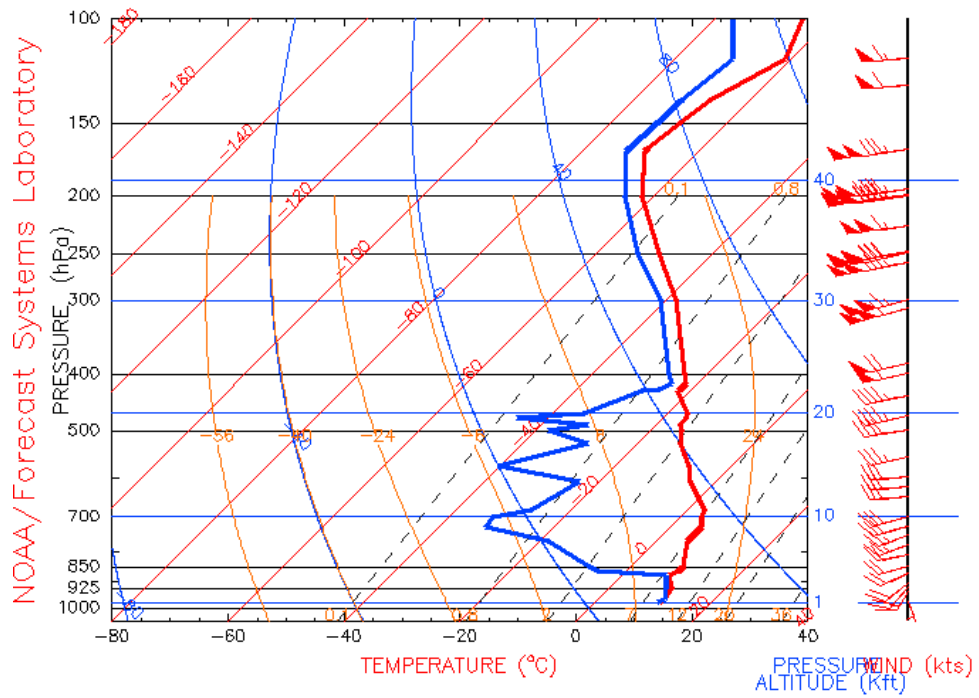
Sounding for ILN, 0 UTC, 6-DEC-2004



Sounding for ILN, 12 UTC, 6-DEC-2004



Sounding for ILN, 0 UTC, 7-DEC-2004



Appendix C.RAMS Source Code Modifications

!*****

For file therm_lib.f90

Subroutine qtc_SiO2(q, tempc, fracliq)

!

! This subroutine is added to give the hydrometeor category "hail"
! the thermal properties of soil (SiO2)

! Input:

! q - internal energy of soil(hail)

! Outputs:

! tempc - temperature [C]

! fracliq - fraction of soil that is liquid [dimensionless]

! Local constants:

! r800 - heat capacity of solid SiO2 [J/kg-K]

! r1600 - heat capacity of liquid SiO2 [J/kg-K]

! r910710 - enthalpy of fusion of SiO2 [J/kg]

!

Real,parameter:: r800=1./800.,r1600=1./1600.,r910710=1./910710.

Real:: q,tempc,fracliq

If (q .ge. 2499510.) Then

 fracliq = 1.

 tempc = (q - 2499510.) * r1600 + 1986. - 273.16

ElseIf (q .ge. 1588800.) Then

 fracliq = (q - 1588800.) * r910710

 tempc = 1986. - 273.16

Else

 fracliq = 0.

 tempc = q * r800 - 273.16

End If

Return

End Subroutine qtc_SiO2

!*****

For file rthrm.f90, subroutine wetthrm3

if (jnmb(7) .ge. 1) then

do k = 1,m1

! call qtc(q7(k,i,j),tcoal,fracliq)

! Change to make call to SiO2 thermal properties

call qtc_SiO2(q7(k,i,j),tcoal,fracliq)

rliq(k) = rliq(k) + rhp(k,i,j) * fracliq

rice(k) = rice(k) + rhp(k,i,j) * (1. - fracliq)

enddo

endif

!*****

For file mic_init.f90

data dstprms/ &

!-----

! shape cfmas pwmas cfvt pwvt dmb0 dmb1

!-----

.5, 524., 3., 3173., 2., 2.e-6, 40.e-6, & !cloud

.5, 524., 3., 149., .5, .1e-3, 5.e-3, & !rain

.179, 110.8, 2.91, 5.769e5, 1.88, 15.e-6, 125.e-6, & !pris col

.179, 2.739e-3, 1.74, 188.146, .933, .1e-3, 10.e-3, & !snow col

.5, .496, 2.4, 3.084, .2, .1e-3, 10.e-3, & !aggreg

.5, 157., 3., 93.3, .5, .1e-3, 5.e-3, & !graup

! Change hail parameters to emulate SiO2

.5, 1361., 3., 161., .5, .8e-3, 10.e-3, & !hail

! .5, 471., 3., 161., .5, .8e-3, 10.e-3, & !hail


```

.0429, .8854, 2.5, 316., 1.01, 00, 00, & !pris hex
.3183, .377e-2, 2., 316., 1.01, 00, 00, & !pris den
.1803, 1.23e-3, 1.8, 5.769e5, 1.88, 00, 00, & !pris ndl
.5, .1001, 2.256, 3.19e4, 1.66, 00, 00, & !pris ros
.0429, .8854, 2.5, 4.836, .25, 00, 00, & !snow hex
.3183, .377e-2, 2., 4.836, .25, 00, 00, & !snow den
.1803, 1.23e-3, 1.8, 188.146, .933, 00, 00, & !snow ndl
.5, .1001, 2.256, 1348.38, 1.241, 00, 00/ !snow ros

```

```

subroutine initqin(n1,n2,n3,q2,q6,q7,pi0,pp,theta,dn0,cccnp,cifnp)

```

```

implicit none

```

```

include 'rcommons.h'

```

```

include 'rconstants.h'

```

```

integer :: n1,n2,n3,i,j,k

```

```

real, dimension(n1,n2,n3) :: q2,q6,q7,pi0,pp,theta,dn0,cccnp,cifnp

```

```

real :: air_temp_kelvin

```

```

! Initialize Q2, Q6, Q7, CCN, IFN.

```

```

do j = 1,n3

```

```

  do i = 1,n2

```

```

    do k = 1,n1

```

```

      pitot(k) = pi0(k,i,j) + pp(k,i,j)

```

```

      tair(k) = theta(k,i,j) * pitot(k) / cp

```

```

      if(irain .ge. 1) q2(k,i,j) = tair(k) - 193.16

```

```

      if(igraup .ge. 1) q6(k,i,j) = 0.5 * min(0.,tair(k) - 273.16)

```

```

!      if(ihail .ge. 1) q7(k,i,j) = 0.5 * min(0.,tair(k) - 273.16)

```

```

!      Change internal energy parameterization to emulate SiO2

```

```

      if (tair(k) .le. 100.) then

```

```

        air_temp_kelvin = tair(k) + 273.16

```

```

    else
        air_temp_kelvin = tair(k)
    end if
    if(ihail .ge. 1) q7(k,i,j) = 800. * air_temp_kelvin
!   end of change
!   if (icloud .eq. 7) cccnp(k,i,j) = ???
    if (ipris .eq. 7) cifnp(k,i,j) = 1.e5 * dn0(k,i,j) ** 5.4

    enddo
enddo
enddo
return
end

!*****
For mic_misc.f90, subroutine x02(m1,k1,k2,lcat,dn0,i,j)

elseif (lcat .eq. 7) then

    shedmass = 5.236e-7
    do k = k1(lcat),k2(lcat)

        if (rx(k,lcat) .ge. 1.e-9) then

            rxinv = 1. / rx(k,lcat)
            qx(k,lcat) = qr(k,lcat) * rxinv
!c      qx(k,lcat) = max(-50.,qx(k,lcat))
!   call qtc(qx(k,lcat),tcoal,fracliq)
!   Change to call to SiO2 thermal properties
            call qtc_SiO2(qx(k,lcat),tcoal,fracliq)

!   if (fracliq .gt. 0.95) then

```

```

!   rx(k,2) = rx(k,2) + rx(k,7)
!   qr(k,2) = qr(k,2) + rx(k,7) * alli
!   cx(k,2) = cx(k,2) + cx(k,7)
!   rx(k,7) = 0.
!   qr(k,7) = 0.
!   cx(k,7) = 0.
!   Change to keep hail(SiO2) hail
if (fracliq .gt. 0.95) then
  rx(k,2) = rx(k,2)
  qr(k,2) = qr(k,2)
  cx(k,2) = cx(k,2)
  rx(k,lcat) = rx(k,lcat)
  qr(k,lcat) = qr(k,lcat)
  cx(k,7) = cx(k,7)
!
! take out following IF statement?
!
  elseif (fracliq .gt. 0.3) then

    lhcat = jhcat(k,lcat)
    inc = nint(200. * fracliq) + 1
    dn = dnfac(lhcat) * emb(k,lcat) ** pwmasi(lhcat)
    idns = max(1,nint(1.e3 * dn * gnu(lcat)))
    rshed = rx(k,lcat) * shedtab(inc,idns)
!cc      rmltshed = rx(k,lcat) * rmlttab(inc) + rshed
    rmltshed = rshed
    qrmltshed = rmltshed * alli

!   rx(k,2) = rx(k,2) + rmltshed
!   qr(k,2) = qr(k,2) + qrmltshed
!   rx(k,lcat) = rx(k,lcat) - rmltshed
!   qr(k,lcat) = qr(k,lcat) - qrmltshed

```

```

!
!   Change to keep hail(SiO2) hail
    rx(k,2) = rx(k,2)
    qr(k,2) = qr(k,2)
    rx(k,lcat) = rx(k,lcat)
    qr(k,lcat) = qr(k,lcat)

!       closs = cx(k,lcat) * enmlttab(inc,lhcat)
!       cx(k,lcat) = cx(k,lcat) - closs
!       cx(k,2) = cx(k,2) + closs + rshed / shedmass
    cx(k,2) = cx(k,2) + rshed / shedmass
endif
!*****
For ruser.f90
!   *****
!
subroutine bubble(m1,m2,m3,thp,rtp)
dimension thp(m1,m2,m3),rtp(m1,m2,m3)
!
!do j = 5,15
do j = 4,7
    do i = 4,7
        do k = 11,13
            thp(k,i,j) = thp(k,i,j) + 50.
!e        rtp(k,i,j) = rtp(k,i,j) * 1.2
        enddo
    enddo
enddo
return
end
!cc
!

```

```

! *****
!
subroutine force_hail(m1,m2,m3,rhp)
dimension rhp(m1,m2,m3)
!
do j = 4,7
  do i = 4,7
    do k = 11,13
      rhp(k,i,j) = rhp(k,i,j) + 1.7
    enddo
  enddo
enddo
return
end
!
! *****

For rtimh.f90
! *****
!   +-----+
!   | Adding call to subroutine bubble here for pertebation to |
!   |   model.                               |
!   +-----+
If (time .le. .1 .and. ngrid .eq. 3) Call BUBBLE(nzp,nxp,nyp,a(ithp),a(irtp))
!
CALL TEND0(A)      ! Zero out all tendency arrays.
!
!   +-----+
!   | Adding call to force a concentration of hail in to the |
!   |   model.                               |
!   +-----+
If (time .le. .1 .and. ngrid .eq. 3) CALL FORCE_HAIL(nzp,nxp,nyp,a(irhp))

```

Appendix D. Sample RAMSIN File

This is the RAMSIN file for a wet deposition simulation, 200-micrometer mean hail size.

```
!namelist
##### Change Log
#####
! 4.4.0
!
#####
#####

$MODEL_GRIDS

! Simulation title (64 chars)

  EXPNME   = 'Nuke ILN test run v4.4.01 with offset grids',
  VTABCUST = 'standard',

  RUNTYPE  = 'INITIAL',      ! Type of run: MEMORY,    MAKESFC, MAKESST,
                           !                               MAKEVFILE, INITIAL, HISTORY

  TIMEUNIT = 'h',           ! 'h','m','s' - Time units of TIMMAX,
TIMSTR
  TIMMAX   = 24.,           ! Final time of simulation

! Start of simulation or ISAN processing

  IMONTH1  = 12,            ! Month
  IDATE1   = 06,            ! Day
  IYEAR1   = 2004,          ! Year
  ITIME1   = 0600,          ! GMT of model TIME = 0.

! Grid specifications

  NGRIDS   = 3,             ! Number of grids to run

  NNXP     = 22,22,10,      ! Number of x gridpoints
  NNYP     = 22,22,10,      ! Number of y gridpoints
  NNZP     = 30,30,30,      ! Number of z gridpoints
  NZG      = 11,            ! Number of soil layers
  NZS      = 1,             ! Maximum number of snow layers

  NXTNEST  = 0,1,2,        ! Grid number which is the next coarser
grid

! Coarse grid specifications

  IHTRAN   = 0,             ! 0-Cartesian, 1-Polar stereo
  DELTAX   = 4800.,         !
  DELTAY   = 4800.,         ! X and Y grid spacing
```

```

DELTAZ = 100.,      ! Z grid spacing (set to 0. to use ZZ)
DZRAT  = 1.15,     ! Vertical grid stretch ratio
DZMAX  = 1200.,    ! Maximum delta Z for vertical stretch

ZZ      = 0.0,      ! Vertical levels if DELTAZ = 0
  30.0,   60.0,   90.0,   120.0,   150.0,
 180.0,  210.0,  240.0,  270.0,  300.0,
 330.0,  360.0,  390.0,  420.0,  450.0,
 480.0,  510.0,  540.0,  570.0,  600.0,
 630.0,  660.0,  690.0,  720.0,  750.0,
 780.0,  810.0,  840.0,  870.0,  900.0,
 930.0,  960.0,  990.0, 1020.0, 1050.0,
1080.0, 1110.0, 1140.0, 1170.0, 1200.0,
1230.0, 1260.0, 1290.0, 1320.0, 1350.0,
1380.0, 1410.0, 1440.0, 1470.0, 1500.0,
1533.0, 1569.3, 1609.2, 1653.2, 1701.5,
1754.6, 1813.1, 1877.4, 1948.1, 2025.9,
2111.5, 2205.7, 2309.3,

DTLONG = 90.,      ! Coarse grid long timestep
NACOUST = 4,       ! Small timestep ratio
IDELTAT = -2,     ! Timestep adjustment
                ! =0 - constant timesteps
                ! >0 - initial computation <0 - variable

                ! Nest ratios between this grid and the
next
                ! coarser grid.
NSTRATX = 1,4,4,   ! x-direction
NSTRATY = 1,4,4,   ! y-direction
NNDTRAT = 1,3,3,   ! Time

NESTZ1 = 0,        ! Contort coarser grids if negative
NSTRATZ1 = 3,3,3,2,2,1,
NESTZ2 = 0,        ! Contort coarser grids if negative
NSTRATZ2 = 3,3,3,2,2,1,

POLELAT = 39.7,    ! Latitude of pole point
POLELON = -83.6,   ! Longitude of pole point

CENTLAT = 39.7, 39.5, 39.5, ! Center lat/lon of grids, may or
CENTLON = -83.6, -83.8, -83.8, ! may not be same as pole point.

                ! Grid point on the next coarser
                ! nest where the lower southwest
                ! corner of this nest will start.
                ! If NINEST or NJNEST = 0, use
CENTLAT/LON
NINEST = 1,5,8,    ! i-point
NJNEST = 1,5,8,    ! j-point
NKNEST = 1,1,1,    ! k-point

NNSTTOP = 1,1,1,   ! Flag (0-no or 1-yes) if this
NNSTBOT = 1,1,1,   ! Nest goes the top or bottom of the

```

```

! coarsest nest.

GRIDU   = 0.,0.,0.,      ! u-component for moving grids
GRIDV   = 0.,0.,0.,      ! v-component for moving grids
!       (still not working!)

$END

$MODEL_FILE_INFO

! Variable initialization input

INITIAL  = 2,             ! Initial fields - 1=horiz.homogeneous,
!                       2=variable
VARFPFX  = 'isan/a',     ! Varfile initialization file prefix
VWAIT1   = 0.,           ! Wait between each VFILE check (s)
VWAITTOT = 0.,           ! Total wait befor giving up on a VFILE
(s)

NUDLAT   = 5,             ! Number of points in lateral bnd region
TNUDLAT  = 900.,         ! Nudging time scale(s) at lateral
boundary
TNUDCENT = 0.,           ! Nudging time scale(s) in center of
domain
TNUDTOP  = 00.,          ! Nudging time scale (s) at top of domain
ZNUDTOP  = 15000.,       ! Nudging at top of domain above height(m)

! History file input

TIMSTR   = 6.,           ! Time of history start (see TIMEUNIT)
HFILIN   = 'hist/a-H-2004-12-07-180000.vfm',
! Input history file name

! Analysis file input for assimilation (currently LEAF variables)

IPASTIN  = 0,            ! Initialize various fields from analysis
file?
! 1=yes, 0=no
PASTFN   = 'anal/a-A-2004-12-06-060000-head.txt',
! Input analysis file name

! History/analysis file output

IOUTPUT  = 2,            ! 0=no files, 1-save ASCII, 2-save binary
HFILOUT  = 'hist/a25',   ! History file prefix
AFILOUT  = 'anal/a25',   ! Analysis file prefix
ICLOBBER = 1,            ! 0=stop if files exist, 1=overwrite files
IHISTDEL = 1,            ! 0=keep all hist files, 1=delete previous
FRQHIS   = 21600.,       ! History file frequency
FRQANL   = 1800.,        ! Analysis file frequency
FRQLITE  = 1200.,        ! Analysis freq. for "lite" variables
! = 0 : no lite files
XLITE    = '/0:0/',      ! nums>0 are absolute grid indexes
YLITE    = '/0:0/',      ! nums<0 count in from the domain edges
ZLITE    = '/0:0/',      ! nums=0 are domain edges

```



```

AVGTIM   = 0.,           ! Averaging time for analysis variables
                        ! must be abs(AVGTIM) <= FRQANL
                        ! > 0 : averaging is centered at FRQANL
                        ! < 0 : averaging ends at FRQANL
                        ! = 0 : no averaged files
FRQMEAN  = 10800.,      ! Analysis freq. for "averaged" variables
FRQBOTH  = 3600.,      ! Analysis freq. for both "averaged" and
                        ! "lite" variables
KWRITE   = 1,           ! 1-write,0-don't write scalar K's to
anal.
! Printed output controls
FRQPRT   = 3600.,      ! Printout frequency
INITFLD  = 1,           ! Initial field print flag 0=no
prnt,1=prnt
! Input topography variables
SFCFILES = 'sfc/sfc',  ! File path and prefix for surface files.
SSTFPFX  = 'sst/sst',  ! Path and prefix for sst files
ITOPTFLG = 1,1,0,      ! 2 - Fill data in "rsurf"
ISSTFLG  = 1,1,0,      ! 0 - Interpolate from coarser grid
IVEGTFLG = 1,1,0,      ! 1 - Read from standard Lat/Lon data
file
ISOILFLG = 2,2,2,      ! Soil files not yet available: avoid
isoilflg=1
NOFILFLG = 2,2,2,      ! 2 - Fill data in "rsurf"
                        ! 0 - Interpolate from coarser grid
IUPDSST  = 0,           ! 0 - No update of SST values during run
                        ! 1 - Update SST values during run
                        ! The following only apply for IxxxxFLG=1
ITOPTFN  = './geodata/topol0m/H',
          './geodata/DEM30s/EL',
ISSTFN   = './geodata/sst/S',
          './geodata/sst/S',
IVEGTFN  = './geodata/ogedata/GE',
          './geodata/ogedata/GE',
ISOILFN  = ' ',         ! Soil files not yet available
! Topography scheme
ITOPSFLG = 3,3,3,      ! 0 = Average Orography
                        ! 1 = Silhouette Orography
                        ! 2 = Envelope Orography
                        ! 3 = Reflected Envelope Orography
TOPTENH  = 1.,1.,1.,  ! For ITOPSFLG=1, Weighting of topo
                        ! silhouette averaging
                        ! For ITOPSFLG=2 or 3, Reflected Envelope
                        ! and Envelope Orography enhancement
factor

```

```

    TOPTWVL = 4.,4.,4.,          ! Topo wavelength cutoff in filter

! Surface Roughness scheme

    IZ0FLG = 1,1,1,             ! 0 = Based of vege, bare soil and water
surface                               ! 1 = Subgrid scale orographic roughness
    ZOMAX  = 2.,2.,2.,         ! Max zo for IZ0FLG=1
    ZOFACT = 0.005,           ! Subgrid scale orographic roughness factor

! Microphysics collection tables

    MKCOLTAB = 0,              ! Make table: 0 = no, 1 = yes
    COLTABFN = './geodata/micro/ct2.0',
                                ! Filename to read or write

$END

$MODEL_OPTIONS

    NADDSC = 0,                ! Number of additional scalar species

! Numerical schemes

    ICORFLG = 1,              ! Coriolis flag/2D v-component - 0 =
off, 1 = on

    IBND    = 1,              ! Lateral boundary condition flags
    JBND    = 1,              ! 1-Klemp/Wilhelmson, 2-Klemp/Lilly,
                                ! 3-Orlanski, 4-cyclic
    CPHAS   = 20.,           ! Phase speed if IBND or JBND = 1
    LSFLG   = 0,             ! Large-scale gradient flag for variables
other than                               ! normal velocity:
                                ! 0 = zero gradient inflow and outflow
                                ! 1 = zero gradient inflow, radiative
b.c. outflow                               ! 2 = constant inflow, radiative b.c.
outflow                                    ! 3 = constant inflow and outflow
    NFPT    = 0,              ! Rayleigh friction - number of points
from the top
    DISTIM  = 60.,           ! - dissipation time
scale

! Radiation parameters

    ISWR TYP = 1,             ! Shortwave radiation type
    ILWR TYP = 1,             ! Longwave radiation type
                                ! 0-none, 2-Mahrer/Pielke, 1-Chen
    RADFRQ  = 1200.,         ! Freq. of radiation tendency update (s)
    LONRAD  = 1,             ! Longitudinal variation of shortwave
                                ! (0-no, 1=yes)

! Cumulus parameterization parameters

```

```

NNQPARM = 1,1,1,          ! Convective param. flag (0-off, 1-on)
CONFRQ  = 1200.,        ! Frequency of conv param. updates (s)
WCLDBS  = .001,         ! Vertical motion needed at cloud base for
                        !   to trigger convection

! Surface layer and soil parameterization

NPATCH  = 3,             ! Number of patches per grid cell (min=2)

NVEGPAT = 2,             ! Number of patches per grid cell to be
filled from              !   vegetation files (min of 1, max of
NPATCH-1)

ISFCL   = 1,             ! Surface layer/soil/veg model
                        !   0 - specified surface layer gradients
                        !   1 - soil/vegetation model

NVGCON  = 1,             ! Vegetation type (see below)

!   1 -- Crop/mixed farming      2 -- Short grass
!   3 -- Evergreen needleleaf tree 4 -- Deciduous needleleaf tree
!   5 -- Deciduous broadleaf tree 6 -- Evergreen broadleaf tree
!   7 -- Tall grass              8 -- Desert
!   9 -- Tundra                  10 -- Irrigated crop
!  11 -- Semi-desert             12 -- Ice cap/glacier
!  13 -- Bog or marsh            14 -- Inland water
!  15 -- Ocean                   16 -- Evergreen shrub
!  17 -- Deciduous shrub         18 -- Mixed woodland

PCTLCON = 1.,           ! Constant land % if for all domain
NSLCON  = 6,             ! Constant soil type if for all domain

!   1 -- sand                    2 -- loamy sand        3 -- sandy loam
!   4 -- silt loam                5 -- loam              6 -- sandy clay loam
!   7 -- silty clay loam          8 -- clay loam         9 -- sandy clay
!  10 -- silty clay              11 -- clay             12 -- peat

ZROUGH  = .05,           ! Constant roughness if for all domain
ALBEDO  = .2,            ! Constant albedo if not running soil
model

SEATMP  = 280.,         ! Constant water surface temperature

DTHCON  = 0.,            ! Constant sfc layer temp grad for no
soil

DRTCON  = 0.,            ! Constant sfc layer moist grad for no
soil

SLZ     = -.50,-.40,-.30,-.25,-.20,-.16,-.12,-.09,-.06,-.03,-.01,
                        ! Soil grid levels

SLMSTR  = 0.35,0.35,0.35,0.35,0.35,0.35,0.35,0.35,0.35,0.35,0.35,
                        ! Initial soil moisture

```

```

STGOFF  = 5.,5.,5.,5.,3.5,2.,.5,-1.,-1.5,-1.8,-2.,
          ! Initial soil temperature offset
          !   from lowest atmospheric level

! Eddy diffusion coefficient parameters

IDIFFK  = 1,1,1,          ! K flag:
                          ! 1 - Horiz deform/Vert Mellor-Yamada
                          ! 2 - Anisotropic deformation
                          !   (horiz & vert differ)
                          ! 3 - Isotropic deformation
                          !   (horiz and vert same)
                          ! 4 - Deardorff TKE (horiz and vert same)
IHORGRAD = 1,          ! 1 - horiz grad frm decomposed sigma
grad
                          ! 2 - true horizontal gradient.
                          !   Non-conserving, but allows small DZ
CSX     = .2,.2,      ! Deformation horiz. K's coefficient
CSZ     = .2,.2,      ! Deformation vert. K's coefficient
XKHKM   = 3.,3.,      ! Ratio of horiz K_h to K_m for
deformation
ZKHKM   = 3.,3.,      ! Ratio of vert K_h to K_m for deformation
AKMIN   = 1.,1.,      ! Ratio of minimum horizontal eddy
                          !   viscosity coefficient to typical value
                          !   from deformation K

! Microphysics

LEVEL   = 3,          ! Moisture complexity level

ICLOUD  = 4,          ! Microphysics flags
IRAIN   = 2,          !-----
IPRIS   = 5,          ! 1 - diagnostic concen.
ISNOW   = 2,          ! 2 - specified mean diameter
IAGGR   = 2,          ! 3 - specified y-intercept
IGRAUP  = 2,          ! 4 - specified concentration
IHAIL   = 2,          ! 5 - prognostic concentration

CPARM   = .3e9,      ! Microphysics parameters
RPARM   = 1e-3,      !-----
PPARM   = 0.,        ! Characteristic diameter, #
concentration
SPARM   = 1e-3,      !   or y-intercept
APARM   = 1e-3,
GPARM   = 1e-3,
HPARM   = 2e-4,

GNU     = 2.,2.,2.,2.,2.,2.,2., ! Gamma shape parms for
          ! cld rain pris snow agrg graup hail

$END

$MODEL_SOUND

!-----

```

```

! Sounding specification
!-----

! Flags for how sounding is specified

  IPSFLG   = 1,           ! Specifies what is in PS array
                    !   0-pressure(mb) 1-heights(m)
                    !   PS(1)=sfc press(mb)

  ITSFLG   = 0,           ! Specifies what is in TS array
                    !   0-temp(C) 1-temp(K) 2-pot. temp(K)

  IRTSFLG  = 3,           ! Specifies what is in RTS array
                    !   0-dew pnt.(C) 1-dew pnt.(K)
                    !   2-mix rat(g/kg)
                    !   3-relative humidity in %,
                    !   4-dew pnt depression(K)

  IUSFLG   = 0,           ! Specifies what is in US and VS arrays
                    !   0-u,v component(m/s)
                    !   1-umoms-direction, vmoms-speed

  HS       = 0.,

  PS       =
1010.,1000.,2000.,3000.,4000.,6000.,8000.,11000.,15000.,20000.,
      25000.,

  TS       = 25.,18.5,12.,4.5,-11.,-24.,-37.,-56.5,-56.5,-56.5,-56.5,

  RTS      = 70.,70.,70.,70.,20.,20.,20.,20.,10.,10.,10.,

  US       = 10.,10.,10.,10.,10.,10.,10.,10.,10.,10.,10.,

  VS       = 0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,

$END

$MODEL_PRINT

!-----
! Specifies the fields to be printed during the simulation
!-----

  NPLT     = 4,           ! Number of fields printed at each time
                    !   for various cross-sections (limit of
50)

  IPLFLD   = 'WP','RH','RH','RH',
                    ! Field names - see table below

  PLFMT(6) = '3PF7.3',   ! Format spec. if default is unacceptable

  IXSCTN   = 3,3,3,3,

```

```

                                ! Cross-section type (1=XZ, 2=YZ, 3=XY)

ISBVAL      = 10,5,10,15,
                                ! Grid-point slab value for third direction

! The following variables can also be set in the namelist:  IAA,
! IAB, JOA, JOB, NAAVG, NOAVG, PLTIT, PLCONLO, PLCONHI, and PLCONIN.

!   'UP'   - UP(M/S)           'RC'   - RC(G/KG)           'PCPT' - TOTPRE
!   'VP'   - VP(M/S)           'RR'   - RR(G/KG)           'TKE'  - TKE
!   'WP'   - WP(CM/S)          'RP'   - RP(G/KG)           'HSCL' - HL(M)
!   'PP'   - PRS(MB)           'RA'   - RA(G/KG)           'VSCL' - VL(M)
!   'THP'  - THP(K)
!   'THETA'- THETA(K)          'RL'   - RL(G/KG)           'TG'   - TG (K)
!   'THVP' - THV(K)           'RI'   - RI(G/KG)           'SLM'  - SLM (PCT)
!   'TV'   - TV(K)            'RCOND'- RD(G/KG)           'CONPR'- CON RATE
!   'RT'   - RT(G/KG)          'CP'   - NPRIS              'CONP' - CON PCP
!   'RV'   - RV(G/KG)          'RTP'  - RT(G/KG)           'CONH' - CON HEAT
!
!                                     'CONM' - CON MOIS
!   'THIL' - Theta-il (K)      'TEMP' - temperature (K)
!   'TVP'  - Tv (K)            'THV'  - Theta-v (K)
!   'RELHUM'-relative humidity (%) 'SPEED'- wind speed
(m/s)
!   'FTHRD'- radiative flux convergence (??)
!   'MICRO'- GASPRC
!   'Z0'   - Z0 (M)            'ZI'   - ZI (M)            'ZMAT' - ZMAT (M)
!   'USTARL'-USTARL(M/S)      'USTARW'-USTARW(M/S)      'TSTARL'-TSTARL (K)
!   'TSTARW'-TSTARW(K)        'RSTARL'-RSTARL(G/G)      'RSTARW'-RSTARW(G/G)
!   'UW'   - UW (M*M/S*S)      'VW'   - VW (M*M/S*S)
!   'WFZ'  - WFZ (M*M/S*S)      'TFZ'  - TFZ (K*M/S)
!   'QFZ'  - QFZ (G*M/G*S)      'RLONG'- RLONG
!   'RSHORT'-RSHORT

$END

$ISAN_CONTROL

!-----
! Isentropic control
!-----

ISZSTAGE = 1,                    ! Main switches for isentropic-sigz
IVRSTAGE = 1,                    !   "varfile" processing

ISAN_INC = 0600,                 ! ISAN processing increment (hhmm)
                                !   range controlled by TIMMAX,
                                !   IYEAR1,...,ITIME1

GUESS1ST = 'PRESS',             ! Type of first guess input- 'PRESS',
'RAMS'

I1ST_FLG = 1,                    ! What to do if first guess file should be
used,                             !
                                !   but does not exist.
                                !   1 = I know it may not be there,

```

```

!           skip this data time
!       2 = I screwed up, stop the run
!       3 = interpolate first guess file from
nearest
!           surrounding times, stop if unable
!           (not yet available)

    IUPA_FLG = 3,      ! UPA-upper air, SFC-surface
    ISFC_FLG = 3,      ! What to do if other data files should be
used,
!           but does not exist.
!       1 = I know it may not be there,
!           skip this data time
!       2 = I screwed up, stop the run
!       3 = Try to continue processing anyway

! Input data file prefixes

    IAPR      = './data/dp-p', ! Input press level dataset
    IARAWI    = './data/dp-r', ! Archived rawinsonde file name
    IASRFCE   = './data/dp-s', ! Archived surface obs file name

! File names and dispose flags

    VARPFX    = './isan/a',   ! isan file names prefix
    IOFLGISZ  = 0,            ! Isen-sigz file flag: 0 = no write, 1 =
write
    IOFLGVAR  = 1,            ! Var file flag:          0 = no write, 1 =
write

$END

$ISAN_ISENTROPIC

!-----
! Isentropic and sigma-z processing
!-----

!-----
! Specify isentropic levels
!-----

    NISN      = 43,          ! Number of isentropic levels
    LEVTH     =
280,282,284,286,288,290,292,294,296,298,300,303,306,309,312,
315,318,321,324,327,330,335,340,345,350,355,360,380,400,420,
440,460,480,500,520,540,570,600,630,670,700,750,800,

!-----
! Analyzed grid information:
!-----

    NIGRIDS   = 2,          ! Number of RAMS grids to analyze

```

```

TOPSIGZ = 2000.,      ! Sigma-z coordinates to about this height

HYBBOT  = 4000.,      ! Bottom (m) of blended sigma-z/isentropic
                    ! layer in varfiles

HYBTOP  = 6000.,      ! Top (m) of blended sigma-z/isentropic
layr

SFCINF  = 1000.,      ! Vert influence of sfc observation
analysis

SIGZWT  = 1.,         ! Weight for sigma-z data in varfile:
                    ! 0. = no sigz data,
                    ! 1. = full weight from surface to HYBBOT

NFEEDVAR = 1,         ! 1 = feed back nested grid varfile, 0 =
not

!-----
! Observation number limits:
!-----

MAXSTA  = 500,        ! maximum number of rawinsondes
                    ! (archived + special)

MAXSFC  = 5000,       ! maximum number of surface observations

NONLYS  = 0,          ! Number of stations only to be used
IDONLYS = '76458',   ! Station IDs used

NOTSTA  = 0,          ! Number of stations to be excluded
NOTID   = 'r76458',  ! Station IDs to be excluded
                    ! Prefix with 'r' for rawinsonde,
                    ! 's' for surface

IOBSWIN = 7200,       ! Observation acceptance time window
                    ! Obs are accepted at the analysis time T
if
                    ! for IOBSWIN > 0: T-IOBSWIN < obs_time <
T+IOBSWIN
                    ! for IOBSWIN = 0: T = obs_time
                    ! for IOBSWIN < 0: T-|IOBSWIN| < obs_time

STASEP  = .1,         ! Minimum sfc station separation in
degrees.
                    ! Any surface obs within this distance
                    ! of another obs will be thrown out
                    ! unless it has less missing data,
                    ! in which case the other obs will be
                    ! thrown out.

ISTAPLT = 0,          ! If ISTAPLT = 1, soundings are plotted;
ISTAREP = 0,          ! If ISTAREP = 1, soundings are listed;
                    ! no objective analysis is done.
                    ! If ISTAREP/ISTAPLT = 0, normal processing
                    ! is done

```



```

IGRIDFL = 4,          ! Grid flag=0 if no grid point, only obs
obs          !           1 if all grid point data and
              !           2 if partial grid point and obs
              !           3 if only grid data
              !           4 all data... fast

GRIDWT = .01,.01,    ! Relative weight for the gridded press
data          ! compared to the observational data in
              ! the objective analysis

GOBSEP = 5.,         ! Grid-observation separation (degrees)
GOBRAD = 5.,         ! Grid-obs proximity radius (degrees)

WVLNTH = 1200.,900., ! Used in S. Barnes objective analysis.
              ! Wavelength in km to be retained to the
              ! RESPON % from the data to the upper air
              ! grids.

SWVLNTH = 750.,300., ! Wavelength for surface objective analysis

RESPON = .90,.9,     ! Percentage of amplitude to be retained.

$END

```

References

- Bridgman Charles J. "Introduction to the Physics of Nuclear Weapons Effects," Ft. Belvoir: Defense Threat Reduction Agency (DTRA), 2001
- DTRA "Hazard Prediction and Assessment Capability (HPAC) User Guide Version 4.0.3," Alexandria: Defense Threat Reduction Agency (DTRA), 2003
- Flatau, Piotr J., et al. "The CSU-RAMS Cloud Microphysics Module: General Theory and Code Documentation," Fort Collins: Department of Atmospheric Science, Colorado State University, 1989
- Hegg, Dean A. "The Impact of Clouds on Aerosol Populations," Seattle: Department of Atmospheric Sciences, University of Washington, 2001
- Hobbs, Peter V. "Aerosol-Cloud-Climate Interactions," San Diego: Academic Press, 1993
- Kinser, Aaron M. "Simulating Wet Deposition of Radiocesium from the Chernobyl Accident," Wright-Patterson AFB: Air Force Institute of Technology, 2001
- Loosmore, Gwen A. and Richard T. Cederwall "Precipitation scavenging of atmospheric aerosols for emergency response applications: testing an updated model with new real-time data," Livermore: Atmospheric Science Division, Lawrence Livermore National Laboratory, 2003
- Mircea, Mihaela, Sabina Stefan and Sandro Fuzzi "Precipitation scavenging coefficient: influence of measured aerosol and raindrop size distributions," Bucharest: University of Bucharest, Faculty of Physics, 2000
- Van den Heever, Susan C., et al. "The Impacts of Saharan Dust on Florida Storm Characteristics," Fort Collins: Department of Atmospheric Science, Colorado State University, 2004
- Walko, Robert L. and Tremback, Craig J. "RAMS The Regional Atmospheric Modeling System Version 3b User's Guide," Fort Collins: *Aster Division Mission Research Corporation, 1995
- Walko, Robert L., et al. "New RAMS Cloud Microphysics Parameterization Part I: the Single-moment Scheme," *Atmospheric Research* 38: 29-62 (1995).
- Warner, Steve et al. "IDA Paper P-3554, User-Oriented Measures of Effectiveness for the Evaluation of Transport and Dispersion Models," Alexandria: Institute for Defense Analyses, 2001

Vita

John W. Englert was born on in Boulder, Colorado. He graduated from Centaurus High School in Lafayette, Colorado. He entered undergraduate studies at Fort Lewis College, Durango, Colorado where he graduated with a Bachelor of Science degree in Physics in May 1996. He was commissioned in 1997 through Officer Training School at Maxwell AFB.

His first assignment was with the Systems Acquisition directorate, Space and Missile Systems Center, Los Angeles AFB, California. While still stationed at Los Angeles AFB, he was assigned to the Defense Meteorological Satellite Program as a test manager. His next assignment was as the modeling and simulation program manager for the Electronic Warfare Directorate, Air Force Flight Test Center, Edwards AFB, California. He was then selected to attend the Air Force Institute of Technology where he is a candidate for a Master of Science degree. Following graduation, Captain Englert will be assigned to the Defense Threat Reduction Agency in Alexandria, VA.

REPORT DOCUMENTATION PAGE

*Form Approved
OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE (DD-MM-YYYY)		2. REPORT TYPE		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code)