A Prototype Operational Mesoscale Air Dispersion Forecasting System Using RAMS and HYPACT

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INTRODUCTION

Large quantities of potential air contaminants are handled during routine and launch operations at the Kennedy Space Center/Cape Canaveral Air Force Station (KSC/CCAFS). Dozens of possible release sites and chemicals have been identified which could form evaporating pools generating puffs and plumes ("cold spills"). Emissions involving combustion or exothermic reactions could produce buoyant plumes. Launch vehicle exhaust plumes and debris clouds from normal and aborted missions could include mixtures of vaporized fuel, combustion products and aerosols composed of hydrochloric acid droplets, aluminum oxide and radionuclide particles from on-board, nuclear powered electrical generators. An extensive network of surface layer wind monitors has been established, in part, to serve as input for real-time emergency response dose assessment systems. While a considerable improvement over those used in many other facilities, the techniques currently employed at KSC/CCAFS also have their deficiencies[1]. Previous studies have documented the complex local wind patterns caused by interactions of the islands, estuaries and larger scale Atlantic sea breeze circulations[2]. Strong upward motions (2-3 m/sec) can vertically translocate plumes released from the surface layer to altitudes of 1000 m or more. Strong subsidence (>30 cm/sec) can transport elevated pollutants down into the surface layer. Complex, multiple thermal internal boundary layers (TIBL) result in highly inhomogeneous vertical diffusion patterns[3]. If the contaminant is composed of a broad spectrum of aerosol sizes, gravitational sedimentation results in differential advection, causing substantial departures from dispersion estimates assuming zero settling velocities. Such three-dimensional wind fields can not be adequately resolved using surface layer data even when supported by limited upper air information. Furthermore, even if the domain-wide, 3-D structure of winds and turbulence could be observed, systems such as land and sea breezes evolve very quickly. Needed are forecasts, at a similar resolution, over the entire domain during the period in which hazardous concentrations remain in the area. This suggests the requirement for a mesoscale prognostic numerical modeling system. Recent advances in atmospheric prognostic modeling[4], dispersion modeling[5] and high performance computing using work stations[6] now allow for deployment of operational forecasting models integrated with multi-purpose transport and diffusion codes.

This paper reports on the design phase for ERDAS - the Emergency Response Dose Assessment System. It will be tested for its operational suitability at KSC/CCAFS in late 1993. If the concept proves viable, the ERDAS will eventually be deployed within the Cape Canaveral Forecast Facility (CCFF) to supplement a number of existing meteorological and dispersion forecasting tools. The ERDAS includes two major software systems, RAMS and HYPACT. The Regional Atmospheric Modeling System (RAMS) is a 3-D, primitive equation, non-hydrostatic, two-way multiple nested grid prognostic mesoscale model. RAMS output drives the Hybrid Particulate and Concentration Transport (HYPACT) Model which generates trajectories, streaklines, flow visualizations and point, areal and volumetric concentration and dosage fields. HYPACT can simulate releases from a variety of source types, ranging from cold spills to launch vehicle exhaust plumes. Dry deposition and differential transport of a spectrum of aerosol sizes due to gravitational settling are treated. The prognostic model can also provide meteorological forecasts suitable for ingest into other existing environmental systems, such as those assessing acoustic propagation.

Project goals include (1) developing and delivering a turn-key, integrated, operating prototype software and hardware system, (2) providing engineering versions of the prognostic meteorological (RAMS) and dispersion models (HYPACT) controlled by a graphical user interface (GUI), (3) designing the system to be initialized with existing resources available at the CCFF, (4) configuring the system to be usable, given the skill level and time resources of CCFF personnel, and (5) providing output which addresses specific operational and special purpose requirements related to atmospheric transport and diffusion.

DESIGN CONSIDERATIONS AND KEY COMPONENTS

ERDAS is being designed and developed with a number of general criteria in mind. Most importantly, it strives to provide the foundation for a general purpose solution to the forecasting of the local meteorological environment at KSC/CCAFS over the next 12-24 hours and in turn being able to assess dispersion potentials for ranges from several hundred meters to 100 km or more from a variety of source types. The software systems are highly modular. Thus, once the base ERDAS system is initially configured, future enhancements can be added with relative ease.

The CCFF forecasting staff is already heavily tasked. Therefore the level of effort required to initialize and run the models should be minimized. ERDAS will have two modes (1) routine operations, in which a limited sub-set of features are utilized and (2) planning, in which the full range of features can be exercised. For the routine operational mode, the total time commitments per shift should be on the order of 30 minutes under nominal conditions. During any actual emergency involving an unplanned release of air contaminants, results are needed within five to 15 minutes, further limiting the level of operator complexity. It is anticipated that the meteorological model will produce forecasts that are suitable for over 75% of the hours in a typical year. However, there will be certain meteorological regimes (tropical storms, widespread deep convection, etc.) for which the current version of RAMS will not be properly initialized or configured. Thus, completion of a front end "Suitability Check" will be required before a forecaster proceeds to employ the ERDAS for actual dispersion computations. The GUI will be designed so that virtually all operations can be "point and click." All input values will have appropriate defaults. RAMS will be initialized twice daily (based on 1200 UTC and 0000 UTC) data, and run for 24 hours. Thus, there will always be a meteorological forecast available to drive the HYPACT code. Since the KSC observational network does provide valuable data regarding surface layer conditions, for the first 30 minutes to an hour after dispersion model initialization the observations will be combined with the RAMS 3-D model output to weight the flow field towards the observations in those areas in which the measurements are suitable. Profiler and Doppler sodar winds could also be ingested. The basic HYPACT output will be designed to be available within about five minutes after specification of the source, again largely by point and click requests through the GUI. (Some more complex dispersion calculations will take longer). Both the RAMS and HYPACT model output will be highly graphical, easy to interpret and, to the extent possible, emulate current display conventions used in the CCFF. Though the primary motivation to develop ERDAS is for emergency response support, in its planning mode it will provide a useful tool for new source evaluation and contingency studies. The hardware configuration is presented in Figure 1. The general characteristics of the ERDAS are outlined schematically in Figure 2. The following sections present some details regarding the various components of the ERDAS.

RAMS - The Regional Atmospheric Modeling System

RAMS is a non-hydrostatic, primitive equation, prognostic mesoscale modeling system which has evolved from codes developed by Profs. Roger A. Pielke[7] and William R. Cotton[8] of Colorado State University. RAMS can be run in 2-D or 3-D modes. Any number of vertical levels can be selected, with several dozen being typical. The vertical levels telescope from the surface, starting several meters above the ground, and provide detailed resolution of planetary boundary layer structure. Surface heat and moisture fluxes are computed as a function of variable land use, albedo, roughness, soil type, soil moisture and topography. There is full treatment of long and shortwave radiative fluxes. Clouds and precipitation microphysics can be included when desired. The horizontal domain and grid spacings are of arbitrary size. RAMS uses multiple, nested, two-way interactive grids. RAMS has been used with grid sizes as small as 2 meters to as large as 100 km[9]. However, since computational requirements increase markedly with the inverse of the grid spacing (for a given domain size), the size of the horizontal grid becomes an important design decision. RAMS is a modeling system with a wide variety of potential configurations. Table I summarizes those being employed in ERDAS. RAMS and its predecessors have been used by researchers in many institutions to simulate a wide range of atmospheric phenomena, including land/sea breezes, orographic cloud systems, mountain/valley flows, large eddies, thunderstorms, boundary layer development in complex terrain, and the impact of terrain and land use variability upon mesoscale atmospheric structure.

RAMS will be initialized and run twice daily. Fixed inputs include topography, USGS-provided land use/land characteristics and climatological sea surface temperature patterns. RAMS will have a non-homogeneous initialization with non-stationary boundary conditions since temporal variability in the outer boundary conditions is needed. Data sets such as NMC grid point analyses and forecast, NWS rawinsonde and SAO data, as well as local mesonetwork and boundary layer wind profiler data can be utilized within the RAMS isentropic analysis package used as part of the model initialization procedure. New regional analysis packages using the products of the NWS modernization program are coming into more general use, such as MAPS (the Mesoscale Analysis and Prediction System) and LAPS (the Local Analysis and Prediction System). If such become available at CCFF, the files will be accessed and used in ERDAS. Soil moisture will be estimated using one of several techniques still under consideration. Measurements of sea surface and estuary water temperatures can be inserted to override the climatological default values.

The model outputs are highly flexible. Output files include the basic state variables (U,V,W wind components; potential temperature; specific humidity, pressure) at each model grid point and time step. In addition, a number of derived variables can be produced, including divergence, turbulence intensity, Pasquill-Gifford stability class and mixing depth. The model output can be configured to emulate any number of observation systems as "synthetic data". Therefore it will be possible to use RAMS to produce animations of forecasted wind fields in the same format as appearing on the MARSS display, or predictions of profiler or rawinsonde observations. Output can be formatted to be used directly in other codes such as REEDM. Table 2 summarizes some of the RAMS output options. RAMS output will be the prime input into the HYPACT dispersion code. For approximately the first hour, the available observations will also be incorporated into the HYPACT input files, using the RAMS output as a template for the initial objective analyses. Figure 3 summarizes the steps taken by an ERDAS operator using the system in its routine functions.

The development of multiple, nested, two-way interactive grids greatly increases the flexibility of the RAMS code. Large portions of the domain can be covered at coarse resolution, with finer grids nested inside the larger grid and located over the area(s) of concern. Figure 4a shows the three grids proposed for use in ERDAS. A 60 km mesh covers the southeastern United States. Florida will be resolved using a 15 km mesh. A 110 x 110 km region around KSC/CCAFS will use a 3 km mesh. This represents the coarsest mesh felt to resolve adequately both the sea breeze and island/estuary perturbations. As work station processors become even more powerful, spawning a finer mesh grid (approximately 1000 meters) directly over KSC/CCAFS is readily accomplished.

The Hybrid Particle and Concentration Transport (HYPACT) Model

The concept of a Lagrangian dispersion model is not of recent vintage. Still, its widespread application has been limited by (1) lack of available 3-D input data and (2) considerable computational requirements. RAMS can provide an appropriate input to an LPDM. One original LPDM is based on ideas developed by McNider, Moran, Uliasz and Pielke[10,11]. An LPDM emits from one to many tens of thousands of particles at times and locations specified by the user. Once emitted, the particles are subjected to a velocity field which advects them through space. The velocity field is a time series of gridded data sets comprising a resolved velocity (from RAMS) and a turbulent or subgrid velocity computed from normally-distributed, random numbers whose standard deviation is determined from local turbulence conditions at a certain particle location (also derived from RAMS). The source configurations are highly flexible. Cartesian volume(s) may be located anywhere in the domain and configured to represent point, volume and area as well as vertical and horizontal line sources. The emissions may be instantaneous, continuous, intermittent or time variable. The particles can be treated as gases or aerosols. Half lives for chemicals and radionuclides may be assigned. Gravitational settling and impaction can be treated. Each particle is assigned attributes, including the source, time of release and quantity of chemical mass or radiation it represents. An LPDM can be used to illustrate the most likely individual trajectories as well as streaklines. The ensemble particle cloud is ideal for visualizing the transport and diffusion mechanisms. Concentrations and dosages can be defined using receptor grid cells of variable size and geometric configuration. Outputs include instantaneous and maximum concentrations reached with the passage of a puff or plume. An LPDM coupled with meteorological fields provided by RAMS (or its equivalent) is a generalized solution to mesoscale dispersion in a variety of complex mesometeorological and terrain environments.

ERDAS will employ HYPACT, developed by Marek Uliasz and Robert Walko for ASTeR, Inc. HYPACT represents the next generation of dispersion modeling systems. In addition to retaining the many features of an original LPDM code, it also utilizes the best attributes of an Eulerian modeling system. Although the RAMS code can directly compute the dispersion of a passive contaminant in an Eulerian framework, HYPACT has certain advantages because it combines in one code the best features of both the Lagrangian and Eulerian dispersion estimating methodologies. The advantage of the Lagrangian method is greatest near a source region when the source is small and unresolvable on the Eulerian grid. A comparable Eulerian treatment would necessarily represent the source by a volume no smaller than one grid cell, and would immediately begin diffusing the tracer into adjacent cells. A Lagrangian approach, on the other hand, is fully capable of representing a source of any size and of maintaining a concentrated, narrow plume downwind of the source until atmospheric dispersion dictates that the plume should broaden. In contrast, at large distances from the source where the tracer plume is typically broad and well mixed, representation of the plume by Lagrangian particles can become inefficient due to the large number of particles required to achieve a smooth characterization of the plume. The hybrid Lagrangian and Eulerian approach used in HYPACT represents a tracer by Lagrangian particles near the source, but can convert particles to Eulerian concentrations where appropriate at large distances downwind.

HYPACT is a modular code which continues to add new features. The turbulent velocity components can be represented by either a first order Markov chain scheme or a fully random walk scheme. The initial features include a level 2.5 turbulence closure scheme. The dispersion and size sorting of heavy particles (typically D>1 micrometer) are treated separately from gases and submicron aerosols. Liquid aerosol evaporation, linear chemical transformation and radiological decay could be specified. Two options for dry deposition are available. Plume rise from buoyant and/or momentum sources can be taken into account using several approaches, including a Lagrangian plume rise technique. Concentrations are calculated using either a simple averaging over specified sampling volumes or, alternately, by using a more computationally efficient kernel density estimator.

Computational Aspects

Until recently, running a regional or mesoscale prognostic model was considered the domain of mainframe, Cray-class supercomputers. The emergence of work stations in the late 1980s signaled a "sea change" in how such models might be applied in local forecast offices[12]. Rather than relying solely on regional weather prediction centers for numerical guidance, a field forecast office, such as the CCFF, could employ the high performance computing power of increasingly more powerful work stations. Indeed, our experience over the past three years is that in terms of pure throughput, plus the added convenience of onboard visualization of the model results, the work station was both faster and far more cost-effective[13].

The RAMS code is written in standard FORTRAN 77 and runs on a variety of platforms. In the applications shown here, it was run on an IBM RS/6000 series machine. Our group has utilized primarily the IBM RS/6000 series machines (rated at 7 to 40+ megaflops in the single processor versions, with 32 to 512+ Mbyte memory). Other vendors have introduced machines of similar capabilities. It is expected that rapid price drops and performance improvements will continue in these product lines for the foreseeable future. ERDAS will employ the RS/6000-550 with 64 megabyte memory (see Figure 1). RAMS has been benchmarked on the IBM RS/6000-550 machine achieving throughput that is a substantial fraction of a single processor Cray Y/MP.

Even with their impressive performance, work stations have limitations. As mesh size diminishes, run times increase dramatically. Certain RAMS options, such as explicit cloud microphysics, also require substantial computational resources. For these reasons, the RAMS configuration in the initial ERDAS will be limited to a 3 km inner mesh size and will not treat convective cloud formation. These restrictions will disappear as faster processors become available. Figure 4a shows the RAMS configuration for forecasts using three grids with 60, 15 and 3 km mesh sizes. The initial goal is to provide forecasters with new 24 hour forecast model output within six hours of initialization. Figure 6 summarizes the number of horizontal grid points and vertical levels, mesh sizes Δx, and computational time steps which have tentatively been adopted for the ERDAS.

Another justification for using a dedicated, local work station as opposed to a remote mainframe is the sheer volume of model-generated output. RAMS and HYPACT runs can easily generate on the order of 1-2 gigabytes of files. Timely transmission of such large files from a remote machine for local interactive display is problematic. Using high resolution (1024 x 1280 pixel) 24 bit color graphics hardware and software capabilities, RAMS and HYPACT outputs are immediately available to the user in many formats. Color animated visualizations display on command the meteorological fields in a variety of fixed and arbitrary vertical and horizontal planes. Plume visualizations can be combined with meteorological variables. The animation and image manipulation features dramatically increase the meteorologist's ability to interact with and comprehend the model output, which is inherently three-dimensional and time dependent.

Three graphic packages will be provided to the ERDAS user: (1) NCAR Graphics, fixed 2-D horizontal and vertical planes with contours and/or color filled patterns with pseudo-animation, (2) savi3D interactive display[14], which provides the user with a great deal of flexibility in viewing both meteorological and air quality output in full three-dimensions as well as providing animation and (3) AVS-based, full 3-D interactive capabilities. All interactions with the model output will be through a GUI which will be designed to provide the optimal balance of flexibility and simplicity at each of the three ERDAS modes.

Figure 4 b,c,d is a typical ERDAS display showing the AVS- rendered meteorology and a dispersing plume at several resolutions. Typical HYPACT results, shown using NCAR Graphics, are presented in Figure 5 a,b,c. In this case, a near ground release (H = 2 m) was simulated, beginning at 1500 UTC and continuing for 120 minutes. A total of 7200 particles were used, requiring about 5 minutes computation time. The initial flow was to the east in an offshore, residual land breeze. The plume soon intersected an advancing sea breeze front. The plume initially was carried aloft but gradually became entrained into the upper portions of the advancing marine air mass. By 1800 UTC the plume was being advected northwestward. It was intersected by multiple TIBLs as it passed over various islands comprising the KSC/CCAFS complex. Portions of the plume matter were fumigated to the surface in complex, blotchy patterns. The ERDAS operator would be able to retrieve such a display in color and step through the time sequences in a pseudo-animation.

PROJECT PRIORITIES

The priorities for the RAMS portion of the ERDAS system is to have a suitable, 24-hour prognostic meteorological forecast continuously on call. The design for the dispersion modeling portion of ERDAS involves (1) developing a generalized treatment of key dispersion processes (HYPACT), and (2) specifying the source terms and accident scenarios relevant to KSC/CCAFS. In order to maintain continuity with systems currently in use within the Air Force, we will provide emulations of both the OB/DG and AFTOX dispersion models[15,16]. In addition to running with current data, these codes will then have the additional feature of providing estimates using forecasted weather. This will allow predictions of both long lasting releases and analyses of potential impacts for planned activities later in the day. An approximate prioritization of scenarios includes:

1. LAUNCH VEHICLE ABORT CLOUDS; use of HYPACT to specify the dispersion of both gases and aerosols (over a spectrum of sizes) for debris clouds from a launch vehicle abort.

2. SPILLS OF TOXIC CHEMICALS AT LAUNCH PADS AND STORAGE FACILITIES; the "cold spill" scenario, in which evaporation takes place from pools; also treatment of momentum and buoyant jets if adequately specified; a suite of products will be provided ranging from single trajectories to emulations of OB/DG and AFTOX using RAMS forecast data, and HYPACT, ranging from plume visualization using a small sample of particles to detailed concentrations and dosage estimates using a large number of particles (>10,000).

3. PLUMES FROM SRM GROUND FIRES AT LAUNCH PADS, PROCESSING AND STORAGE FACILITIES; use HYPACT with either specified or computed plume rise for one or more burn locations.

4. METEOROLOGICAL INPUTS TO REEDM, BLAST AND MARSS, AND SIMPLE THUNDERSTORM PROBABILITY GUIDANCE; files will be created which will allow other systems to access forecasted data fields in the same format as current observations; the thunderstorm potential display will alert users to possible degradation of system performance due to convective storm development during the forecast period.

5. VENTING OF TOXIC CHEMICALS FROM STORAGE FACILITIES; either momentum or buoyant releases, using OB/DG, AFTOX and HYPACT.

6. EXHAUST GROUND CLOUDS FROM NOMINAL LAUNCHES OF TITAN, ATLAS, DELTA AND STS VEHICLES; using HYPACT to simulate dispersion of the ground cloud and exhaust plume gaseous and aerosol species.

At this time we are not planning to implement a treatment for dense gases, although such is a possible future enhancement.

The initial ERDAS configuration will not activate the explicit cloud microphysics modules. Therefore, while the local flow features which trigger sea-breeze thunderstorms will be represented, the resultant convective response of the atmosphere will not. The RAMS model is capable of simulating convective storms explicitly. Considerable success was achieved in modeling Merritt Island Thunderstorm and Atlantic sea breeze convection in a recently completed project[17]. Before this option is installed in ERDAS, two advances are required. Since the inclusion of the microphysical module currently slows RAMS down by a factor of four over its "dry" implementation, either more efficient microphysics and/or faster processors must be employed. Work is proceeding on a faster microphysics package (speed-up by a factor of two). With work station performance doubling every 12 to 18 months, it is simply a matter of time before ERDAS can treat convective cloud impacts upon local dispersion. We note, however, that previous work has suggested that a dry version of RAMS can successfully diagnose the initiation and development of thunderstorms generated by local thermal forcing. In these cases, the atmosphere was initially quiescent, with the convective initiation predicted from model-predicted boundary layer convergence. Since a 6 to 24 hour dispersion forecast not accounting in some way for the potential for convective disturbances in the boundary layer is potentially misleading, we propose an interim solution. Previous thunderstorm forecasting experiments at KSC showed that relatively simple diagnostics applied to a "dry" prognostic model demonstrated skill at predicting the initiation of sea breeze storms during the upcoming day[18]. Various candidate storm diagnostics will be examined, including the K index, the KLIW index, convective available potential energy, and the output of 1-D diagnostic cloud models. As part of the ERDAS display, the spatial and temporal evolution of the convective storm potential diagnostic will be available to the forecaster. This will help flag those upcoming periods in which the dispersion estimates may be disrupted by deep convective clouds.

ERDAS STRENGTHS AND LIMITATIONS

Since the ultimate goal of the project is to produce a system suitable for operational use, it is essential that its performance characteristics be well documented. The evaluation of meteorological prognostic simulations and regional dispersion models is an issue undergoing active research[19]. Fortunately, during the summer of 1991, the Convection and Precipitation/Electrification (CaPE) Experiment was conducted over the KSC region providing numerous Doppler radar, aircraft, surface mesonetwork, special rawinsonde and other measurements which will provide an exceptionally rich data base with which to evaluate RAMS. The extensive operational evaluation of ERDAS planned the KSC/CCAFS region will be complemented by several parallel evaluation efforts of the RAMS and HYPACT codes. These are being performed with data collected for the Lake Michigan Ozone Study (LMOS) and a major tracer study in the complex

HYPACT performance evaluation is equally important. Aside from the OB/DG fluorescent particle diffusion tests made three decades ago, no suitable tracer data are available for HYPACT evaluation in the KSC region. Several large field tracer efforts have been conducted elsewhere over the past two years. SF6 releases have been made into complex lake breeze frontal zone flows[20] as well as in mountain/valley wind regimes in the complex terrain of northern Spain. The ERDAS development team is using these data to evaluate the combined RAMS/HYPACT performance. While not KSC/CCAFS site-specific, they will provide a useful performance benchmark. Initial analyses suggest that the models performed well in simulating complex, 3-D transport associated with the lake breeze during the Lake Michigan Ozone Study. In anticipation, we expect that the strengths of the ERDAS system will include:

- generation of credible 3-D, time-dependent, mass consistent wind fields over both the land and water portions of the domain
- proper treatment of mesoscale vertical motion fields, flow discontinuities at mesoscale flow boundaries, wind shears, spatially variable mixing depths and turbulence fields
- accounting for variability in coast line geometry, topography, land use and soil moisture
- use of local observations in combination with model output thus utilizing the best features of both diagnostic and prognostic models
- initialization using available data resources, suitable for use in over 75% of the hours in a typical year
- continued use of OB/DG and AFTOX modules, but with prognostic fields as well as current conditions
- treatment of a variety of source types, gases and aerosols, gravitational settling and dry deposition, over distances ranging from hundreds of meters to tens of kilometers
- efficient GUI and visualizations making initialization and usage of the models simple and efficient, with flexible and expandable software.

The perceived limitations of the ERDAS include:

- the lack of site-specific, three-dimensional tracer data sets against which to evaluate HYPACT performance at KSC/CCAFS
- lack of information regarding the characteristics of many potential sources (a problem shared with other dispersion systems)
- the finest mesh size of 3000 m is still a bit coarse to resolve some details of the local flows (1000 m being preferred)
- convective disturbances will not yet be treated explicitly.

The later two deficiencies can be remedied when workstation resources increase by approximately a factor of ten, either by clustering several currently available units, or by anticipated continued performance improvements. By the mid-1990s, most technological impediments to using prognostic and Lagrangian particle modeling systems will have been greatly alleviated. The issues will then focus on model evaluation, source term characterization and the development of suitable management structures and response procedures for the new resource.

CONCLUSIONS

"Desk top" forecasting is now possible for an ever growing class of mesoscale phenomena that once required mainframe supercomputer access. The ERDAS will provide a more generalized solution to characterizing the 3-D mesoscale flow field, mixing depths and turbulence patterns necessary as input into state-of-the-art transport and diffusion codes. The performance characteristics, strengths and weaknesses of the system must be well understood. The degree of confidence which can be placed in the dispersion calculations must be ascertained. Without a suitable tracer data set for the KSC region, this task will remain uncompleted. We would strongly urge that any tracer program conducted in support of KSC/CCAFS be geared to determining the complete, three-dimensional nature of the dispersion processes. This would include the use of mobile surface and airborne fast-response tracer monitoring systems. The impact of convection upon dispersion has been largely ignored, not just at KSC, but throughout the dispersion community. Enhanced computational power by mid-decade will make it possible to explicitly treat deep convective clouds, their updrafts, outflows and multiple feedbacks with surface layer energy budgets. Ideally, any future tracer program at KSC will avoid the "fair weather bias" and also be conducted during "disturbed" periods induced by convective storms.

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REFERENCES

1. Hosker, R.P., Rao, K. S., Eckman, R. M. ,McQueen, J. T. and Start, G.E. "An Assessment of the Dispersion Models in the MARRS System Used at the Kennedy Space Center," NOAA Air Resources Laboratory, Silver Spring, MD., 91 pp. (1992).
2. Lyons, W. A., R.A.. Pielke, W.R. Cotton, C.J. Tremback, R.L. Walko an C.S. Keen, "The impact of Wind Discontinuities and Associated Zones of Strong Vertical Motion upon the Mesoscale Dispersion of Toxic Airborne Contaminants in Coastal Zones", Proc., Safety & Environmental Protection, JANNAF, Kennedy Space Center, 21 pp. (1991).

3. Lyons, W.A. and R.A. Pielke, "Predicting 3-D Windflows at ape Canaveral Air Force Station using a Mesoscale Numerical Model, "Final Report, USAF SBIR Phase I, Contract No. F04701-89-C-0052, 260 pp. (1990).
4. Pielke, R.A., W.R. Cotton, R.L. Walko, C.J. Tremback, W.A. Lyons, L. Grasso, M.E. Nicholls, M.D. Moran, D.A. Wesley, T.J. Lee and J.H. Copeland, "A Comprehensive Meteorological Modeling System - RAMS", Meteor. and Atmos. Physics, (1992).
5. Pielke, R.A., W.A. Lyons, R.T. McNider, M.D. Moran, D.A. Moran, R.A. Stocker, R.L. Walko and M. Uliasz, "Regional and Mesoscale Meteorological Modeling as applied to Air Quality Studies", Air Pollution Modeling and its Application VIII, H. van Dop and D.G. Steyn, Eds., Plenum Press, NY, 259, (1991).
6. Lyons, W.A., and N.R. Lincoln, "Workstations versus Mainframes", Editor's Page, Environmental Software, 5 (2): 111 (1990).
7. Pielke, R.A., "A Three-Dimensional Numerical Model of the Sea Breeze over South Florida", Mon. Wea. Rev., 102 (1): 115 (1974).
8. Tripoli, G.J. and W.R. Cotton, "The Colorado State University Three-Dimensional Cloud/Mesoscale Model - 1982. Part I: General Theoretical Framework and Sensitivity Experiments," J. de Rech. Atmos. 16 (2): 185 (1982).
9. Lyons, W.A., R.A. Pielke, W.R. Cotton, M. Uliasz, C.J. Tremback, R.L. Walko and J.L. Eastman, "The Application of New Technologies to Modeling Mesoscale Dispersion in Coastal Zones and Complex Terrain," Proc., Int'l. Conf. on Air Pollution, Monterrey, Mexico, Computational Mechanics Publications, Southampton, U.K., 50 pp. (1993).
10. McNider, R.T., M.D. Moran and R.A. Pielke, "Inflnce of Diurnal and Inertial Boundary-Layer Oscillations on Long Range Dispersion," Atm. Envir., 22(11):2445 (1988).
11. Uliasz, M. and R.A. Pielke, "Lagrangian-Eulerian Dispersion Modeling System for Real-Time Mesoscale Applications," Proceedings, 3rd Topical Meeting on Emergency Preparedness and Response, ANS, Chicago, 4 pp. (1991).
12. Cotton, W.R., C.J. Tremback, M.P. Meyers, M.E. Nicholls and T.S. Pedersen, "Prospects for Short-Term and Mesoscale Numerical Forecasting - A Basic Researcher's Perspective," Proc., AES/CMOS 3rd Workshop on Operational Meteorology, Canadian Meteorological Service, Toronto, 6 pp. (1990).
13. Lyons, W.A., R.A. Pielke, W.R. Cotton, C.J. Tremback and R.L. Walko, "Operational Mesobeta-Scale Numerical Weather Forecasting: A Goal within Reach," Preprints, 8th Int'l. Conf. on Interactive Info. and Proc. Systems, AMS, Atlanta, 6 pp. (1992).
14. Lincoln, N.R., M.T. Johnson, C. Carlson, W.A. Lyons, D.A. Moon, C.S. Keen, R.A. Pielke and W.R. Cotton, "Visualizations of Forecasts and Simulations Produced by a Three-Dimensional Mesoscale Numerical Model," Preprints, 7th Int'l. Conf. on Interact. Info. Proc., AMS, New Orleans, 6 pp. (1991).
15. Haugen, D.A. and J.J. Fuquay, "The Ocean Breeze and Dry Gulch Diffusion Programs," Vol. 1, AFCRL-63-791(1), Hanscomb Field, MA, 149 pp. (1963).
16. Kunkel, B.A., "AFTOX 4.0 - The Air Force Toxic Chemical Dispersion Model - A User's Guide," Phillips Laboratory, Hanscomb AFB, MA, 55 pp. (1991).
17. Lyons, W.A., R.L. Walko, M.E. Nicholls, R.A. Pielke, W.R. Cotton, C.S. Keen and A.I. Watson, "Observational and Numerical Modeling Investigations of Florida Thunderstorms Generated by Multi-Scale Surface Thermal Forcing," Preprints, 5th Conf. on Mesoscale Processes, AMS, Atlanta, GA, 6 pp. (1992).
18. Lyons, W.A., R.A. Pielke, W.R. Cotton, C.S. Keen and D.A. Moon, "Final Results of an Experiment in Operational Forecasting of Sea Breeze Thunderstorms," Preprints, 5th Symposium on Weather Forecasting, AMS, Atlanta, GA, 8 pp. (1992).
19. Tesche, T.W., J.L. Haney and R.E. Morris, "Performance Evaluation of Four Grid Based Dispersion Models in Complex Terrain," Atmos. Environ., 21 (2) : 256 (1988).
20. Lyons, W.A., J. L. Eastman, R.A. Pielke, C.J. Tremback and G.W. Wilkerson, "The Use of a Mesoscale prognostic Model to Design a Field Tracer Experiment for the Lake Michigan Ozone Study," Proc., Ppr. 92-87.10, 85th Ann. Meet., AWMA, Kansas City, 16 pp. (1992).

Table 1

RAMS MODEL CONFIGURATION

THREE DIMENSIONAL
MULTIPLE (60-15-3 km Δx) GRID CONFIGURATION
TWO WAY HORIZONTAL & VERTICAL NESTING
TELESCOPING VERTICAL LAYERS (~25)
PRIMITIVE EQUATIONS
NON-HYDROSTATIC
NON-CONDENSING
NON-HOMOGENEOUS INITIALIZATION
TIME VARYING BOUNDARY CONDITIONS
FOUR DIMENSIONAL DATA ASSIMILATION
SHORT & LONG WAVE FLUX DIVERGENCE
VARIABLE TOPOGRAPHY & LAND USE
VARIABLE SOIL MOISTURE & WATER TEMPERATURE
FORECASTING PERIOD: 24 HOURS

Table 2

POTENTIAL RAMS MODEL OUTPUTS

RAMS STATE AND DERIVED VARIABLES

- U,V,W wind components
- Wind vectors, streamlines
- (potential, virtual) temperature
- Mixing ratio, dewpoint, relative humidity
- Pressure (MSL) and pressure gradient
- Divergence, vorticity
- Surface heat flux, lapse rate
- Maximum vertical motion, subsidence fields
- Mixing depth, Pasquill-Gifford Class
- Standard deviation of wind (sigma theta)
- Monin-Obukov length, friction velocity
- Turbulent kinetic energy
- Refractive indices, speed of sound
- LCL, LFC, SWEAT, K, LI, KLIW, CAPE thunderstorm Indices

SYNTHETIC DATA GENERATED FROM RAMS

- WINDS NETWORK
  - Both short and tall towers
  - Tabular format of animated ERDAS Display
  - Files Exported for MARSS display
- SURFACE DIVERGENCE FROM WINDS
- HOURLY KSC RAWINSONDES
  - For use in REEDM and BLAST models
- SURFACE AVIATION HOURLY REPORTS
  - T, Td, DD, VV
  - For NWS, FAA, AWOS/ASOS stations in Florida
  - Offshore Buoy
- PROFILER:
  - ZT Sections of Wind
  - ZT Sections of RASS
- DOPPLER SODAR:
  - ZT Sections of Winds
  - ZT Sections of Vertical Motion

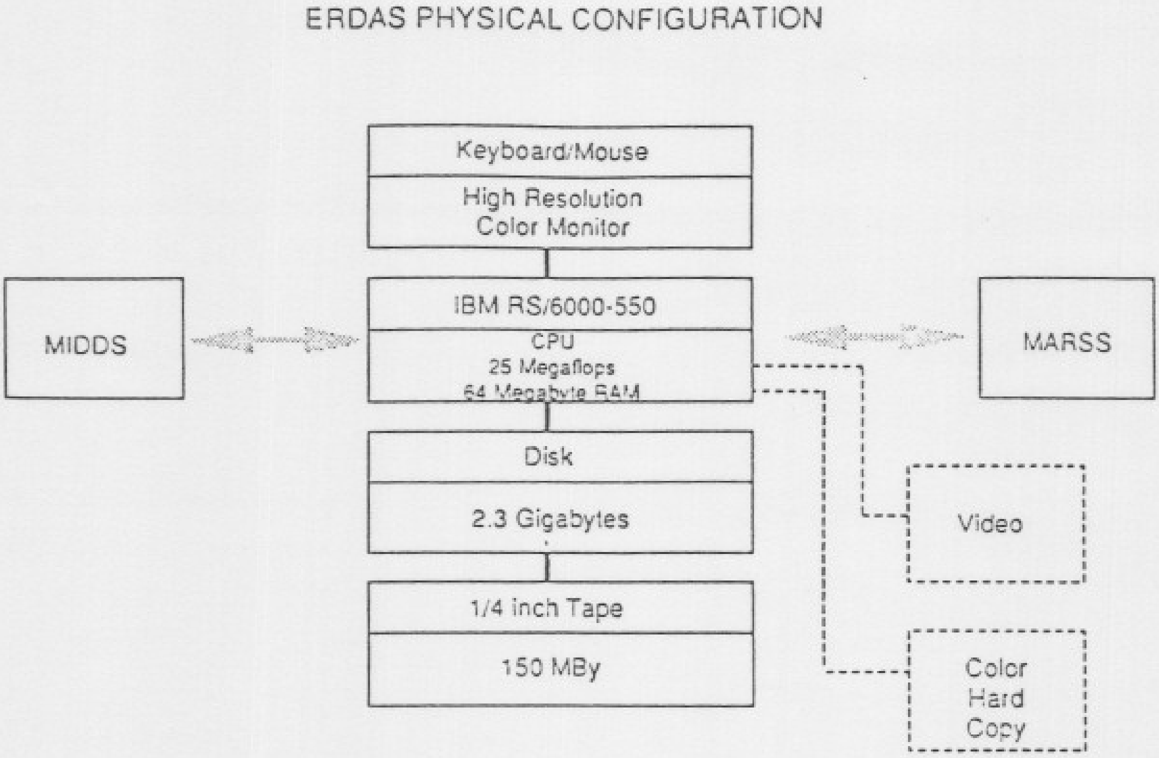

Figure 1. The physical configuration for the ERDAS at KSC/CCAFS.

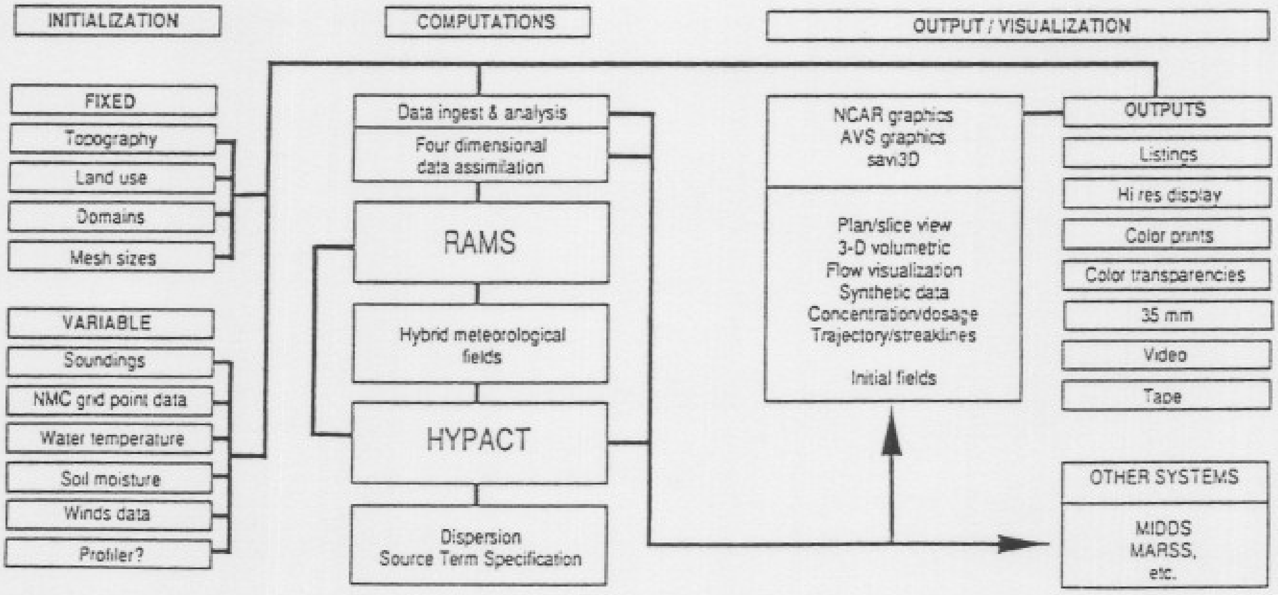

Figure 2. Schematic of the key components of the Emergency Response Dose Assessment System (ERDAS).

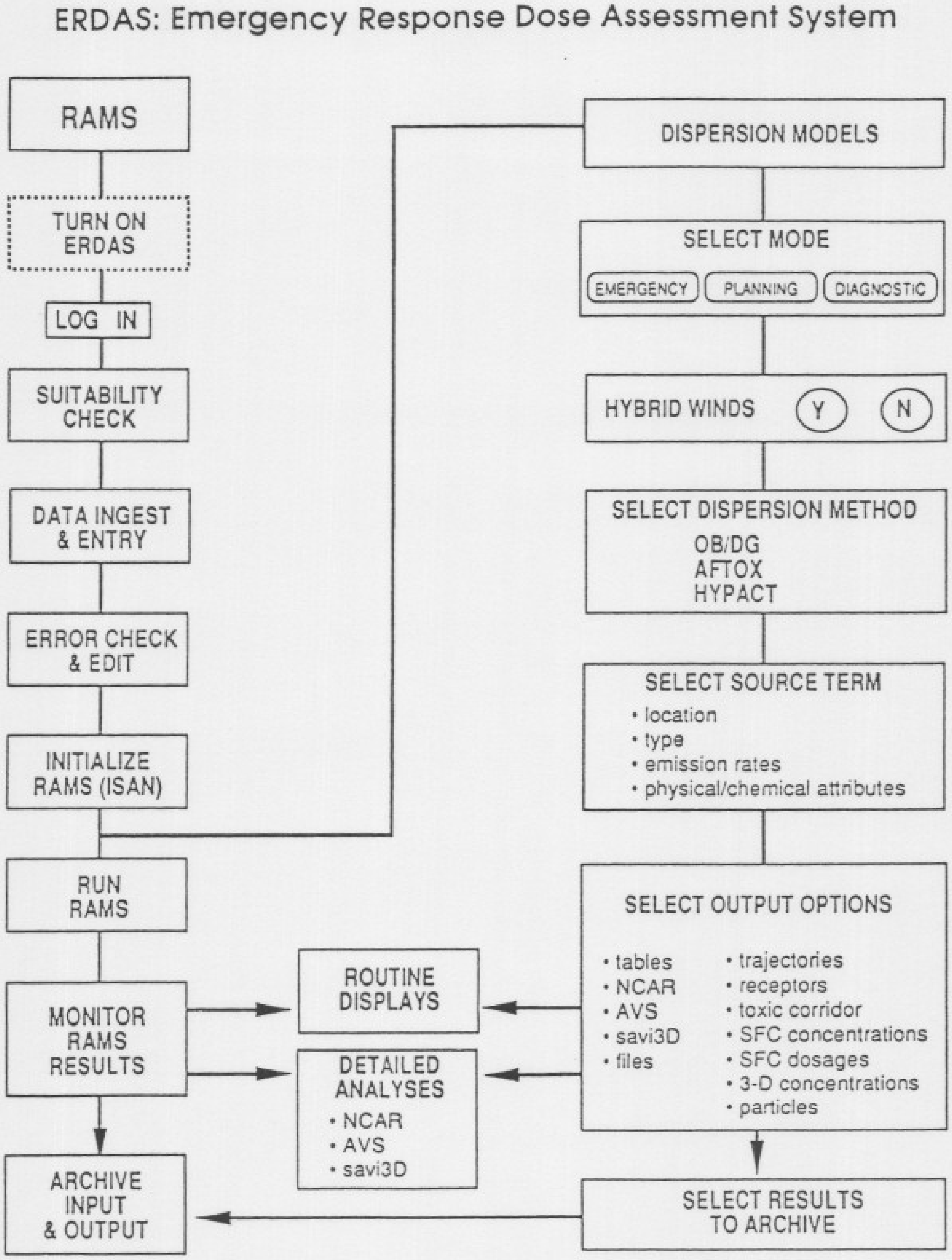

Figure 3. Procedural diagram for ERDAS users in the Cape Canaveral Forecast Facility showing RAMS initialization and possible use of the dispersion module in the event of an accidental release.

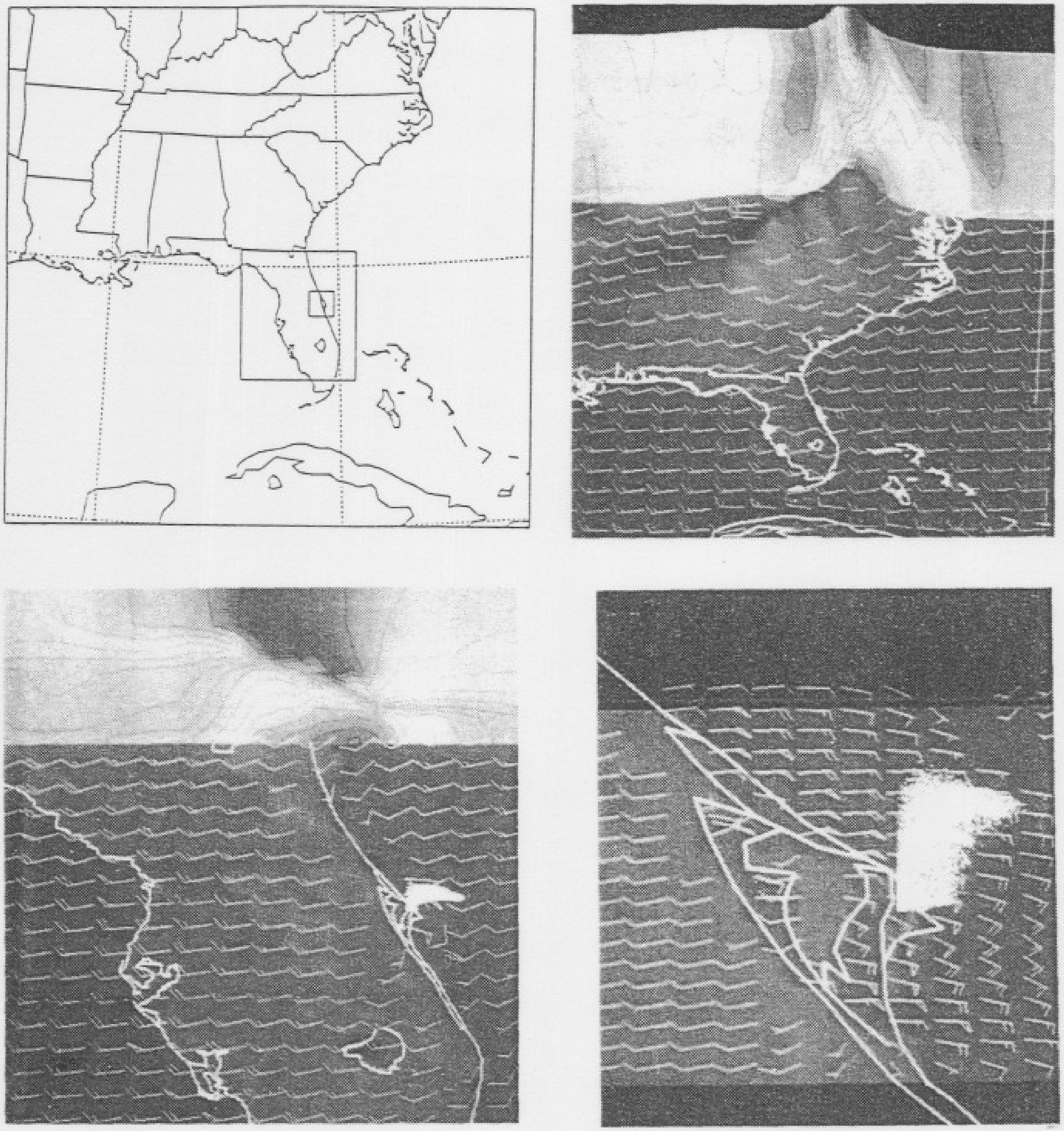

Figure 4. (a, top left.) Three grids proposed for use in ERDAS; (b, upper right) surface winds at 60 km mesh size and vertical motion fields in an arbitrary, user selectable vertical plane; (c, lower left) wind field as resolved with proposed inner grid using a 15 km mesh size, along with a plume from a surface plume release begun 2 hours earlier and the U wind component shown in the vertical plane; and (d, lower right) close up view showing 3 km mesh wind fields and the dispersing plume (one wind barb = 2 m/sec, no barb of < 1 m/sec).

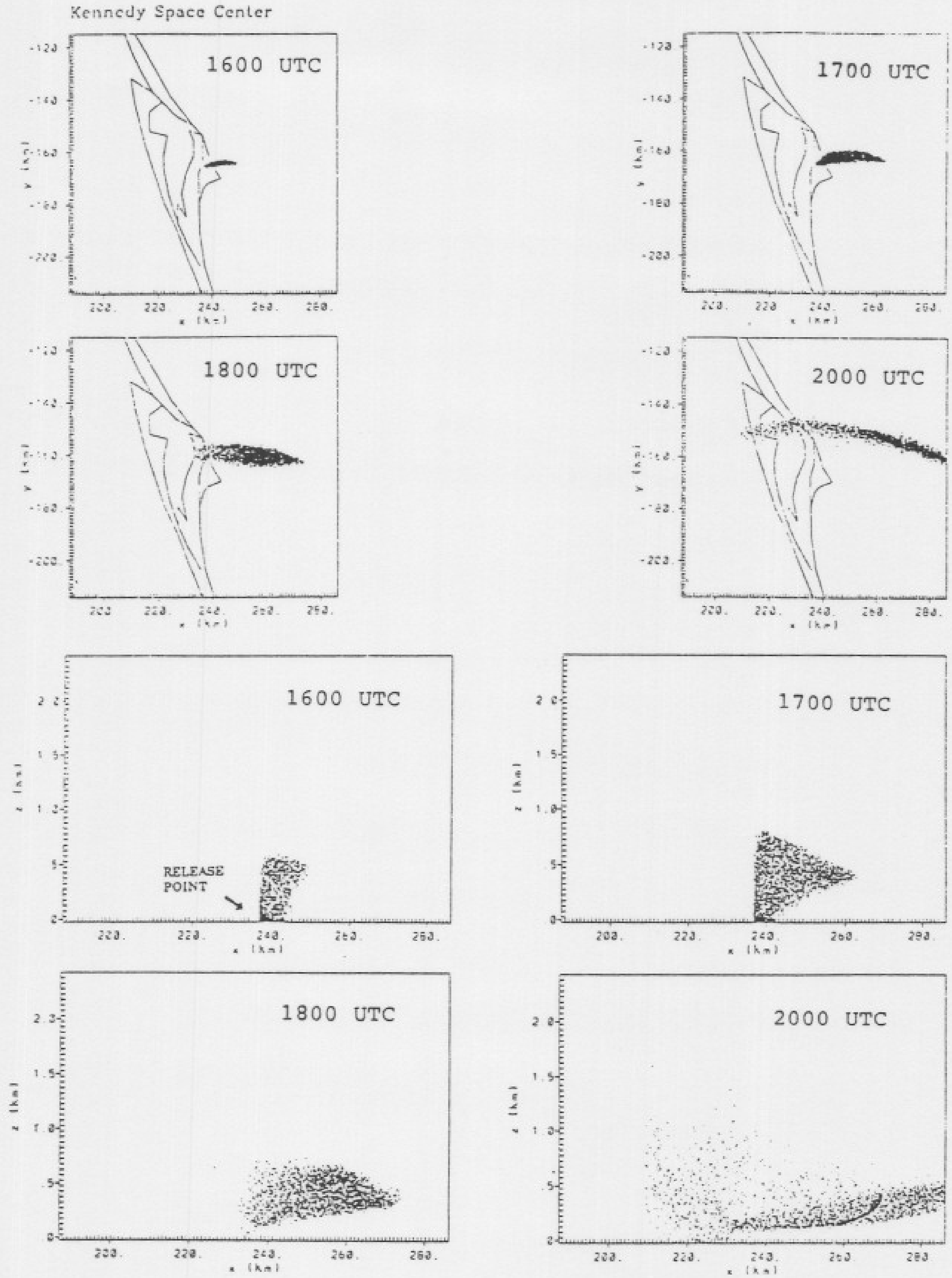

Figure 5a, b. See caption following page.

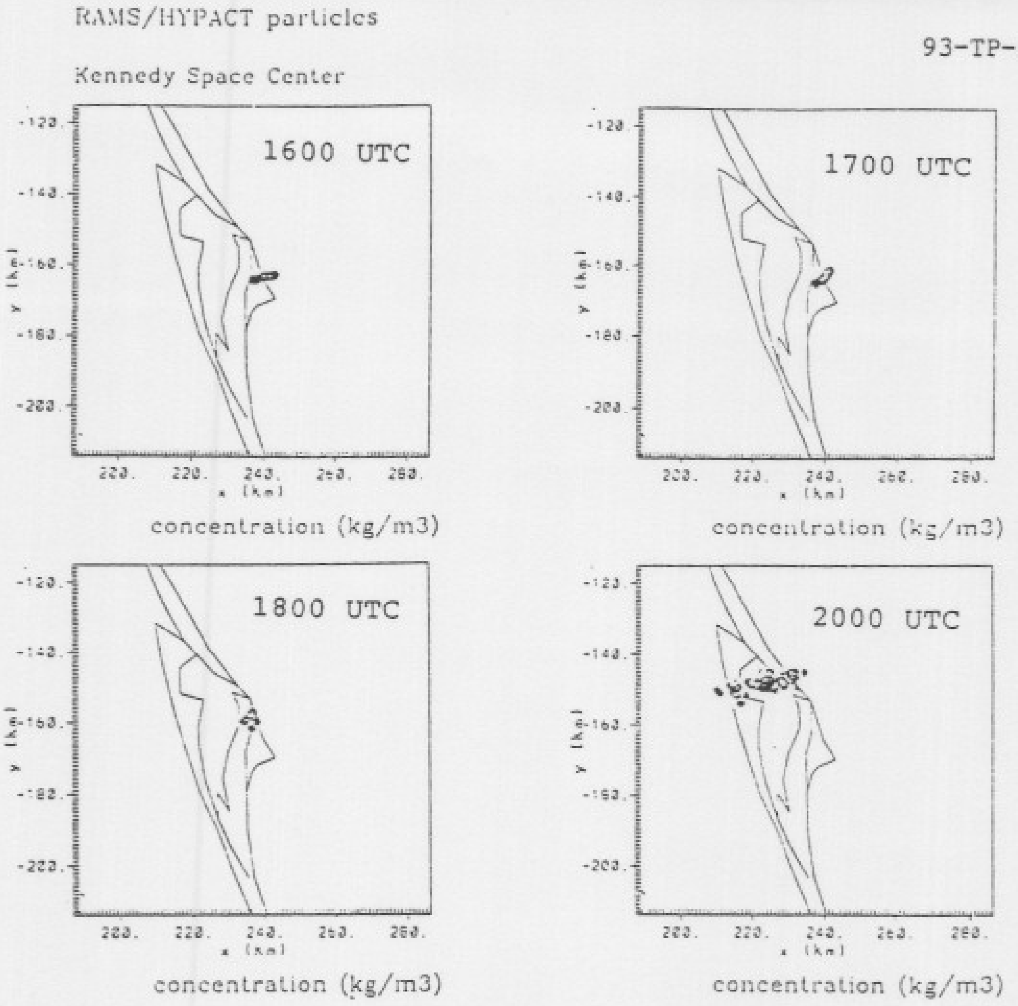

Figure 5 (a). Plan view of HYPACT particles representing a two hour release from a surface source over Cape Canaveral, continuing until 1700 UTC; (b) XZ view of particles showing the plume being carried aloft above the advancing sea breeze front; (c) surface layer concentrations showing the patchy nature of a fumigating plume element as it is advected inland within the strengthening sea breeze.

COMPUTATIONAL CONFIGURATION FOR RAMS
24-HOUR FORECASTS
ESTIMATED RUN TIME: 6 HOURS (IBM RS/6000-550)

GRID NO.	X	°	Y	°	Z	ΔX (km)	TIME STEP (sec)
1	38	x	38	x	25	60	90
2	34	x	38	x	25	15	30
3	37	x	37	x	18	3	12

Figure 6. The proposed horizontal and vertical structure of the RAMS model as configured for the three nests to be used in ERDAS.