USING WORK STATIONS FOR RESEARCH IN NWP MODELING AT NMC

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Summary: To diagnose numerical weather prediction (NWP) model behavior the National Meteorological Center (NMC) is planning an array of UNIX based platform software to display model forecasts from operational and over the counter model integrations. Time sequences and animated two and three dimensional display of model variables from experimental and operational runs depict the complex relationships of various phenomena and diagnose model problems. Animated three dimensional views include 2– and 3– dimensional surfaces, tracer trajectories, and adjustable slicing through the displayed three–dimensional spatial field. The NMC gridded GRIB–ed operational model run data from global and regional models is used as direct input to the VIS5D[2] package. The model dependent variables and physics quantities may be accessible for display, or the user may add custom calculations in standard languages. Existing software packages which contain functional software can manipulate basic or derived quantities into four–dimensional formats, for example, the software GEMPAK[4], GrADS[3], and NMC developed NTRANS[5] will respond to users requests for algebraic functions and scalar and vector differential operations performed on model output to produce diagnostic calculations. With technological improvements in the price performance of work stations, developers of NWP models can now make use of more complex diagnostic software, and we predict that operational forecasters will use these products as well.

1. Introduction to the Research and Development Problem

Model developers/researchers attempt to view the atmosphere's evolving 3–dimensionality by making weather maps and other 2–dimensional projections of physical quantities. By assembling enough model diagnostic views, verifying results with analysis, and including what is known about the atmosphere, developers have produced today's models capable of a range of accurate predictions from now–casting to the medium range. The NMC is moving toward higher horizontal resolution models with finer vertical grids and more complex representation of physics. It has become increasingly difficult to make enough 2–dimensional views of the atmosphere to observe the necessary parameters to diagnose model problems.

The operational forecaster has many of the same problems as the researcher, but on a daily basis with deadlines. They do not routinely examine quantities like model fluxes, internal convective parameters and other model physics quantities now available from models, but this may be because such quantities are not so accessible and the leisure to look into such details is not available when forecast deadlines near. Forecasters have yet to test how useful such quantities as internal convective parameters are in the daily forecast problem. They must have access to make evaluations. In viewing the current forecast problem or assessing the latest model improvement, the weight of the paper alone is cause for concern. Some movement toward digital display and away from paper is a major step in modernizing NWP and forecasting.

Several improvements in the technical aspects of meteorological work stations at the NMC have combined to allow progress for both the developer and forecaster.

1. Work station software has improved considerably in terms of the display and data manipulation qualities of commercial, shareware, public domain and custom and in–house written products.
2. Standards for data storage and transport of common data formats like GRIB and BUFR have been accepted by the meteorological community.

3. These are distributed UNIX operating systems including transparent software that frees users of the intricacies of working across a network in a distributed system are common.
4. A sufficiently powerful work station is now available and affordable to execute the improved software.

These items have combined to allow production of useful meteorological work station products from observations and model output. The goal of the meteorologist is to view the many atmospheric quantities as they evolve in time for a 3–dimensional atmosphere. Projections of these 5–dimensional quantities – 3 space dimensions, one time dimension and a dimension for the quantities to be displayed – make up the complement of what meteorologists have displayed to piece together the weather or model diagnostic situation.

2. Comparing NMC Hurricane Track Forecasts with Satellite and Bogus Observations

The model developer often needs to know if some model change under consideration has improved the prediction. In this example, high resolution hurricane bogus data derived from aircraft observations is used to improve the hurricane track predictions of the NMC Aviation model (AVN). Fig. 1a shows a map of observed and predicted tracks for hurricane Fernanda from 16AUG93 superimposed on the AVN 500 mb height field initial condition.

The display package used to produce Fig 1 is GrADS[3]. GrADS is similar to other 2–dimensional display packages. It includes an easy to use command and scripting language and offers algebraic functionality in addition to the many point and click controls shown on the border of the figure which may be used to alter or animate the display. By default, the NMC version of the GrADS implementation is directly connected to post processed model run data, so, many different models and quantities are available as shown by the top and bottom buttons in the figures. The model level can be selected as shown in the left hand side of the figure. Many other features are available, and, by the use of the Network File System (NFS), only those records of data which are needed to make the map are accessed from the many Gbytes of model output.

The Hurricane symbols show the observed hurricane track every 12 hours which verifies predictions of the UK Met office (squares) as well as two NMC models (circles). The UK Met predicted track did a fair job of verifying against the observations, but both NMC models in this case moved the storm erroneously to the west. Fig. 1b shows the same tracks as Fig. 1a against a background of the UK Met model 500 mb field instead of the corresponding AVN model 500 mb height in Fig 1a. A ridge shown by the shading to the northwest of the storm in the AVN analysis of Fig. 1a is not present in the UK model 500 mb in Fig 1b. The hurricane can pass northward while the winds around the erroneous ridge force the NMC hurricane track predictions westward. In Fig. 1c the 850 mb height is shown superimposed with the Bogus observations and available satellite data which shows a lack of data in the analysis cycle at the location in question and that the westward track predicted for hurricane Fernanda was not due to the hurricane bogus data.

3. An Example of using a 2–Dimensional Display System at NMC

Model developers understand the need to view the atmosphere and model simulations as evolving 3–dimensional patterns. They do this by making maps and cross sections of various atmospheric variables. An example of this is shown in Fig 2 for the NMC Global model convection scheme placed in operation August '93. The GrADS display system was used to create the plots in color. The figures show the black and white copies. Fig 2a shows the convective precipitation 48 hour forecast. Two areas are of interest for our discussion; a mid–latitude light precipitation area near the Aleutians at 165W longitude between 40 and 50 N latitude and an equatorial area of heavy precipitation near 160E longitude. Fig 2b shows the 48 hour forecast convective mass flux from the convection scheme corresponding to Fig 2a. The Aleutian area shows strong convective mass flux while the equatorial area shows less intensity. The model developer knows that the depth over which the convection occurs is behind the difference. A longitudinal cross section of the convective heating; one line through 160W passing through the Aleutian region in Fig 2c and another one through 165E longitude in Fig 2d passing through the equatorial area shows this clearly. At 40–50 N latitude the convective heating extends through low levels 850 – 700 mb while the equatorial area of convective heating shows deep convection from 900 to 100 mb.

4. Meteorological Visualization with Work Stations

The above examples show the method used by model developers to study large data sets consisting of 3 space dimensions, one time dimension and multiple variables. Consider tools that can view the data sets with real numbers at each point of a five dimensional grid (a dimension for variables, time and 3 space dimensions), displaying 2– and 3– dimensional surfaces with the capability to be transparent, animation to capture the time variation of the 2– and 3– dimensional sequences of physical variables, tracer trajectories, geographic marking and earth topography. NMC has been experimenting with the VIS5D[2] display system which has these capabilities. VIS5D is distributed as shareware but requires 64Mb of memory and the equivalent of a Silicon Graphics (SGI) Unix platform with Z–buffer to execute the software. An important factor is that custom software is needed to convert model quantities to VIS5D data sets.

To demonstrate some possibilities for 5D display we first show a standard developer and forecaster view of a forecast problem using the NMC operational Eta model. Fig 3a shows the mean sea level (MSL) pressure and 1000–500 mb thickness for a 30 hour forecast from the NMC regional mesoscale model valid 4NOV93 06Z. A large storm is located in the upper plains states of the United States with a trough extending into the western Gulf of Mexico. Figure 3b shows the 6 hour accumulated convective precipitation and the 700mb vertical velocity also valid 4NOV93 06Z. For the purpose of this demonstration we will discuss two areas each showing separate phenomena: 1) The Rocky mountain area has an apparent wave train in the alternating maxima of vertical motion. 2) A small band of convective precipitation extending from the Gulf of Mexico through the state of Louisiana. A model developer might be interested in what appears as predicted gravity waves over the Rocky mountains and a forecaster may take an interest in the predicted Louisiana precipitation. Since we cannot hope to show the effect of animation in this paper we will show images which verify at the Fig. 3 time period.

The post processed gridded pressure data from each of the NMC operational models is interpolated to an elevation (Z) coordinate and put into VIS5D format. Like most display programs, VIS5D provides the user with a menu driven interface where one may choose 3–dimensional iso–surfaces or 2–dimensional slices (from any line or position) through the 3–dimensional view for one or more of the variables present in the model. The users eye position may be moved to any position by mouse manipulations, and the 3–dimensional view may be pan–ed or zoom–ed using mouse controls. Colors, contours, density, etc... may be changed by pop–up menus. Fortran or C–language programs created by users can be inserted to produce user defined variables in addition to those in the VIS5D input data set. The date and clock hand change appropriately as VIS5D animates the evolving patterns. The user may step through the animation to view single frames. The conversion of these frames from color hard copy to black and white does not reproduce clearly in these pages. For example, Fig 4a shows a view from the Pacific ocean over the Rocky mountains for the same time as shown in Fig 3. A wave train shown by the vertical motion iso–surface over the Rocky mountains corresponds to that shown in Fig. 3b. The horizontal wind iso–surface of 45 m/s is shown intruding from the northwest over the Rocky mountains. An iso–surface of relative humidity is in the background behind the Rocky mountains in the upper plains associated with the large low pressure system. Beyond the Rocky mountains in the southern part (right side) of the picture is the convection which caused the small band of precipitation shown in Fig 3b. It appears as a smoke plume in the relative humidity iso–surface. Fig. 4b shows a second view of this same scene from an eye point above the Atlantic ocean east of Florida. The relative humidity iso–surface traces the upper plains states low pressure system behind which is the Rocky mountain vertical motion wave train. The small area of convection in the northern Gulf of Mexico is now clearly seen. Features such as the wave train over the mountains can be studied by the model developer to determine the vertical and time extent of the phenomena which in this case was long lived. Many features have yet to be catalogued and determinations made as to their cause. Not shown are examples of plane slices through the 3–dimensional volume in any direction or the 3–dimensional wind vectors. Wave phenomena in the wind field or other quantities can be viewed interacting with other variables when the frames are set to animation. Trajectories are placed by the user at any point in the 3–dimensional volume. Trajectories appear as colored dashed lines moving as inert tracers within the flow. In an example not shown, the trajectories showed strong winds which passed through valleys in the California mountains which verified with high wind episodes.

5. **VIS5D Data Flow**

The NMC model post processed pressure fields are in WMO GRIB standard form. Each post processed file contains a single time period of many variables of 3–dimensional data usually on pressure levels. The VIS5D data converter program converts these to elevation coordinate and VIS5D format. To aid the user in making VIS5D files, a C–language program containing X–window calls produces the point and click interface shown in Fig. 5. The user can input one of the operational models or a user defined over the counter run and specify the variables to be extracted. The system defaults to extracting all model 3–dimensional variables, and the user chooses the portion of the model grid to display. If the user has displayed a previous run, its settings appear in the window boxes and may be changed or just re–executed by the "convert" button.

One may use the model output directly or may create derived fields using the functionality of a 2–dimensional display system. Shown in Fig. 6 is a diagram representing the users interaction with the GEMPAK[4] display system. The algebraic functionality of GEMPAK allows the user to create derived quantities and include them with the model basic variables. This interaction is shown in Fig 6. The developer accesses the GEMPAK data file producing diagnostics until the desired diagnostic variables are obtained. The results are then interpolated to the VIS5D file format.

6. **Summary**

Many components have combined to facilitate the diagnostic analysis of high resolution and complex NWP models. They are: Acceptance of common data formats, Distributed processing and networked file systems, Graphical user interface for control, Improved price performance work stations, Graphical display software for visualization of meteorological fields and Software for improved functionality in deriving secondary meteorological quantities at the users demand. The representation of many meteorological variables in animated 3–dimensions remains in a development mode at present. The implementation of more variables representing the physics of the numerical model and atmosphere are sure to be an important research and development tool. It is expected that convective and sensible heating fields, cloud and precipitable water and other specialized fields will be available for 5–dimensional viewing. Once we gain experience in viewing the atmosphere in 5–dimensions instead of numerous projections, this approach may become an important part of the operational environment.

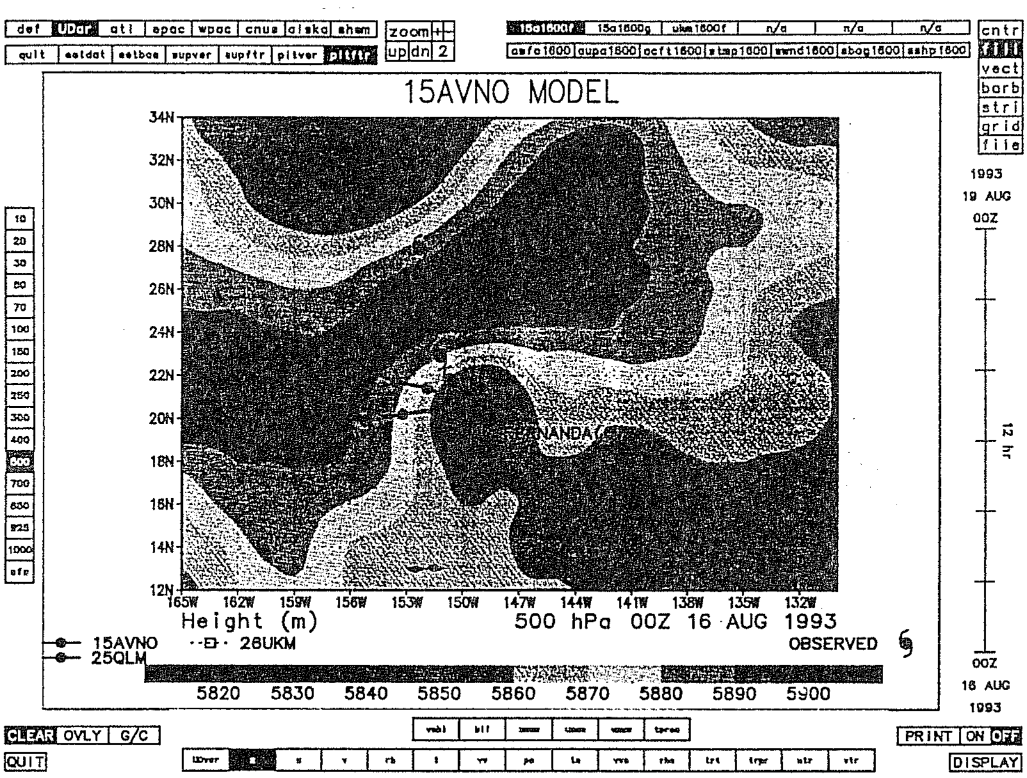


Fig. 1a Observed and predicted tracks for hurricane Fernanda from 16AUG93 00Z superimposed on the 500 mb height field model initial condition.

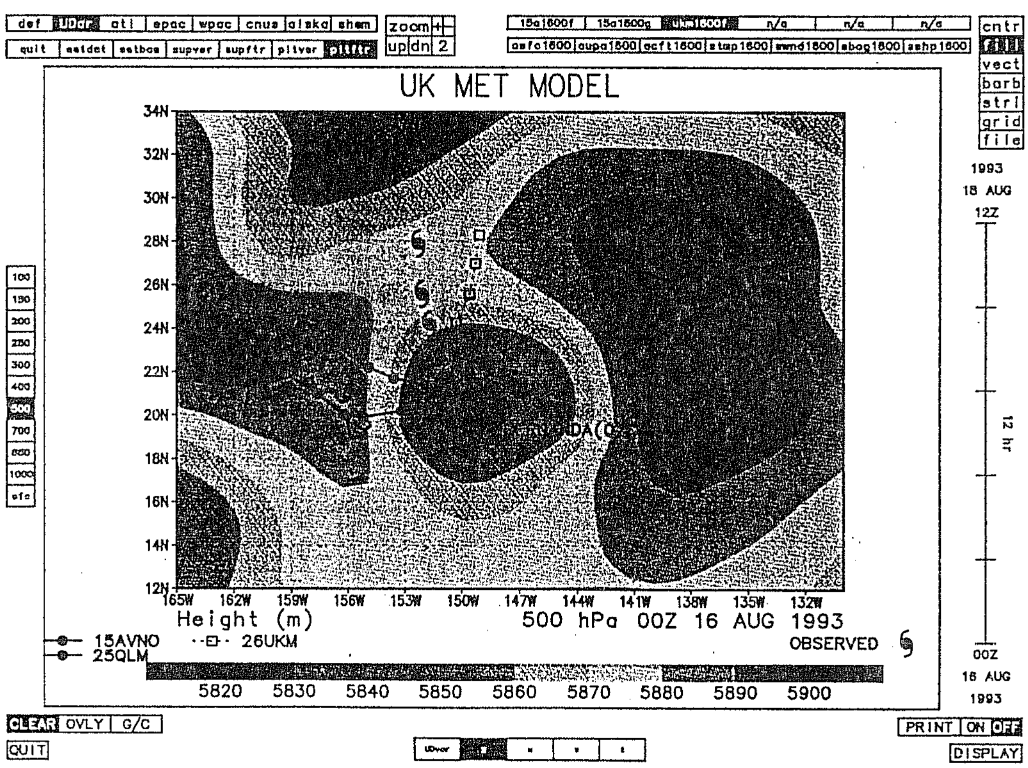


Fig. 1b Same as Fig. 1 but with UK Met office 500mb model initial conditions.

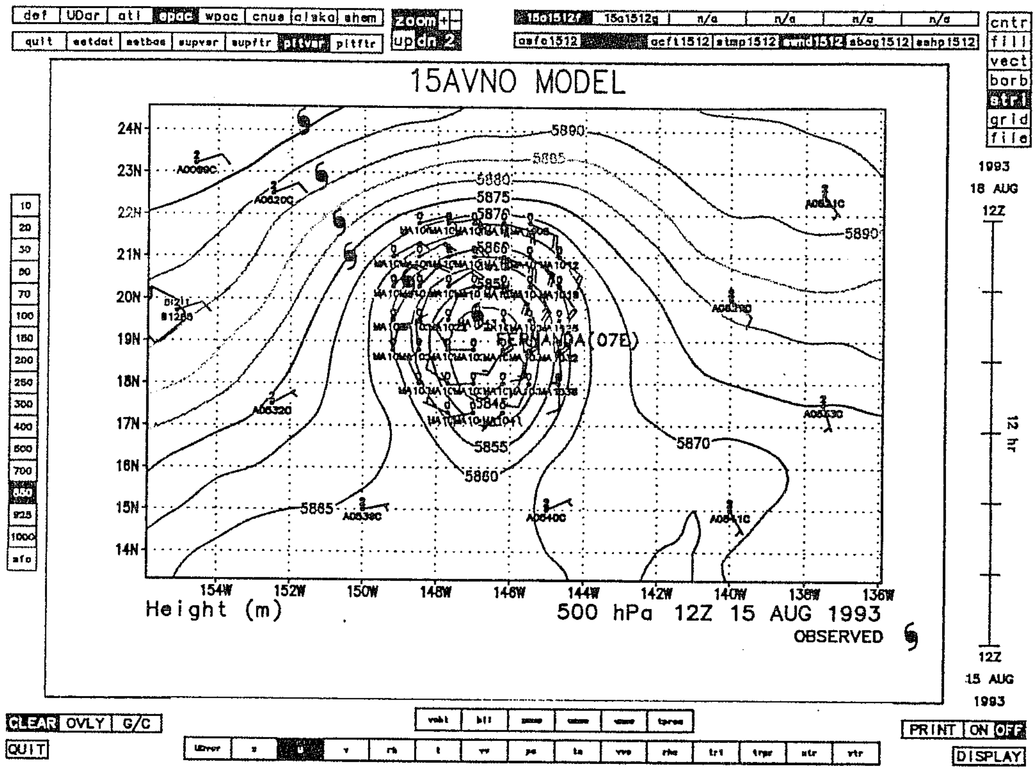


Fig. 1c Same as Fig 1. but just the observed hurricane track and 850 mb height with hurricane is shown with Bogus data and Satellite wind observations included.

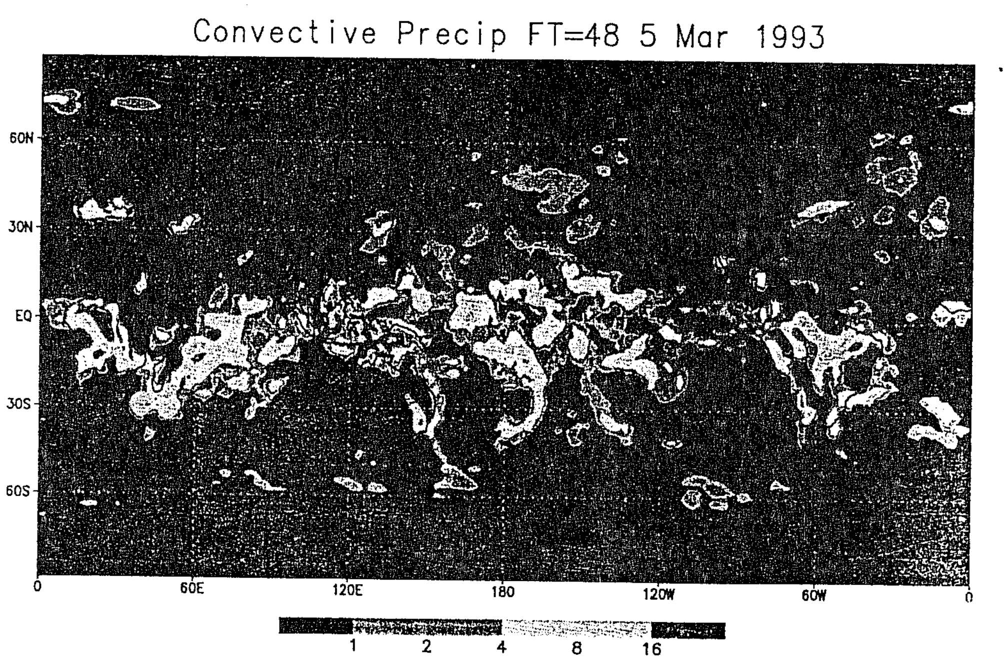


Fig. 2a The 48 hour forecast convective precipitation accumulated over the previous 12 hours in mm.

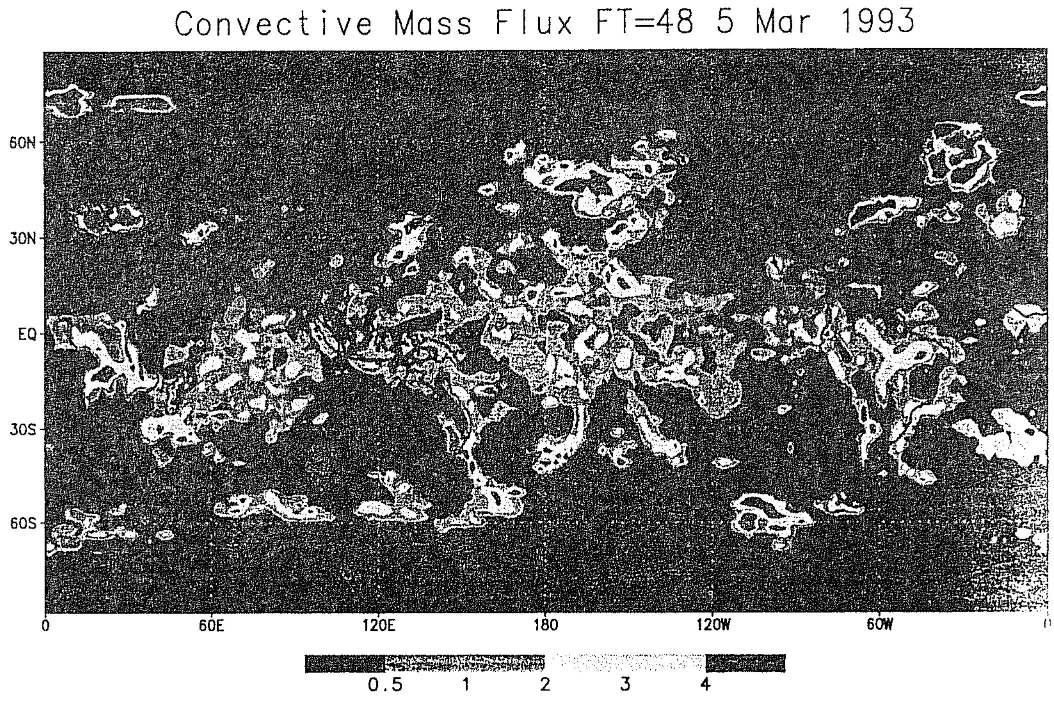


Fig. 2b The 48 hour forecast convective mass flux from the model convection scheme corresponding to Fig 2a [10^{-3} mb/sec].

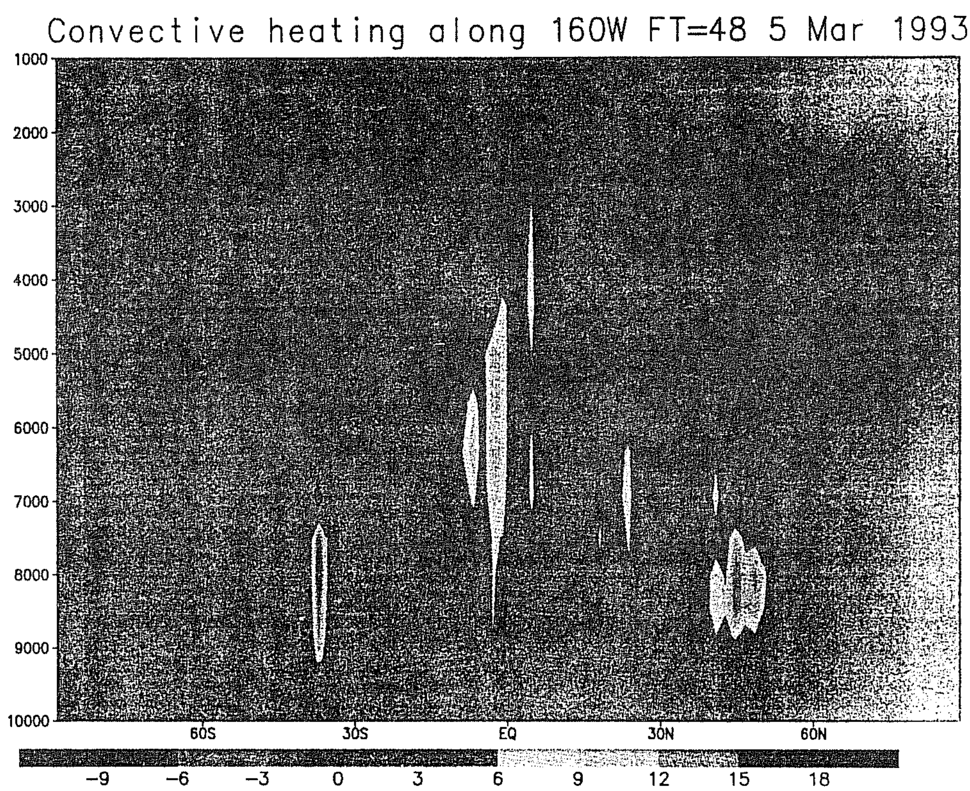


Fig. 2c The convective heating cross section corresponding to Fig 2a on a line through 160W longitude passing through the Aleutian precipitation area.

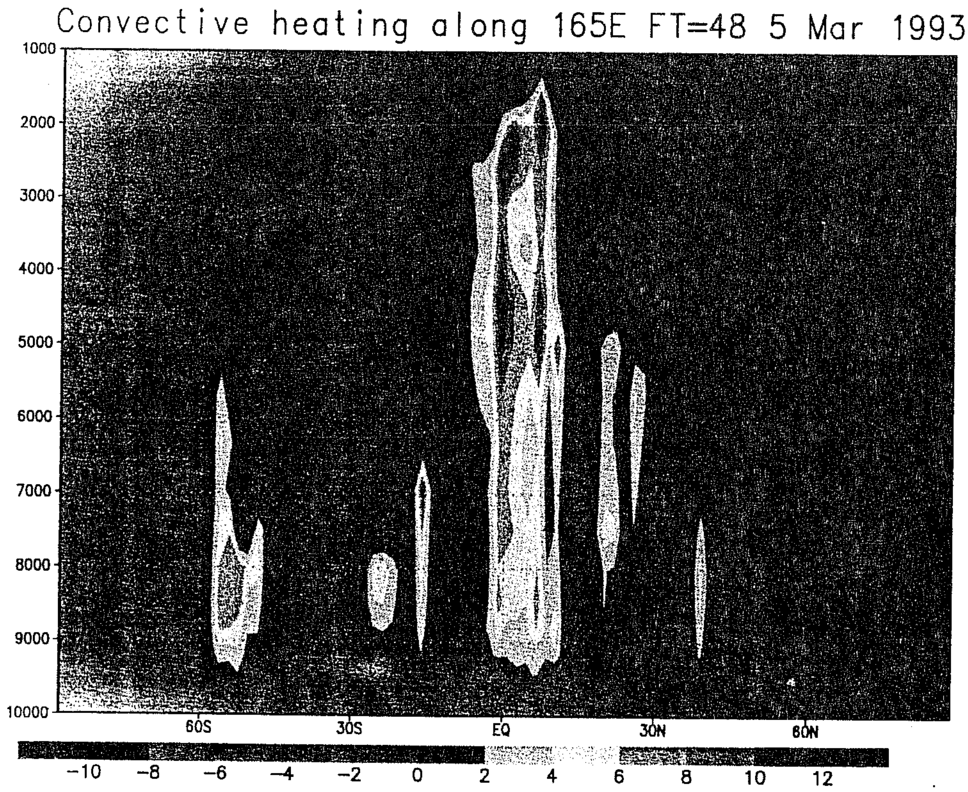


Fig. 2d The convective heating cross section corresponding to Fig 2a,b on a line passing through 165E longitude passing through the equatorial area.

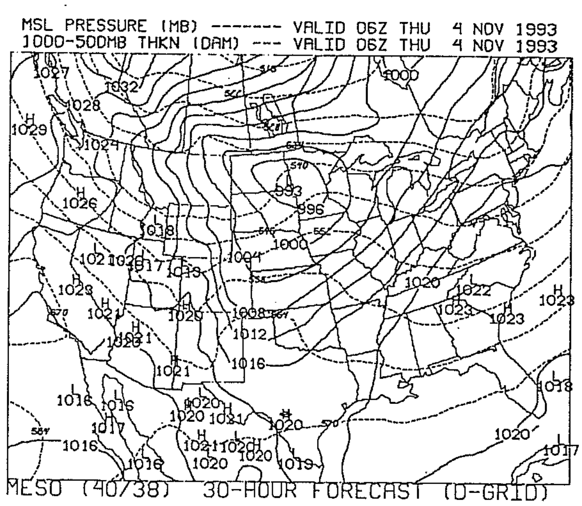


Fig. 3a Mean sea level (MSL) pressure and 1000–500 mb thickness for a 30 hour forecast from the NMC regional mesoscale model valid at 4NOV93 06Z.

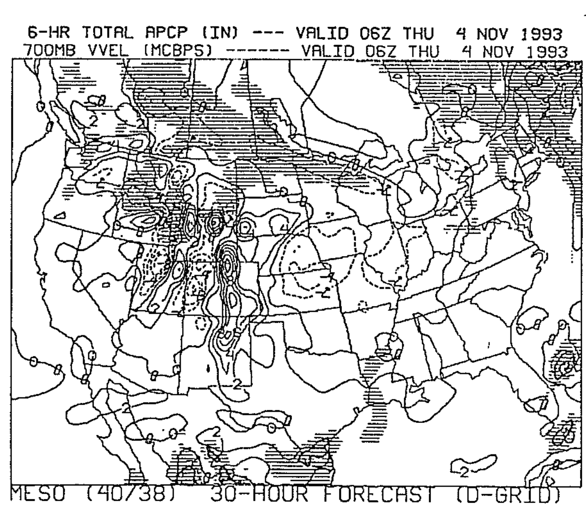


Fig. 3b 6 hour accumulated convective precipitation and the 700mb vertical velocity also valid 4NOV93 06Z.

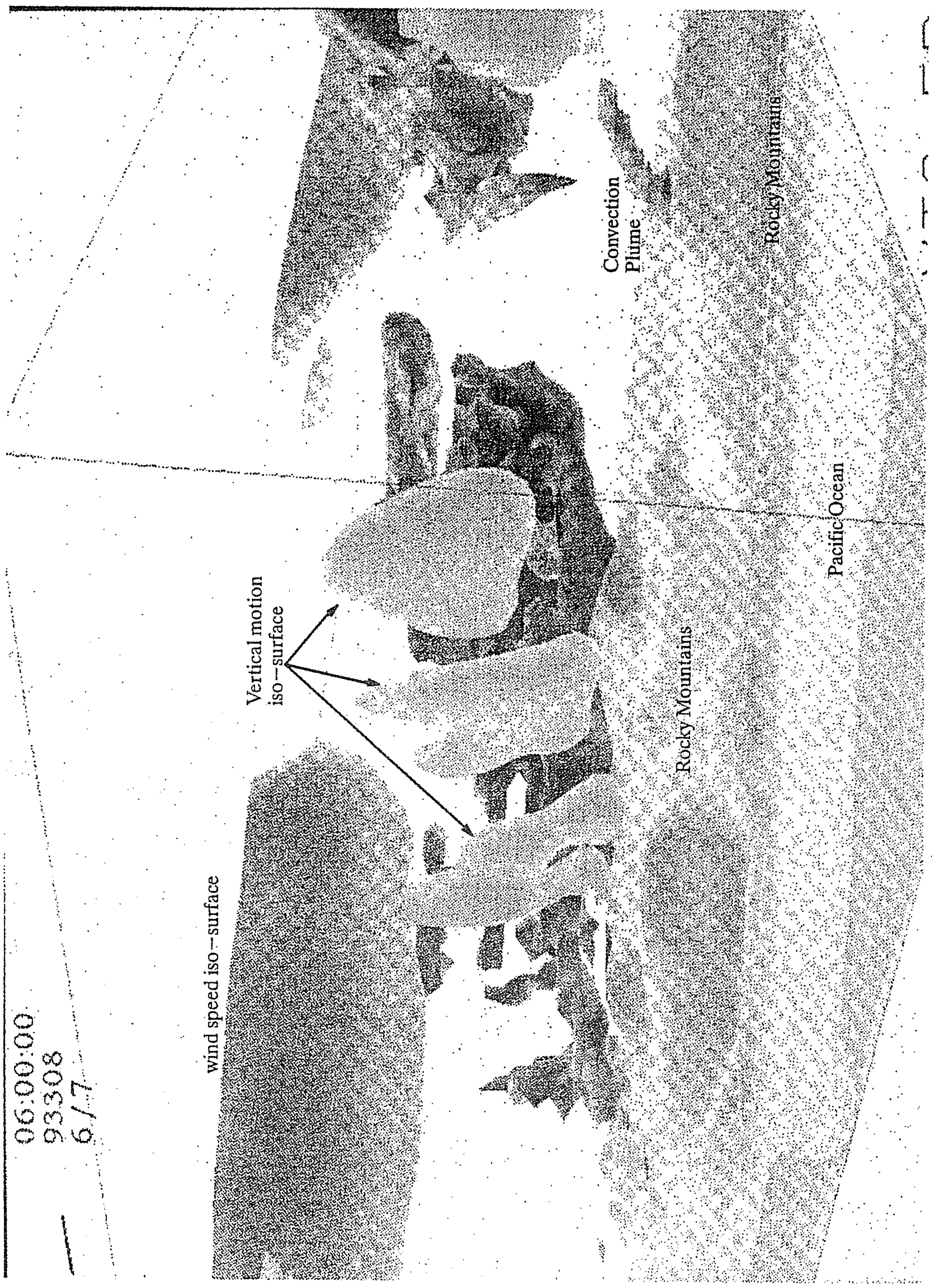


Fig. 4a shows a 3–dimensional forecast view from the Pacific ocean looking east over the Rocky mountains for the same time as shown in Fig 3.

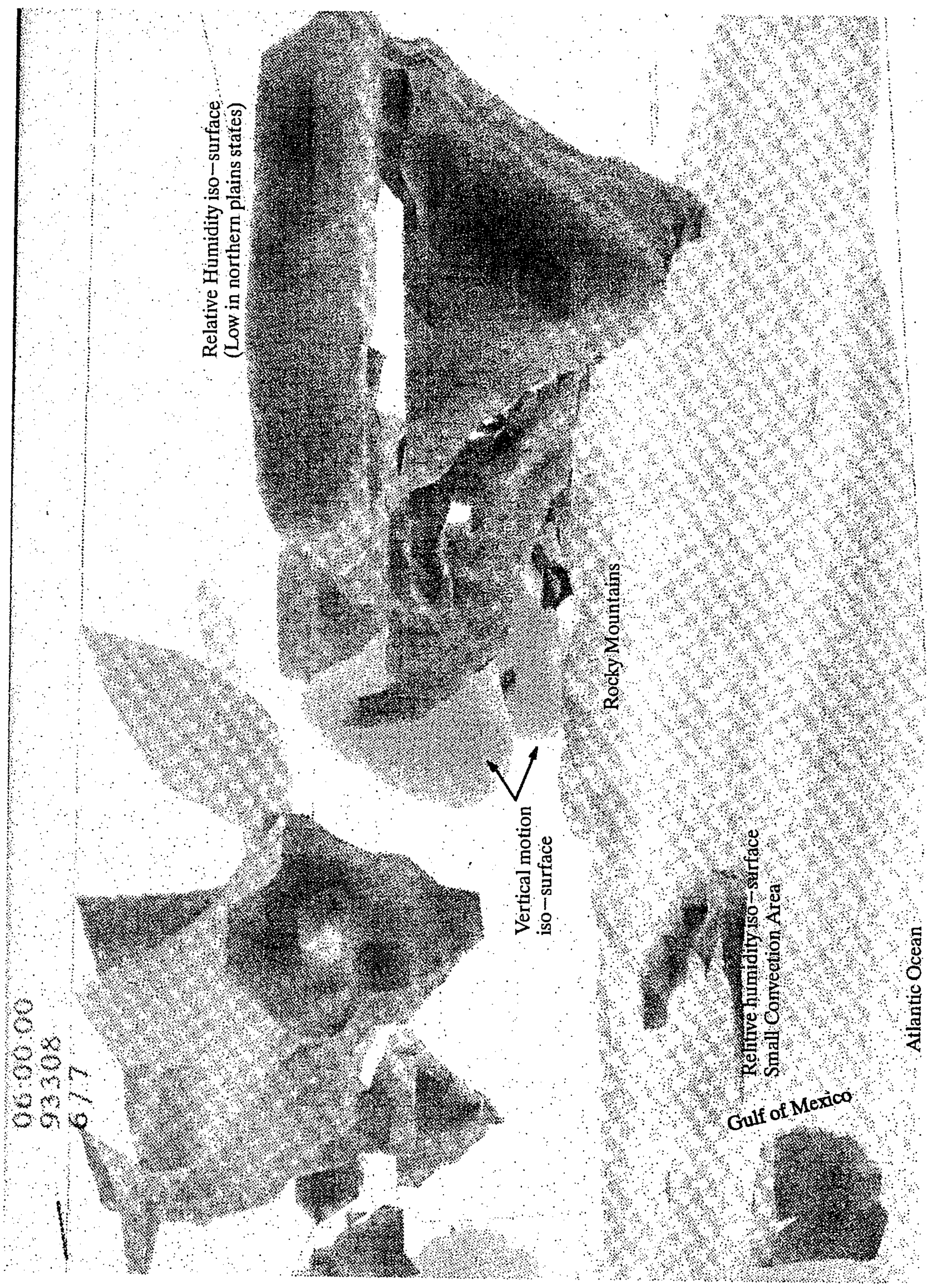


Fig. 4b shows a 3−dimensional forecast view at the same time as Fig. 4a but from an eye point above the Atlantic ocean east of Florida.

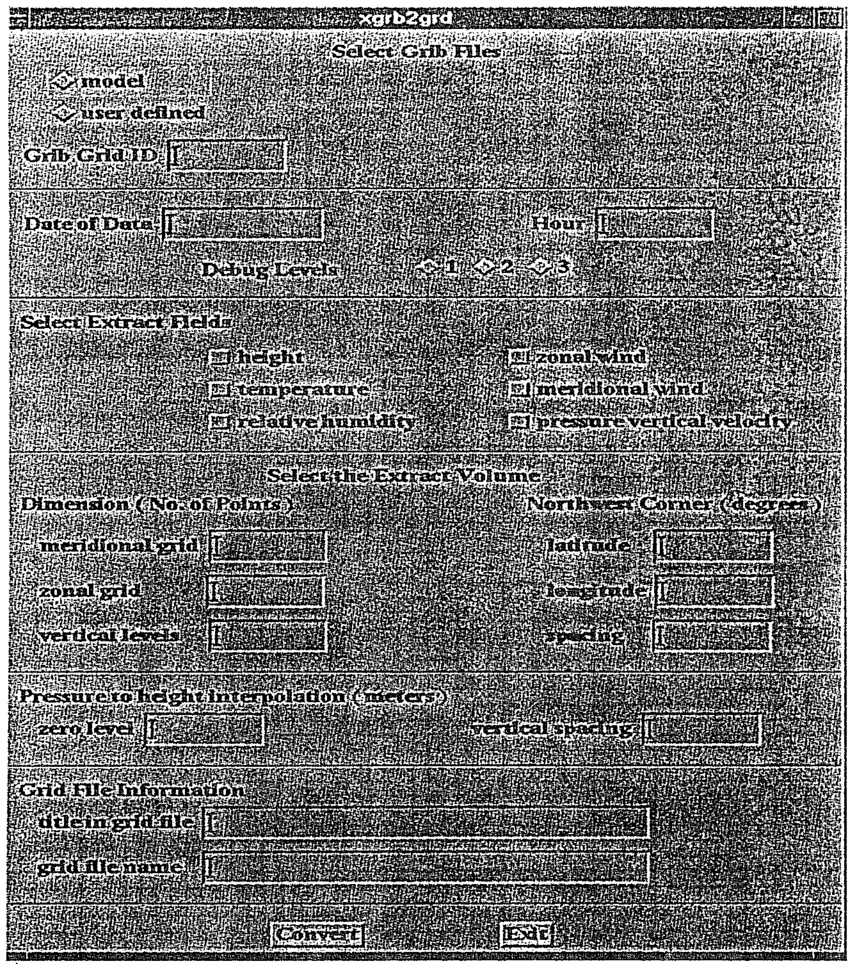
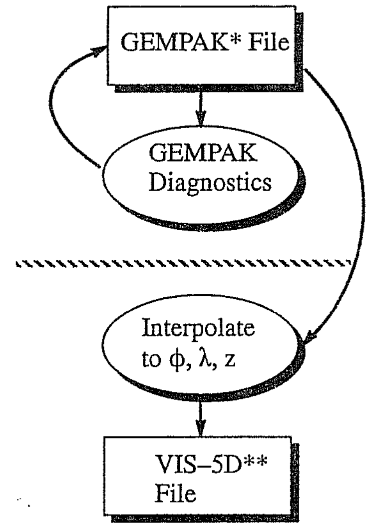


Fig. 5 is an example of a point and click user interface to select the files and parameters needed to create VIS5D files model output.



*GEMPAK is a general meteorological data display and software package developed at NASA/GSFC, Greenbelt, Maryland.

**VIS–5D is a visualization package developed by W. Hibbard, D. Santek and B. Paul at the Space Science and Engineering Center, University of Wisconsin–Madison.

Fig. 6 is a diagram representing the users interaction with the GEMPAK[4] display system to derive variables not in the model run data and produce VIS5D files.

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[4]GEMPAK, NASA/GSFC, Greenbelt, Maryland
[5]NTRANS, Transition Project, National Meteorological Center