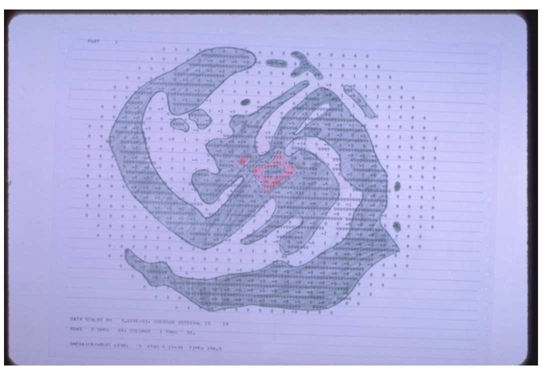
History of the Mesomonster

Penn-State-NCAR Mesoscale Model MM0-MM5

Rick Anthes

Tom Warner Symposium

2 December 2011



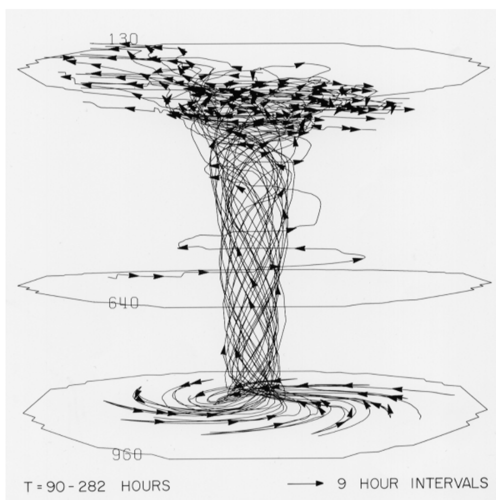


Figure 1: Particle trajectories calculated from a numerical model of an asymmetric hurricane. Labels of 3 levels in mb.

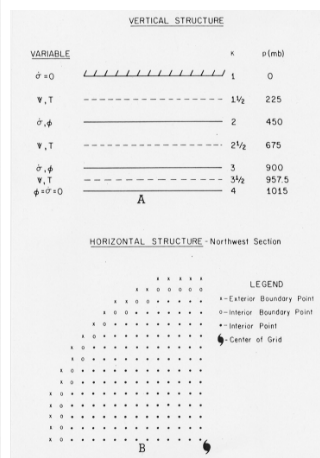
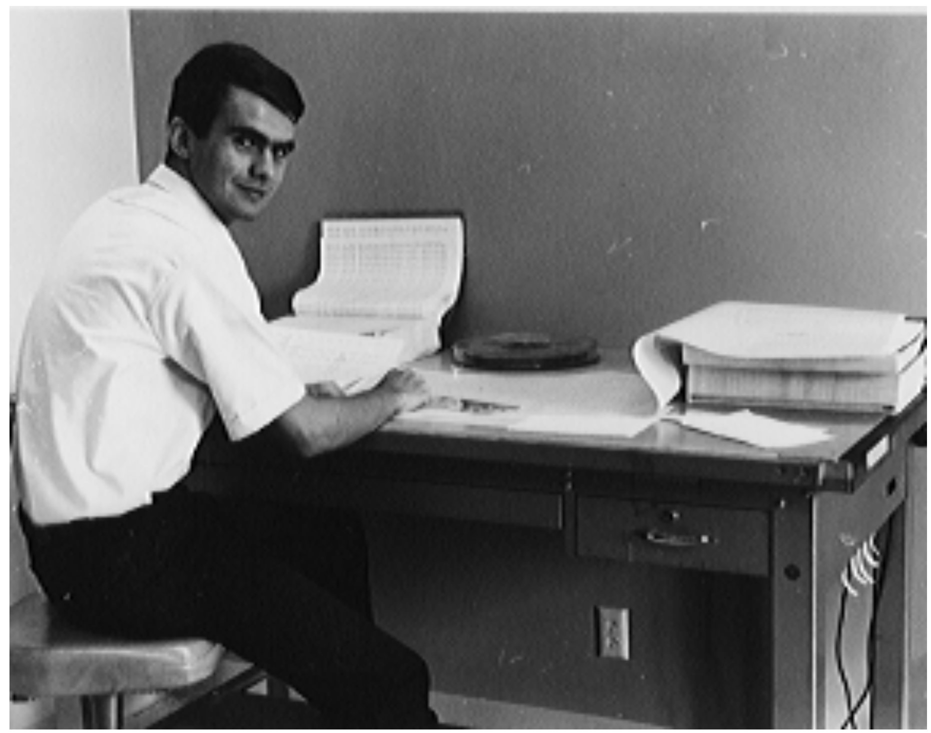


FIGURE 1.—(A) vertical information levels and (B) northwest quadrant of the horizontal grid.

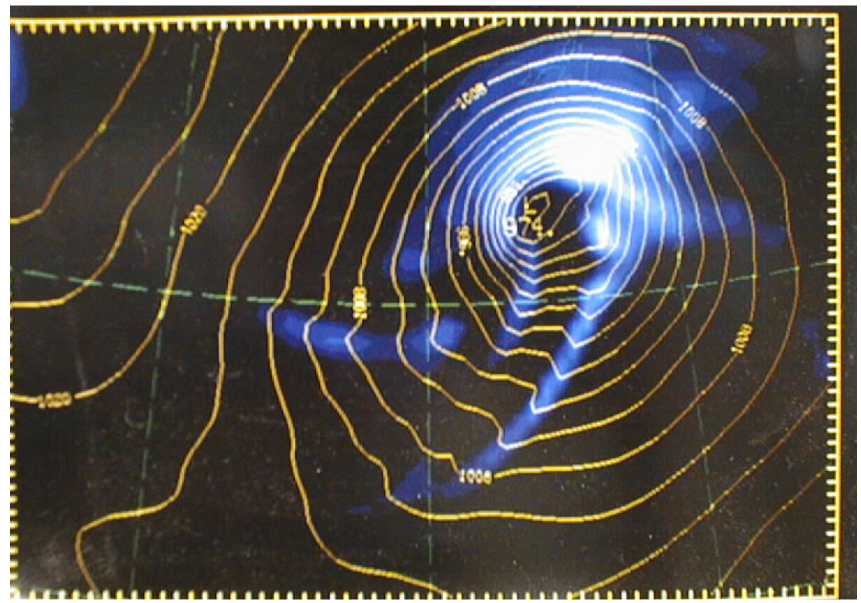
Mesomonster to MM5
25 years of Community Modeling

MM5 is the fifth generation version of the Penn State-NCAR mesoscale model. It is probably the most widely used mesoscale model in the world. It began with the development of a 3-D hurricane model by R. Anthes in the late 1960s at NOAA's National Hurricane Research Laboratory in Miami, Florida.

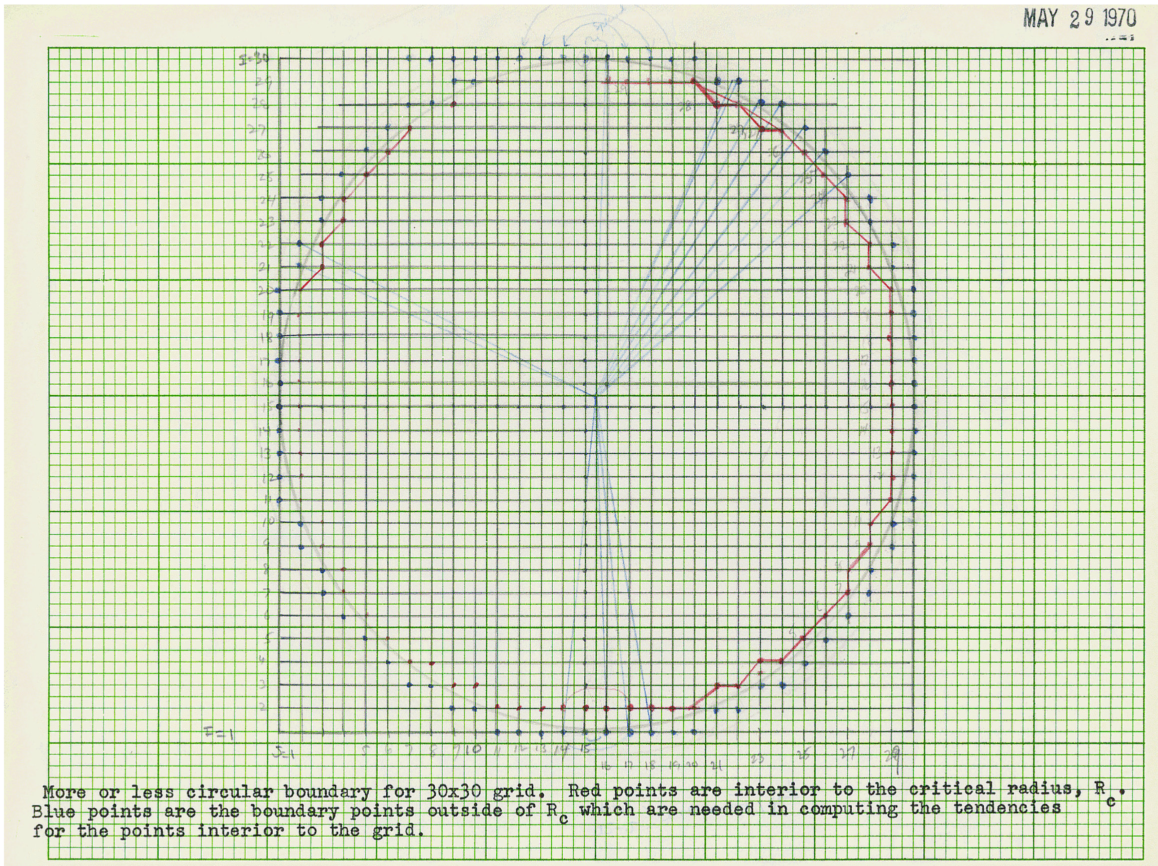


History of MM5

- Beginning in 1972, the hurricane model evolved into general mesoscale model capable of simulating many atmospheric phenomena, real-time forecasting, and climate studies.
- Tom Warner, many scientists and students at Penn State, NCAR and other universities contributed.



1969--Early Grid structures



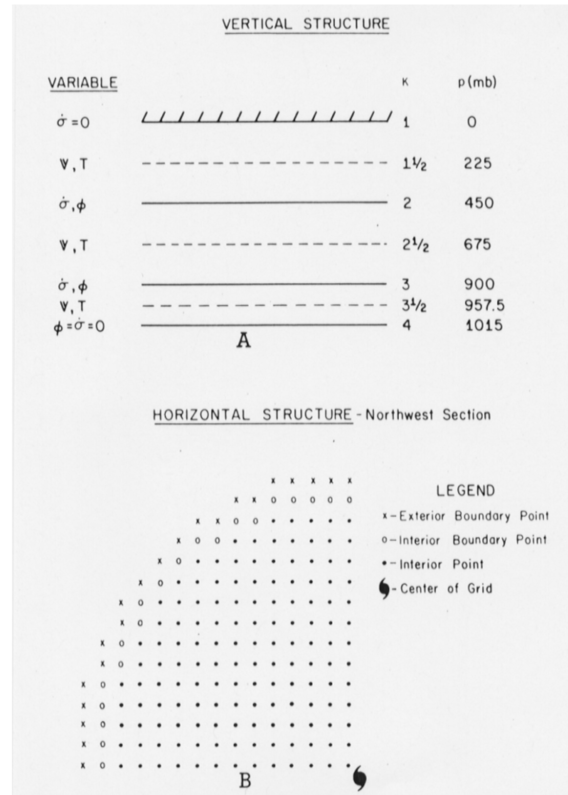


FIGURE 1.—(A) vertical information levels and (B) northwest quadrant of the horizontal grid.

1970--NHRL Miami

- Many 2-D and 3-D experiments
- Variation of horizontal diffusion, lateral boundary conditions (LBC), PBL, H.-L. Kuo cumulus parameterization
- Staggered grids (“Anthes” and “Lilly”)
- Eliminate corners of square grid
- Many “blow ups”
- Oct. 12-First stable and realistic hurricane simulation

Subtle Instabilities

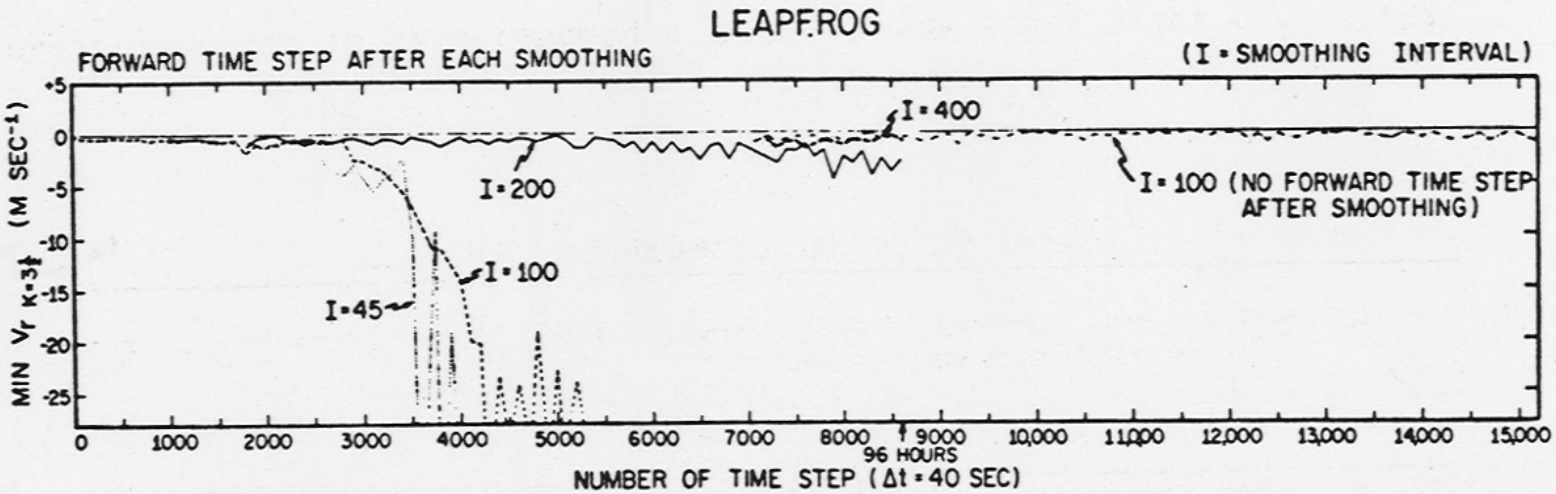
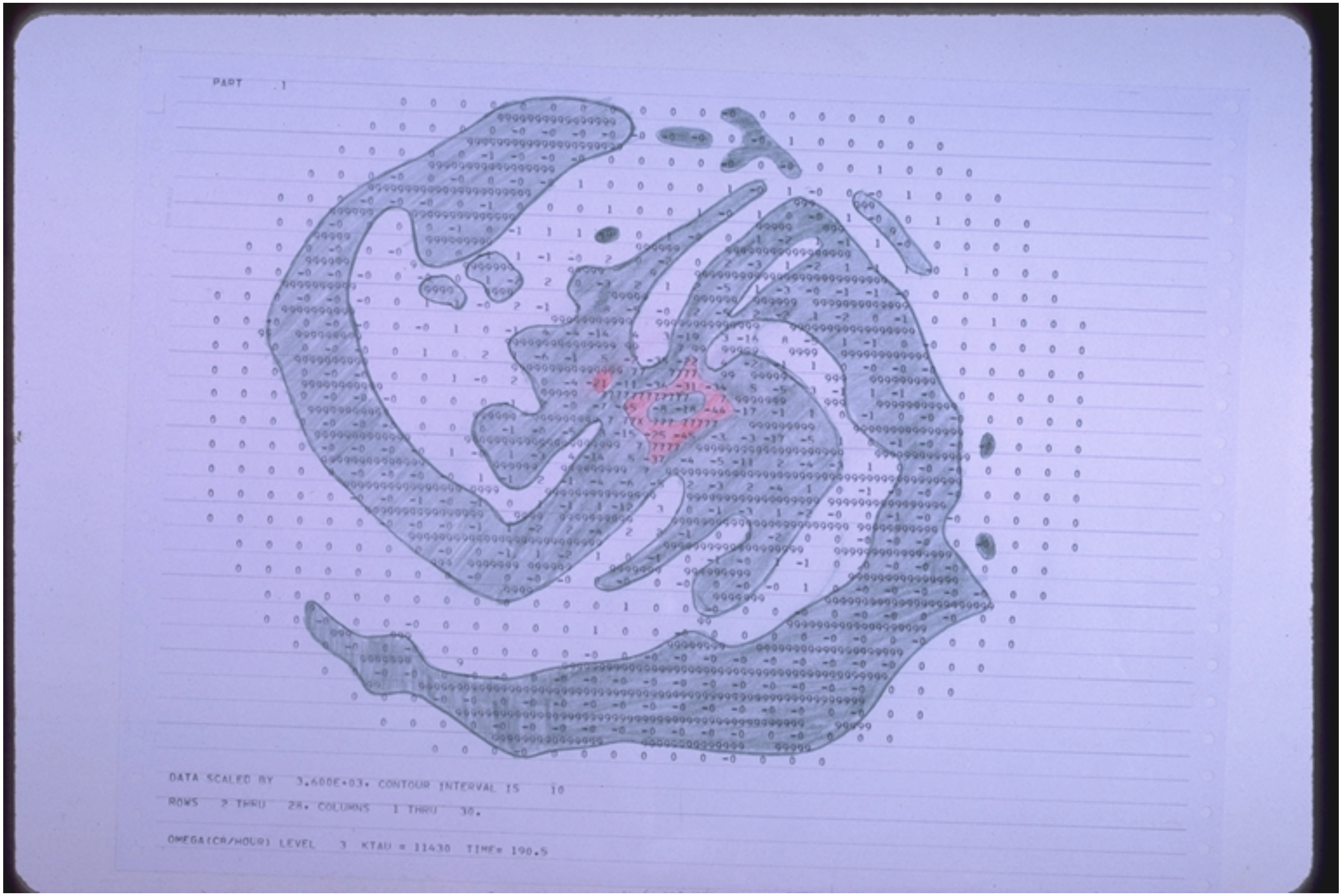
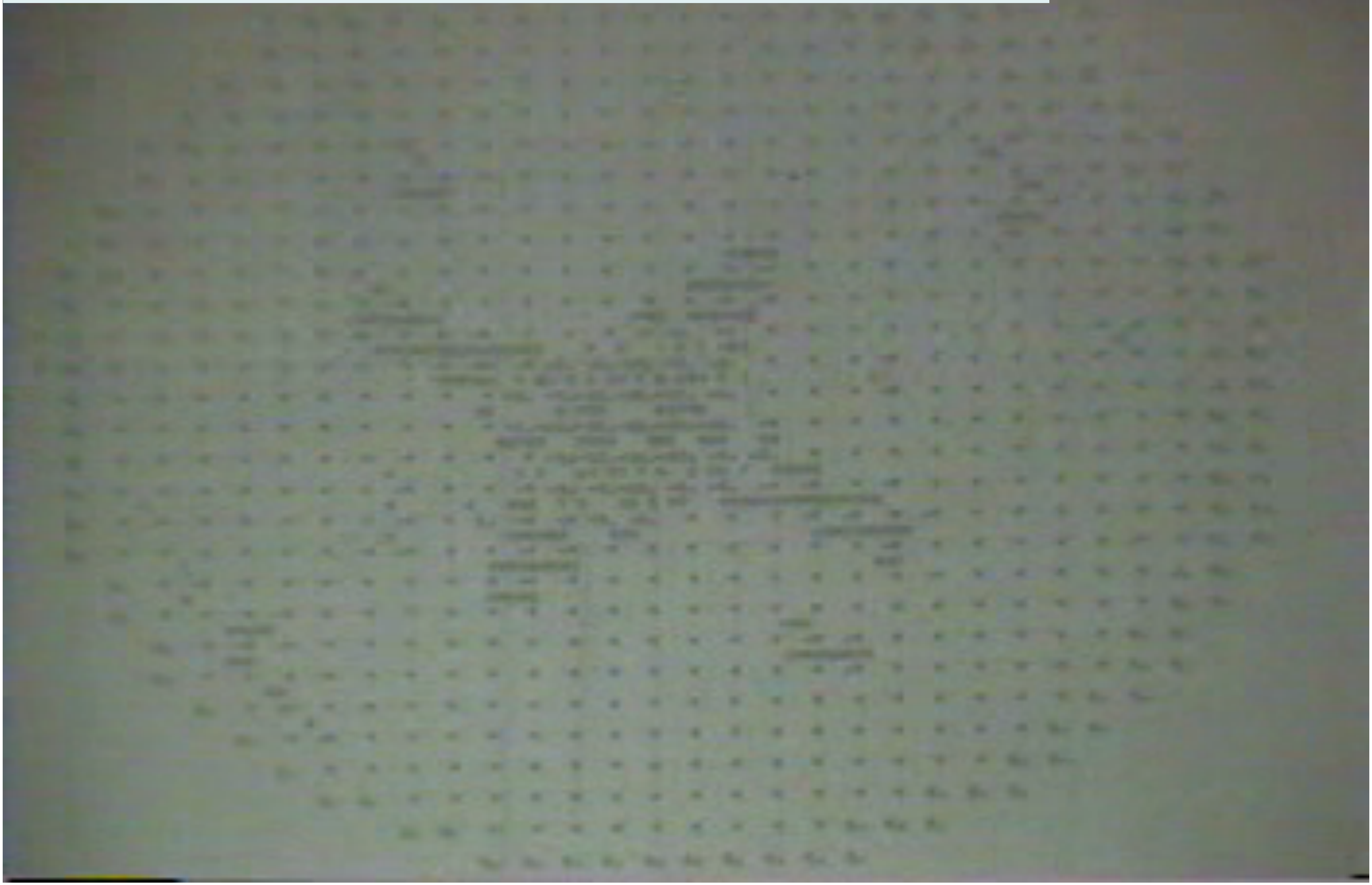


Figure 4. Time variation of maximum boundary layer inflow in experiments utilizing leapfrog time integration and initialized with random perturbations. Experiments which utilize the forward time step after each smoothing procedure become unstable. Resuming the calculation (after smoothing) with the leapfrog scheme is quite stable.

Spiral Rainbands



1970 Animation of hurricane rainbands-click on figure to start animation



3-D Trajectories

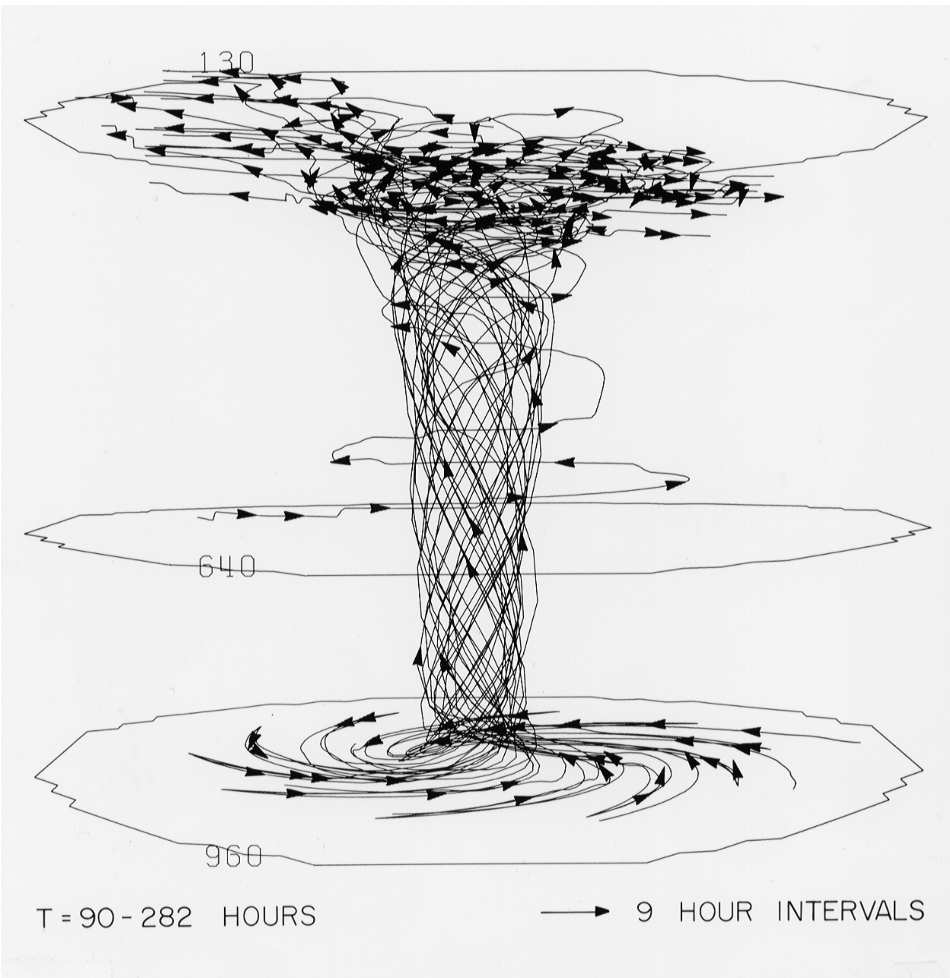
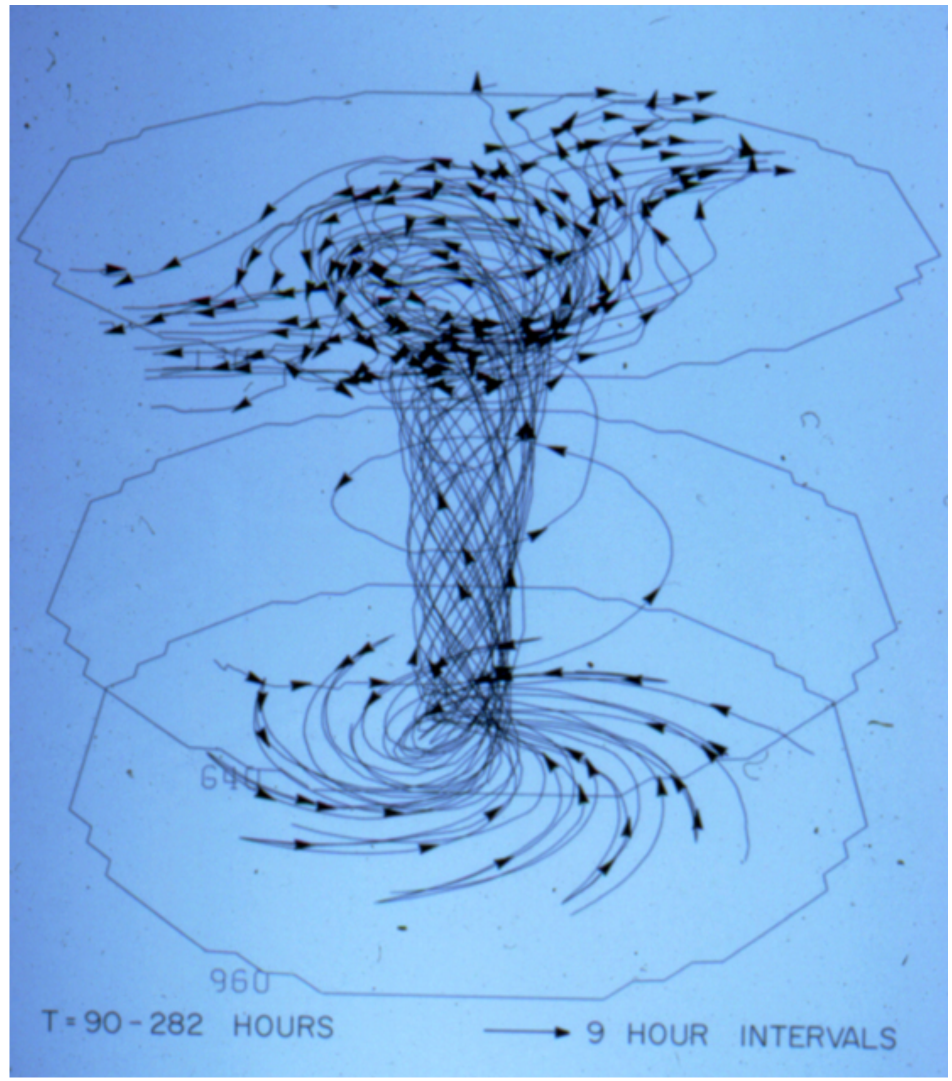


Figure 1: Particle trajectories calculated from a numerical model of an asymmetric hurricane. Labels of 3 levels in mb.



1971--NHRL Miami--Penn State

- April-May--Excellent simulation of hurricane with spiral rainbands
- Used staggered grid (Arakawa “B” grid; movie of propagating spiral bands made from this run
- Rick moved to Penn State in August

1972 PSU The conversion begins (Tom did programming)

- Begin conversion to MM (MesoMonster)
- Variable # layers
- Variable f
- Many 2-D analog experiments, emphasis on LBC, diffusion, stability, time differencing
- First EPA Project

Nov. 5, 1974

EPA presentation

MODELLING ACTIVITIES AT PENN STATE

1. General hydrodynamic model with variable horizontal and vertical resolutions and number of grid points.

   3-D model

   2-D cross section model

2. Modelling on nested grids.

3. Semi-implicit modelling

4. 3-D modelling of nocturnal jet

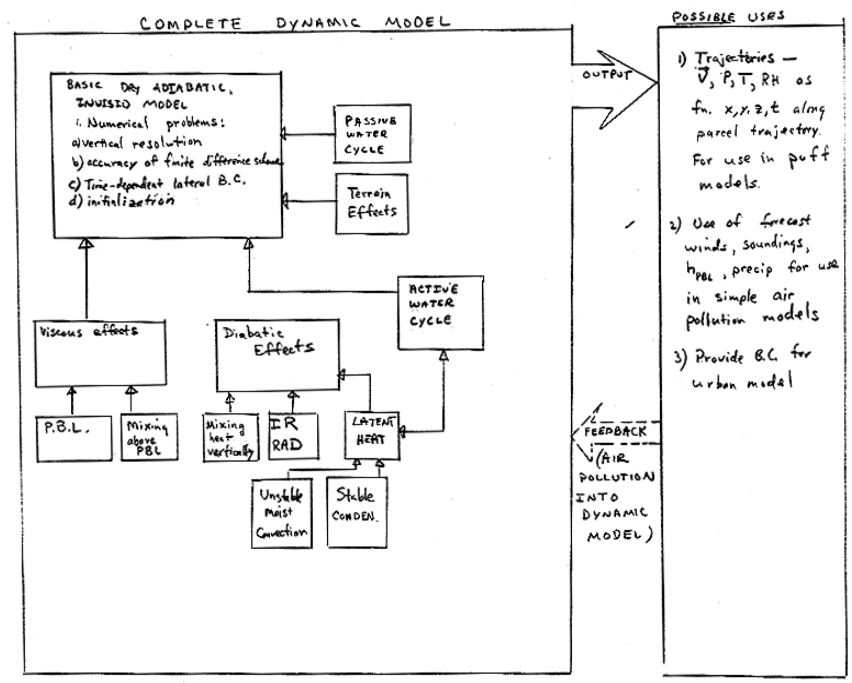
5. Theoretical studies of predictability and required data accuracy on mesoscale through stochastic-dynamic modelling.

6. Dynamic initialization of mesoscale models. (U.S.D.C.)

7. Accurate modeling of PBL using variable K-theory (U.S.D.C)

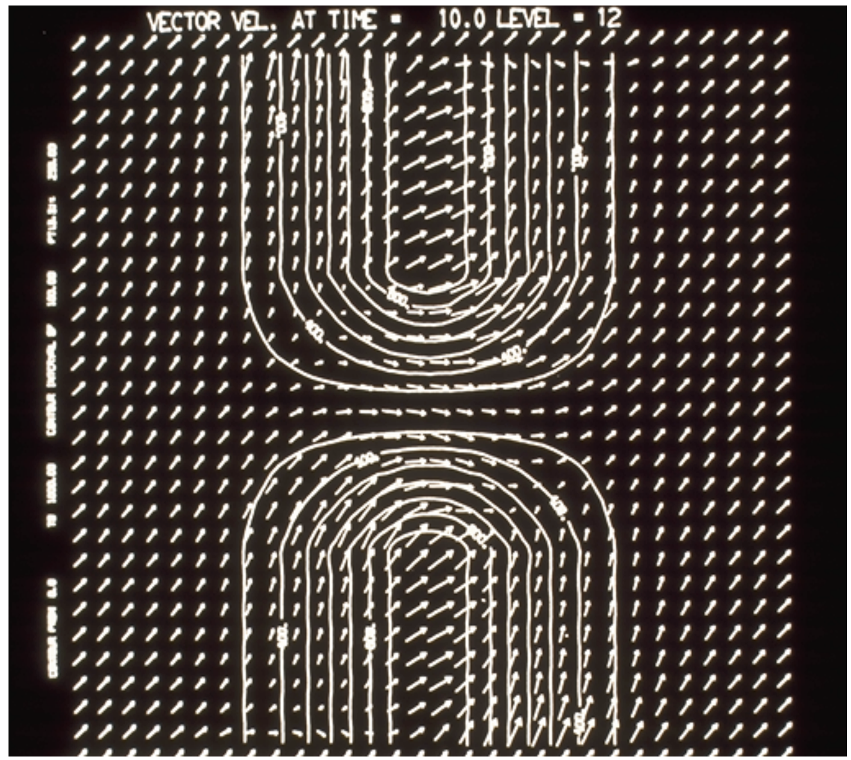
1973 PSU Many computational exps

- New omega calc
- Countergradient heat flux
- “theta sphere”
- Nonzero Pt
- Diff T on p-sfc
- July-White Sands with Tom Warner
- Running on CDC 6600 at NCAR
- 2-D Appalachian flow



July 1973 White Sands

- Tom Warner and Bill Ohmsted
- Beginnings of connections with DoD
- Terrain effects empasized
- Early sfc heat flux
- T. Warner still active connections with Army in 2010



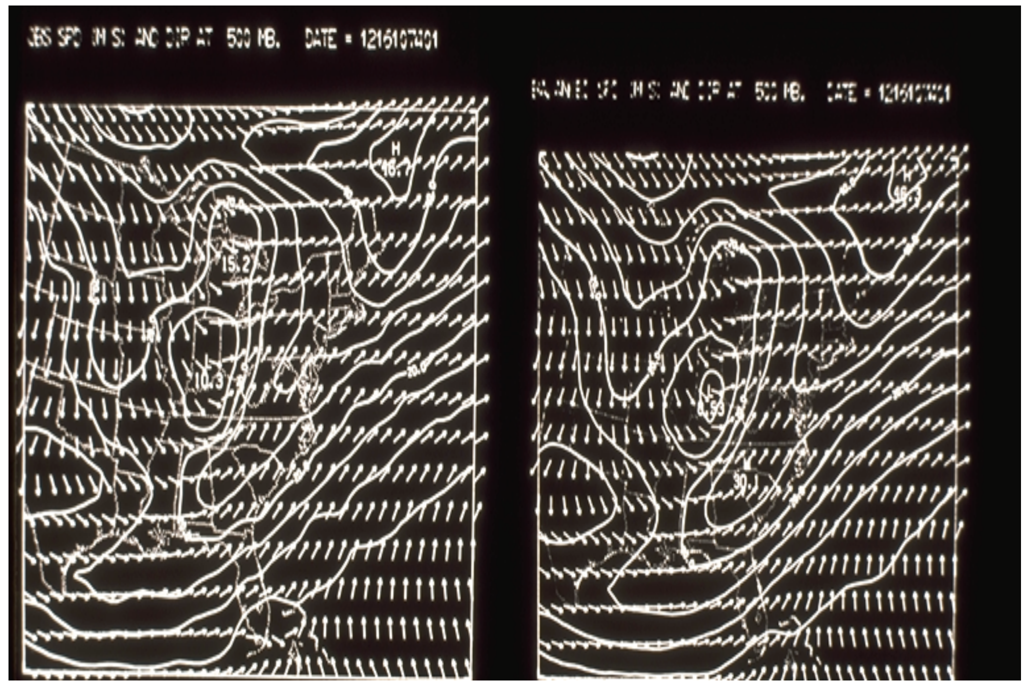
War Story #3--Trips to NCAR

"In the really early days we could not connect remotely to NCAR SCD from PSU and had to cram our model running into visits to NCAR. Because the model runs were computationally demanding, we could only get quick turn-around at night, and thus had to sleep during the days and work the night shift when there was time on the machines. During the day we would tie blankets up over the windows at the Sleazy J Motel on 28th so that we could (try to) sleep."

Tom Warner, 14 June 1999

1974 PSU First Real Data Simulations

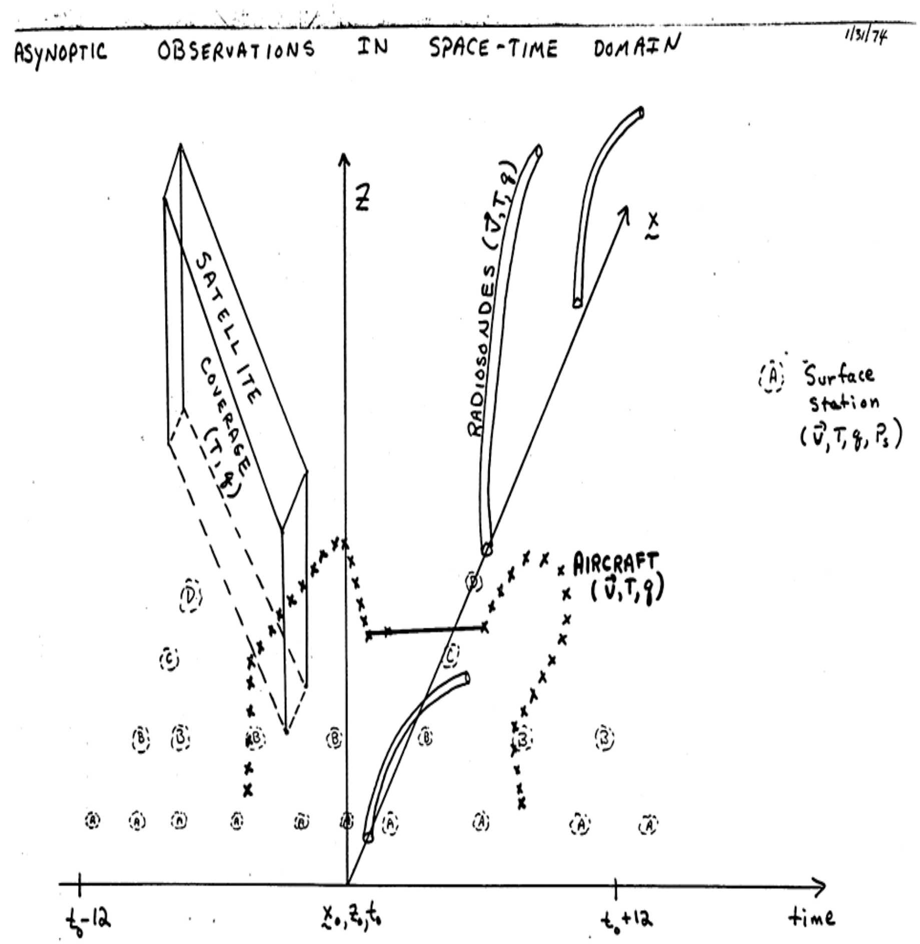
- Balance equation IC
- Time dependent LBC
- May--trip to NCAR for hurricane model exps
- Microfilm output and hand analysis
- Oct 28--1st reference to "MM" in my notes



IC 12 GMT 16 Oct 1974
12-hour forecast

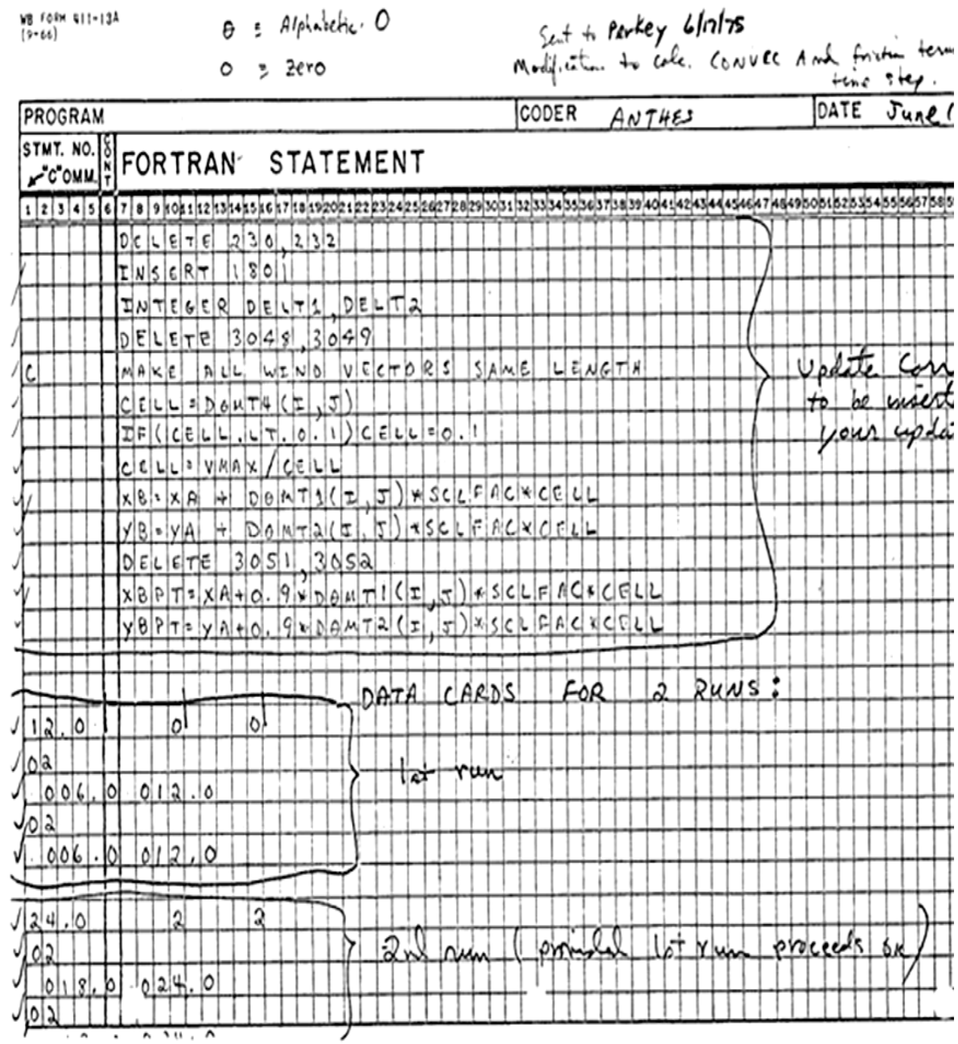
1974 Thinking about data assimilation

- Satellite (T,q)
- Rawinsondes (V,T,q)
- Aircraft (V,T,q)
- Surface (V,T,q,Ps)
- All at different times



1975 PSU Analysis and initialization

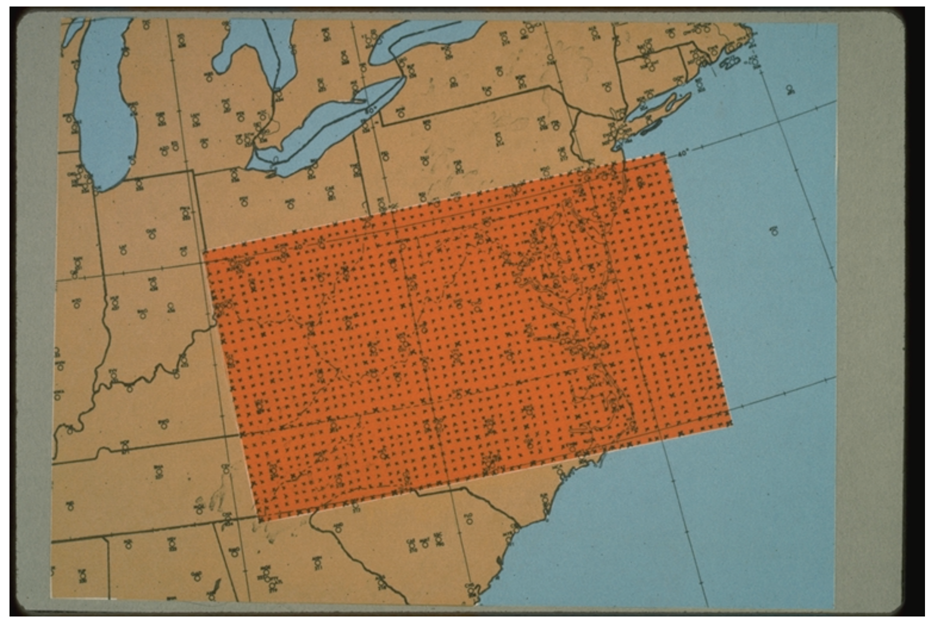
- Analysis scheme on Lambert conformal grid
- "SUPMAP" DD80
- Internal paper "Initialization schemes for Mesoscale models"
- O'lenic's 2-D jet
- Hoke D.I. Exps with 2-D jet
- Niels Busch PBL tests
- Thinking about verification



Ed O’Lenic, Pete Black, Tom Warner 1975

1976 Exps on 30x50 grid

- Many preliminary tests of model on 30x50x12 grid over east coast of US
- Examine horiz diffusion over high terrain in producing heavy rain there in Gary Fried's case
- End of notebook "Mesomonster"



War Story #5 “NCAR EAST”

“We eventually became the first university to be able to connect remotely to SCD, which eliminated the crazy trips. However, we had to use a system at the Land and Water Resources Building in the middle of the university pig farms. The public telephone lines were unreliable and noisy, so we often had to reread the 3 foot deck into the card reader. It often seemed like, when the line was reliable, the card reader would jam. And early on the full model had to be read in each time rather than an update deck, so the decks were really big. For reliability we then went to “leasing” our own telephone line which was “conditioned” and more reliable. I imagined a dedicated wire with a PSU label on it.”

Tom Warner, 14 June 1999

War Story #6

Dealing with 0.3 MB of memory

"There's a statement in my thesis that says the memory limit on Penn State's IBM 36 was a greater problem than its speed (280,000 bytes!), and the 3-D MM1 experiments circa 1975 typically had only 20x25x10 points. Of course, that meant that we all coded the model with overlays and other tricks to make the most of the available memory. When it worked it was elegant, but it was difficult code to understand and debug."

Nelson Seaman, 1 June 1999

Computers and MM in 1976

CDC 7600 5X faster than 6600

IBM 370/195 same as 7600

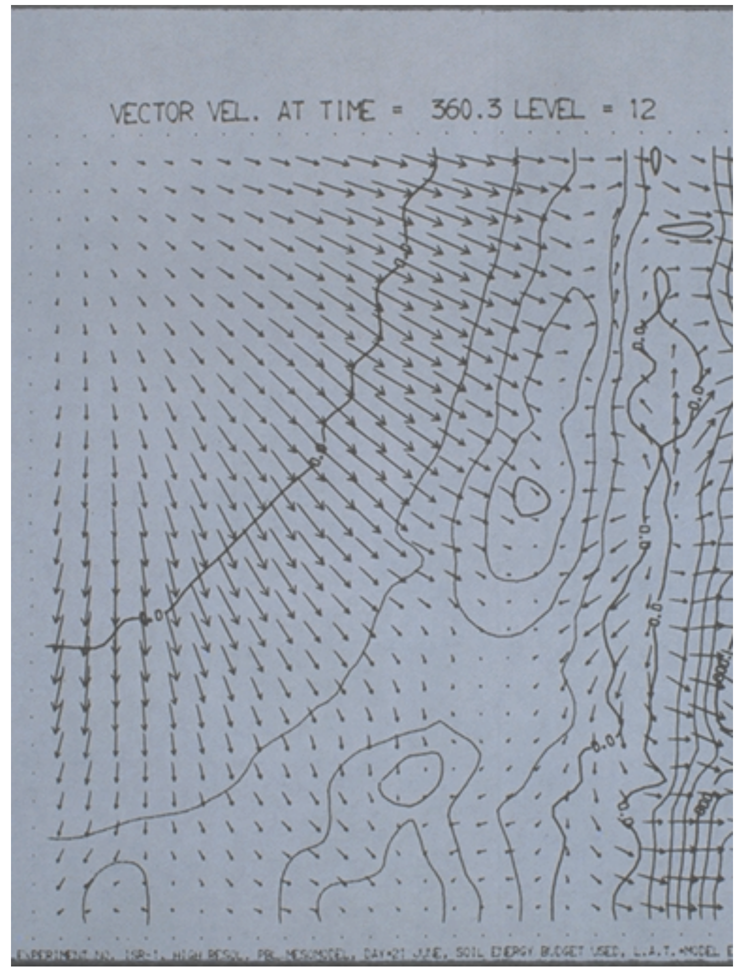
3-D dry MM

6x40x40 DT=30s DX=20km

Storage 140K 12-h run took 30 min on 7600

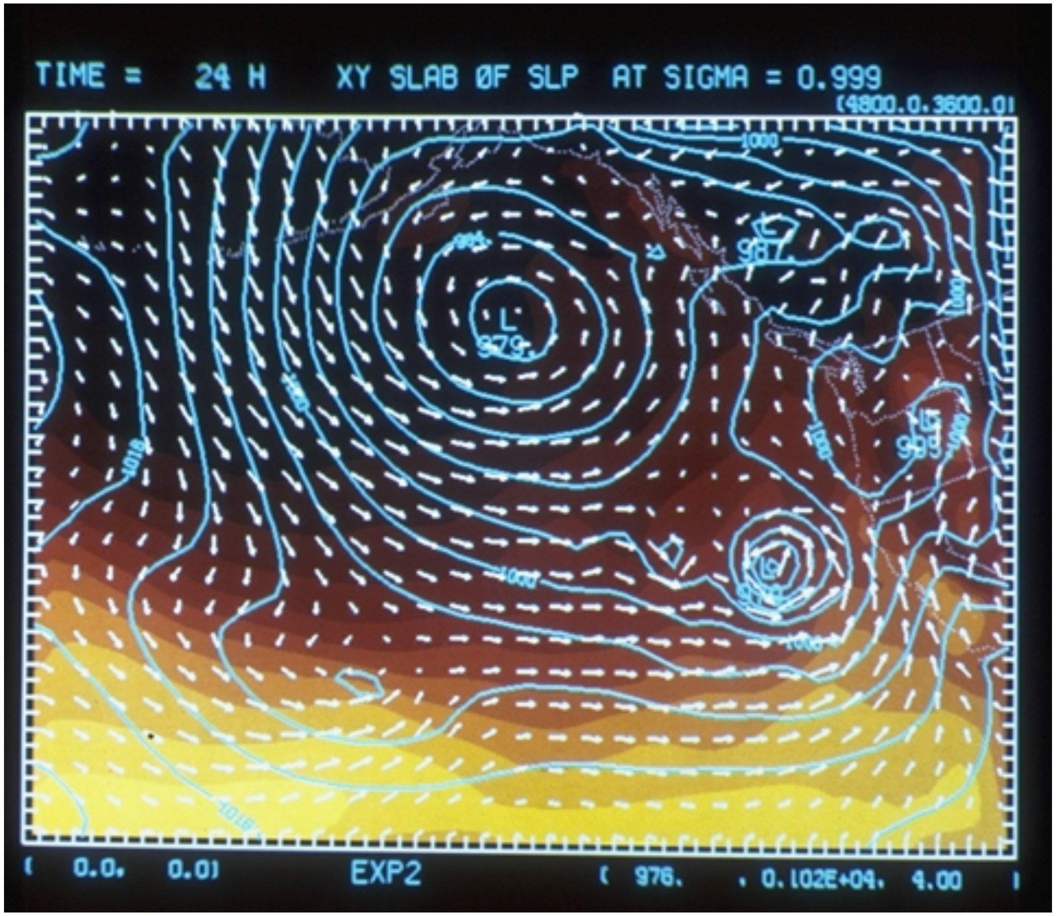
1977 Israel Simulations

- Code and run moist sea breeze
- Circulation theorem in sigma coordinates
- Exps with complex terrain over Israel
- Still experimenting with LBC



1978 PSU

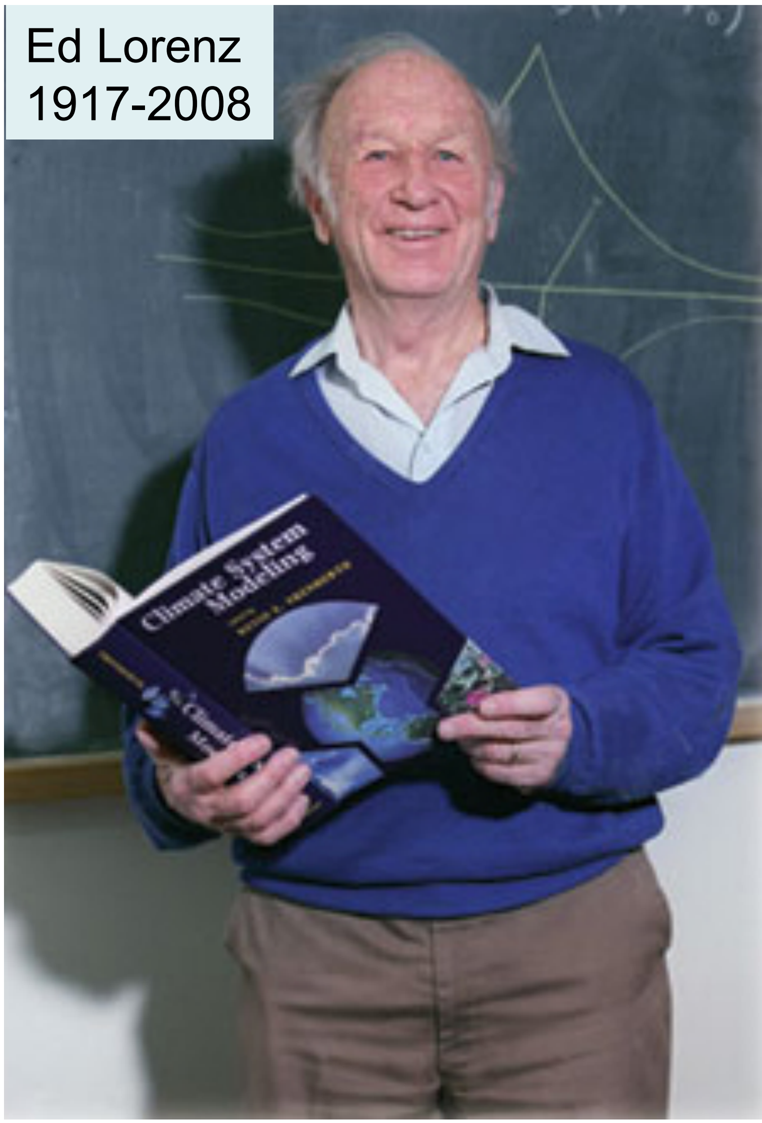
- Matrix method for scoring precipitation
- Convective adj of arbitrary #layers simultaneously

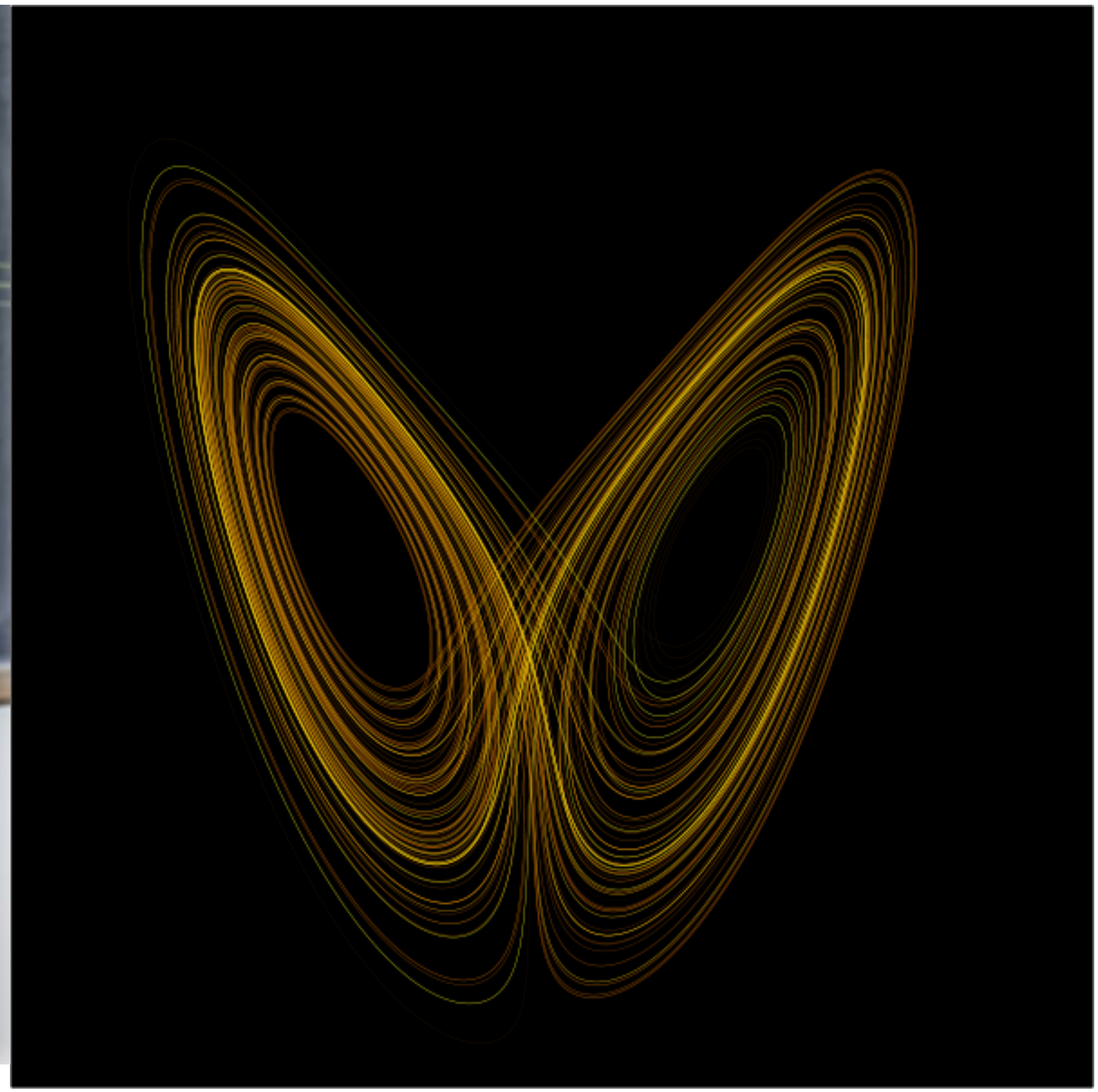


1978 Publications

- Anthes and Warner “Simulation of flow over Israel” Israel Meter. Res. Papers
- Anthes and Warner “Development of hydrodynamic models suitable for air pollution and other mesometeorological studies” MWR
- Anthes “The height of the PBL and production of circulation in a sea breeze model” JAS
- Warner, Anthes and McNab “Num sim with a 3-D mesoscale model” MWR

Does the flap of a butterfly's wing in Brazil set off a tornado in Texas?





But scale interactions go both ways!

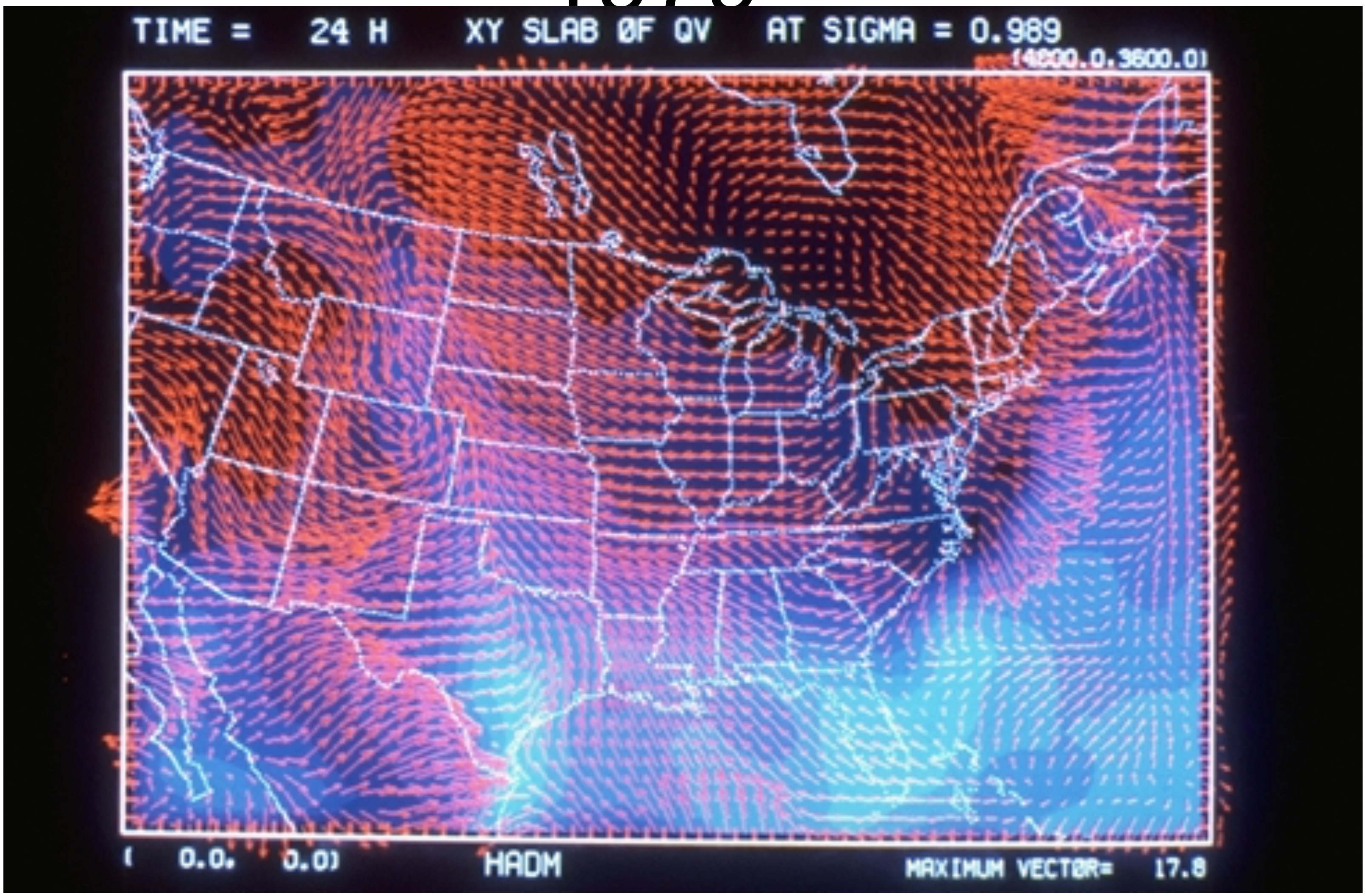
"It is doubtful whether a sufficient number of simultaneous initial observations will ever be available … for these scales, although some mesoscale variability may be revealed by satellites. However, nonlinear processes are capable of producing smaller scale information in the forecast than is present in the initial conditions, as long waves interact to produce energy in shorter waves. Furthermore, a realistic treatment of local forcing in the models will allow mesoscale perturbations to develop from initial conditions that are representative of larger scales. Thus we hypothesize that in many synoptic situations, if the local forcing is modeled correctly, the details of the initial perturbations are not particularly important."

Anthes and Warner
Monthly Weather Review, August 1978

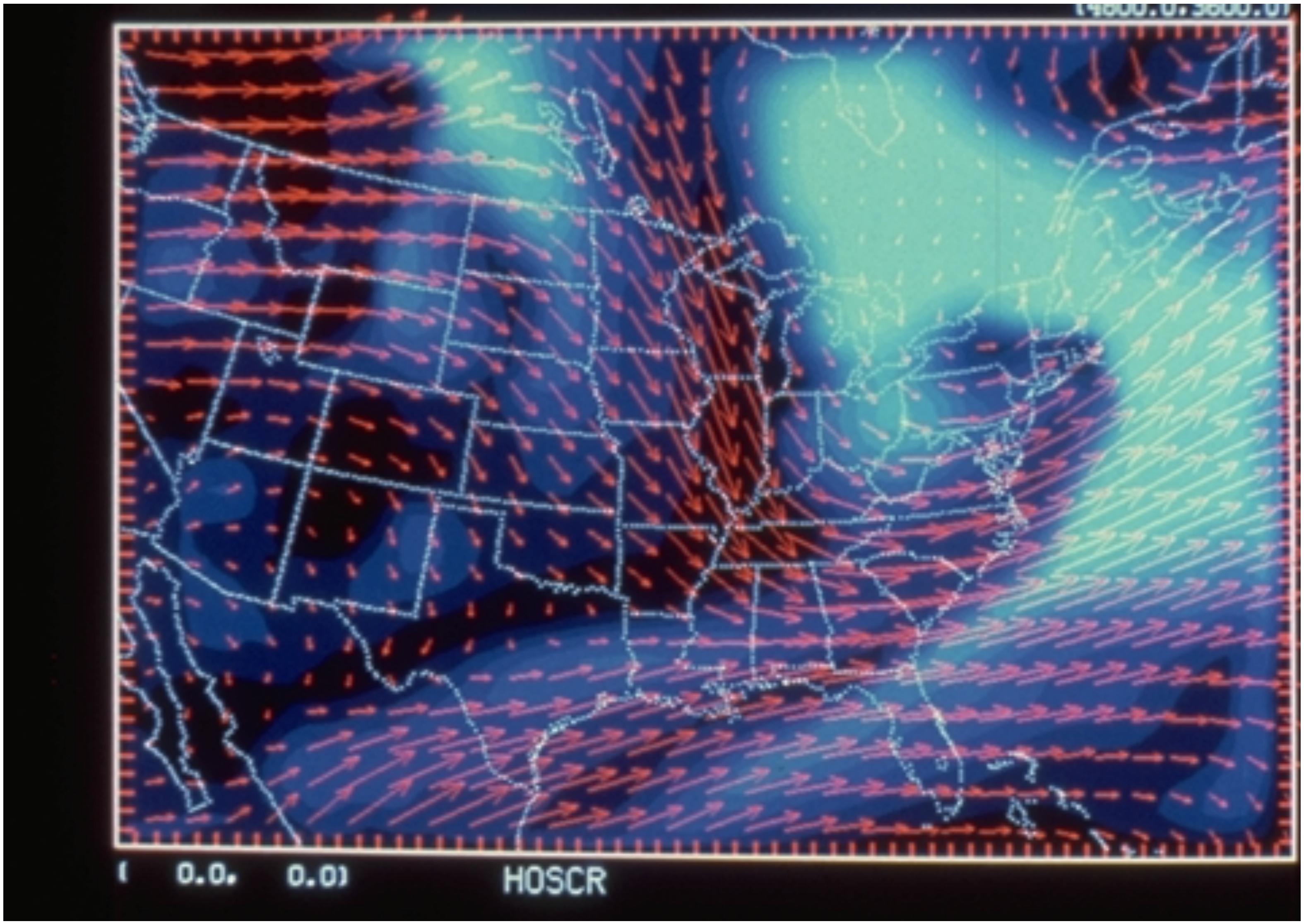
1980 Publications

- Anthes, Seaman and Warner "Comparisons of numerical simulations of the PBL by a mixed-layer and multilevel model" MWR
- Carlson, Anthes, Schwartz, Benjamin and Baldwin "Analysis and prediction of severe storms environment" BAMS

SESAME I   12 GMT 10 Apr 1979



OSCAR 00 22 Apr 1981



1981 Barbecue

Joe Sardi, Dan Keyser, Nancy Norton, Tom Warner, Jean-Yves Caneille

1981 Rick Moves to NCAR

- MM2 mentioned in notes April 3
- Summary of latent heat effects on meso-alpha scale circ (still not accepted by the NWP community as very important)
- Letter to David Chock, GM---Policy on using PSU mesoscale models

EFFECT OF LATENT HEATING ON MESO-α SCALE CIRCULATIONS

Variable	Effect
Horizontal wind	Increase 5-20 m s^{-1}
Vertical circulation	Increase 5-50 cm s^{-1}
Vorticity	
Low level	Increase 5-50 × 10^{-5} s^{-1}
High level	Decrease 5-50 × 10^{-5} s^{-1}
Temperature	
Low level	Little change or decrease
High level	Increase 5-10°C
Surface pressure	Decrease 1-10 mb
Precipitation	
Scale	Decrease
Amount	Increase 1-20 cm

EFFECT OF LATENT HEATING ON MESO-α SCALE FORECASTS OF SEA LEVEL PRESSURE

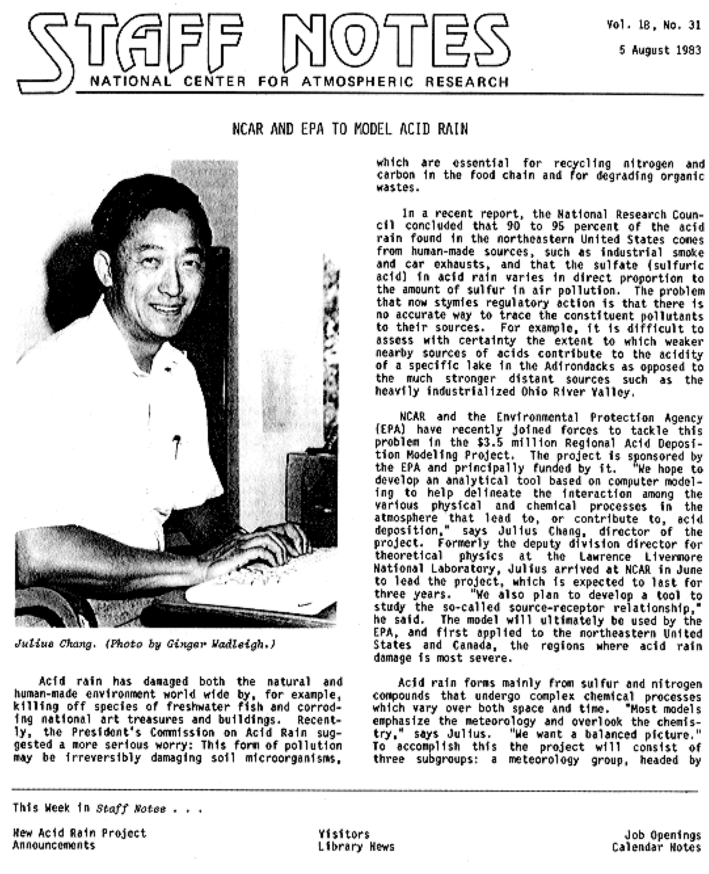
Investigator/ reference	Case description	Number of hours in forecast	Min SLP Diff Wet-dry	Min SLP Diff Variation in N(p)
Anthes & Keyser (1979)	G. Mex. cyclone 78030312	12	-16	-12
Anthes (1979)	G. Mex. cyclone 78012500	12	-10	- 8
	G. Mex. cyclone 78012512	24	-20	-13
Kuo & Anthes (1982)	Mei Yu 75061100 (avg in rain area)	12	- 1	--
		24	- 2	--
Anthes, Kuo & Gyakum (1982)	QE-II storm 78090912	12	- 2	0
		24	- 5	- 3
Chang, Perkey & Kreitzberg (1982)	May 20 SESAME cyclone (700 mb)	24	- 8	--

1981 Publications

- Tarbell, Warner and Anthes “An example of the initialization of the divergent wind in a mesoscale NWP model” MWR
- Seaman and Anthes “A mesoscale semi-implicit numerical model” QJRMS

1983 Acid Deposition Modeling Project

- ADMP provides huge boost to MM effort
- Julius Chang
- Verification software development started
- July---Memo refers to initialization of "MM3"
- July-Sept Quarterly Rpt to EPA begun; mesoscale predictability studies start



STAFF NOTES
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

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NCAR AND EPA TO MODEL ACID RAIN

Julius Chang. (Photo by Ginger Wadleigh.)

Acid rain has damaged both the natural and human-made environment world wide by, for example, killing off species of freshwater fish and corroding national art treasures and buildings. Recently, the President's Commission on Acid Rain suggested a more serious worry: This form of pollution may be irreversibly damaging soil microorganisms, which are essential for recycling nitrogen and carbon in the food chain and for degrading organic wastes.

In a recent report, the National Research Council concluded that 90 to 95 percent of the acid rain found in the northeastern United States comes from human-made sources, such as industrial smoke and car exhausts, and that the sulfate (sulfuric acid) in acid rain varies in direct proportion to the amount of sulfur in air pollution. The problem that now stymies regulatory action is that there is no accurate way to trace the constituent pollutants to their sources. For example, it is difficult to assess with certainty the extent to which weaker nearby sources of acids contribute to the acidity of a specific lake in the Adirondacks as opposed to the much stronger distant sources such as the heavily industrialized Ohio River Valley.

NCAR and the Environmental Protection Agency (EPA) have recently joined forces to tackle this problem in the $3.5 million Regional Acid Deposition Modeling Project. The project is sponsored by the EPA and principally funded by it. "We hope to develop an analytical tool based on computer modeling to help delineate the interaction among the various physical and chemical processes in the atmosphere that lead to, or contribute to, acid deposition," says Julius Chang, director of the project. Formerly the deputy division director for theoretical physics at the Lawrence Livermore National Laboratory, Julius arrived at NCAR in June to lead the project, which is expected to last for three years. "We also plan to develop a tool to study the so-called source-receptor relationship," he said. The model will ultimately be used by the EPA, and first applied to the northeastern United States and Canada, the regions where acid rain damage is most severe.

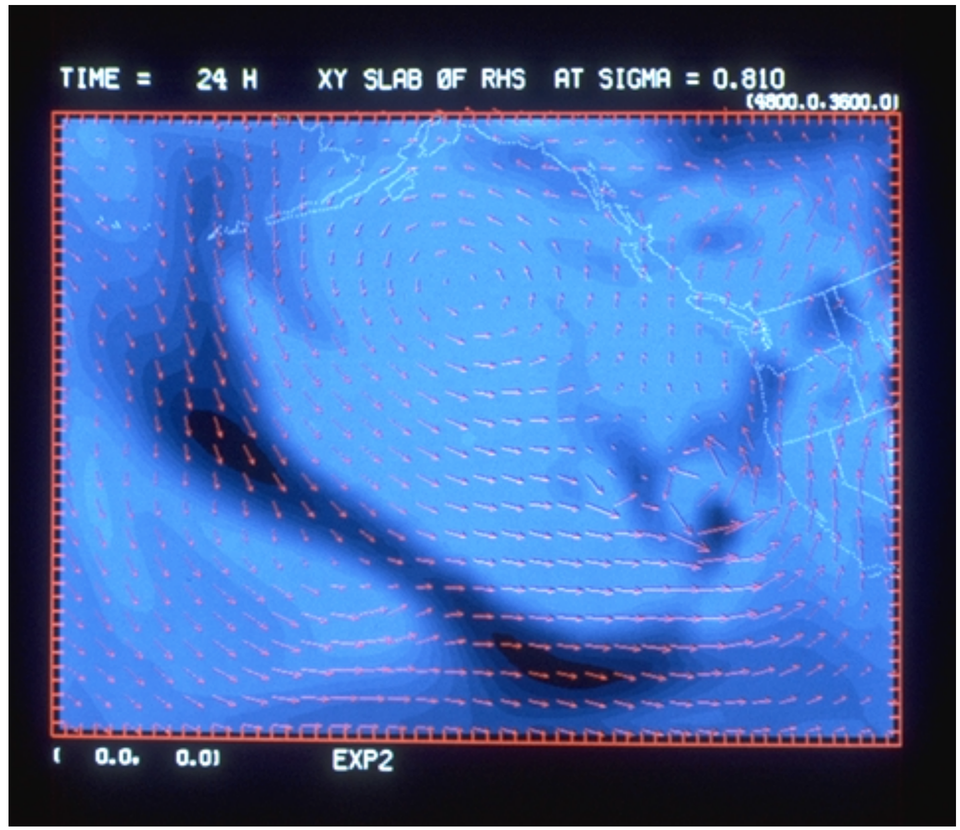
Acid rain forms mainly from sulfur and nitrogen compounds that undergo complex chemical processes which vary over both space and time. "Most models emphasize the meteorology and overlook the chemistry," says Julius. "We want a balanced picture." To accomplish this the project will consist of three subgroups: a meteorology group, headed by

This Week in *Staff Notes* . . .

New Acid Rain Project
Announcements
Visitors
Library News
Job Openings
Calendar Notes

1983 Bill Kuo takes over

- 14 July--"Research Plan for Meteorological Group of ADMP" Kuo and Anthes
- Focus of 1st year was to build a very general system
- Blackadar and bulk PBL, Anthes-Kuo Cu param, Hsie explicit physics, variable sfc characteristics, radiation, NNI, interactive graphics
- QE-II Storm

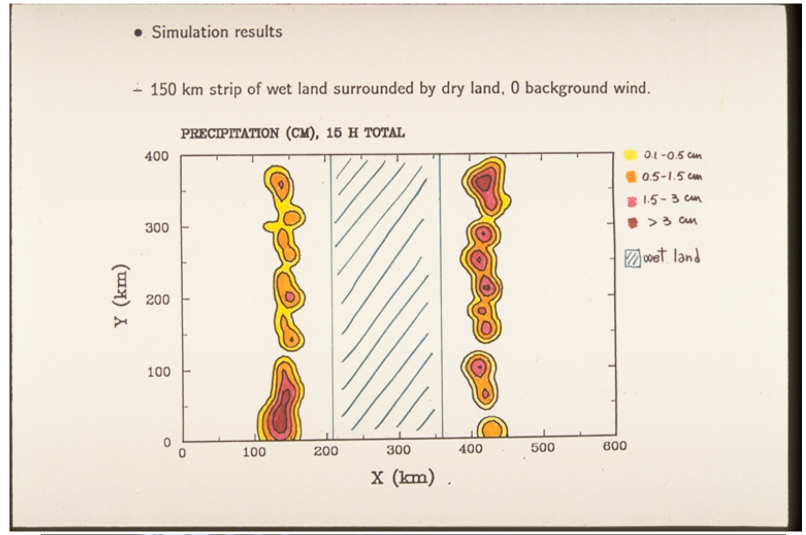


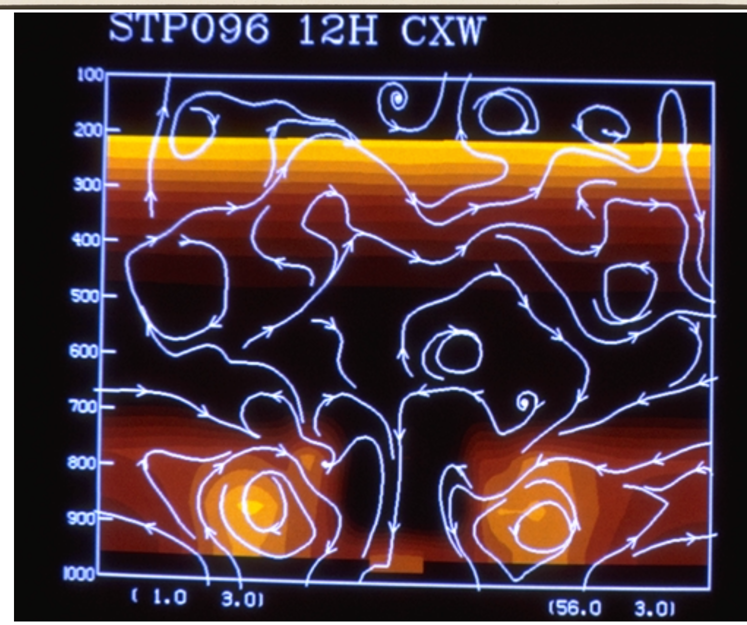
1983 Memo from Kuo to Anthes

- “Mesoscale model on Elmar Reiter’s Personal Computer”
- HP-9836
- 1.3 MB
- 31x41x6 grid
- Version of MM3

Regional Climate Model

- Filippo Giorgi, Gary Bates
- Idealized simulations with various simplified geometries of wet and dry lands (Hong Yan)





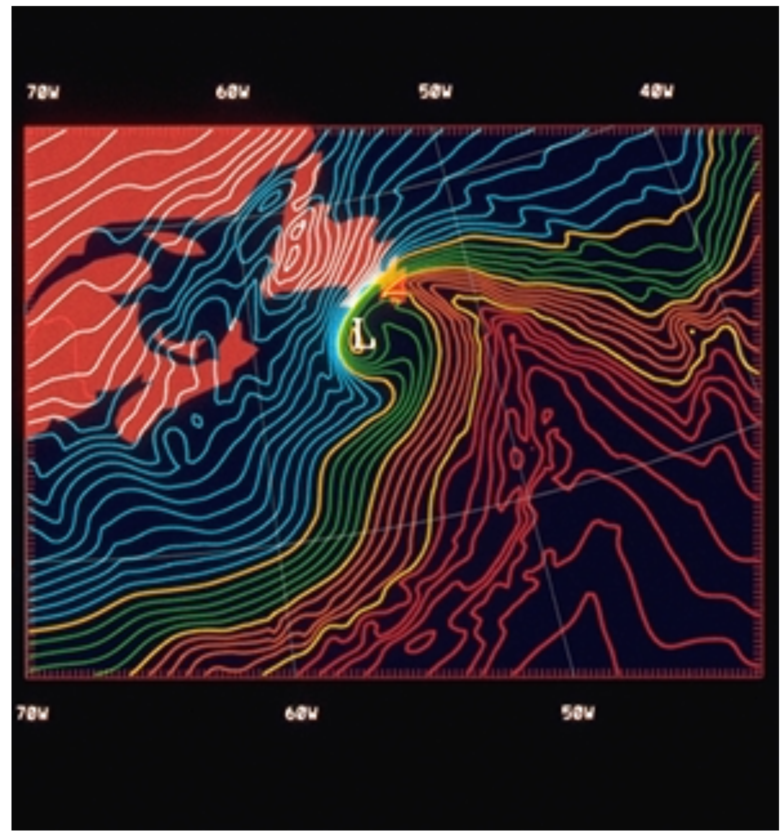
1985 Working with EPA
Letter from Anthes to John F. Clarke, EPA

"I understand from Julius Chang that you and others within EPA have some concerns about a particular aspect of the 72-h simulation of the OSCAR IV (April 22-25, 1981) case that we have presented at various meetings and briefings. The problem is apparently the 400-km error in the East Coast cyclone at 72 hours of the simulation. I suggest that your concerns are not appropriate at this stage of the model development for the following reasons."

"It is unproductive at this time to be concerned about a single error in one preliminary simulation."

1987 MM4 Officially Released

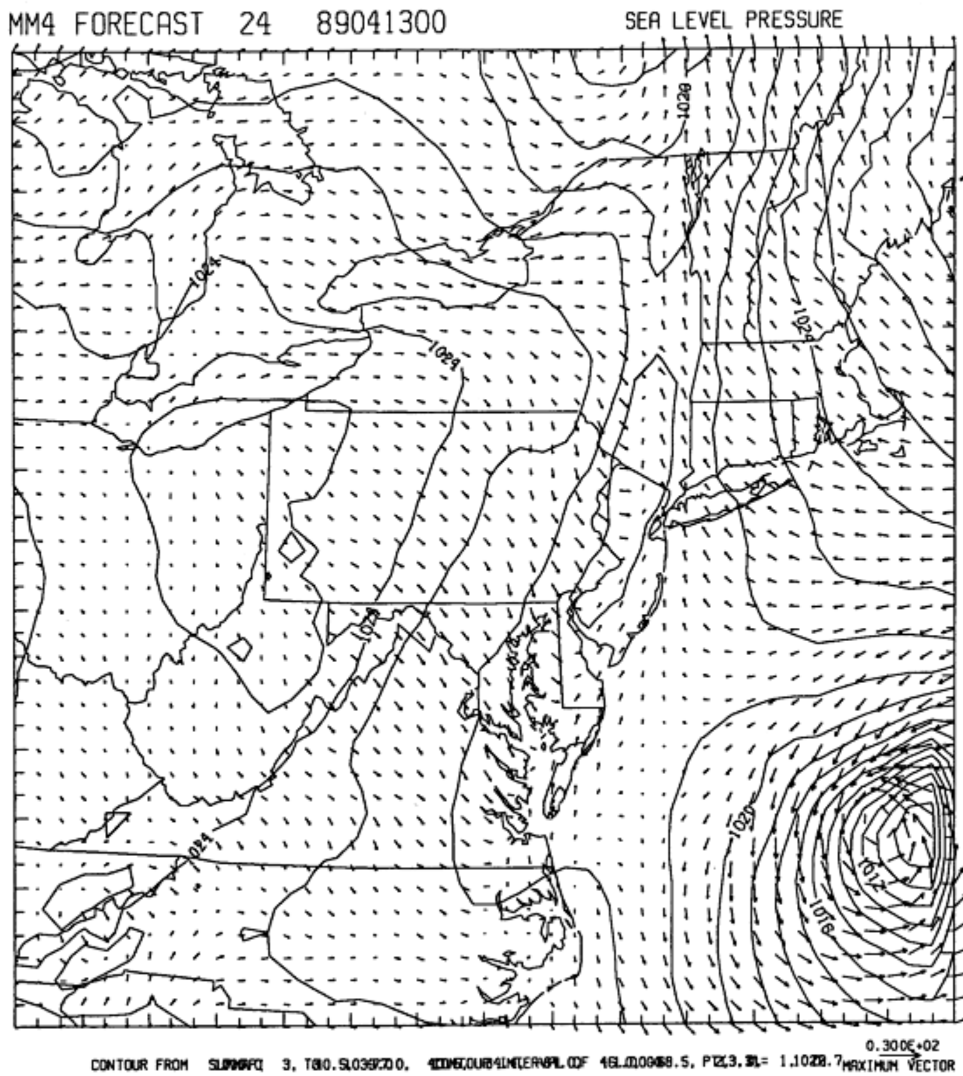
- Anthes, Hsie and Kuo, 1987: Description of the Penn State/NCAR Mesoscale Model Version 4 (MM4). NCAR Tech Note



1988-92 Major Accomplishments

- First MM5 User's workshop in 1991
- George Grell---MM5
  - nonhydrostatic option
  - nesting
  - 4-D data assimilation
  - MM5 Version 0 released in 1992

1989 First Real-time Forecast



The first real-time
MM4 forecast
13 April 1989

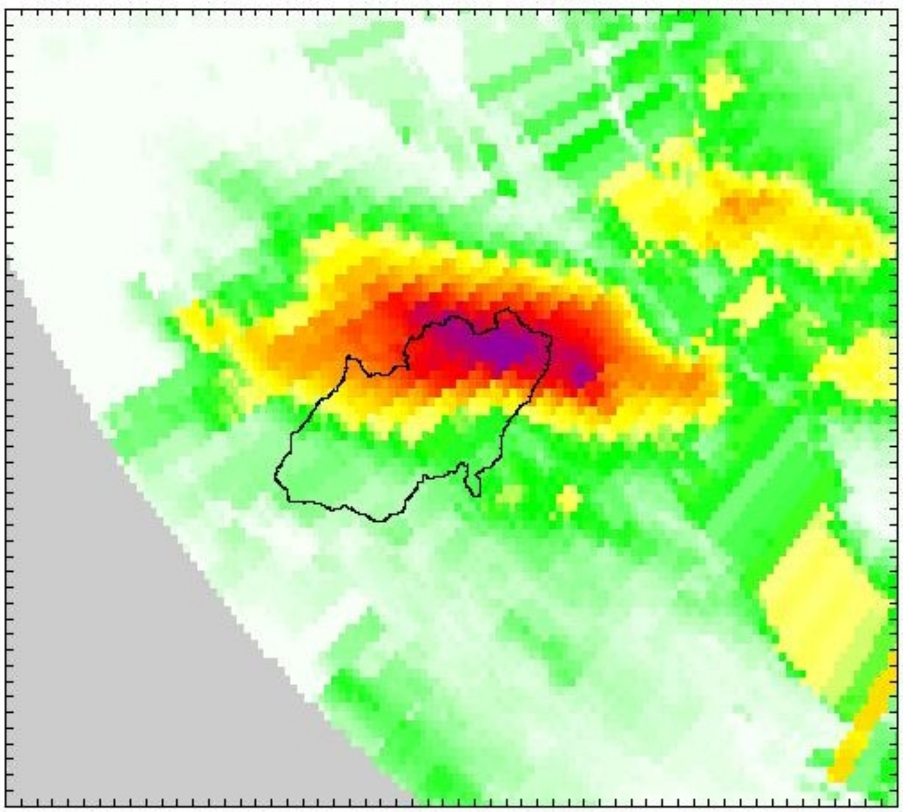
July 2010 Penn State 75th Anniversary

1993-97 Major Accomplishments

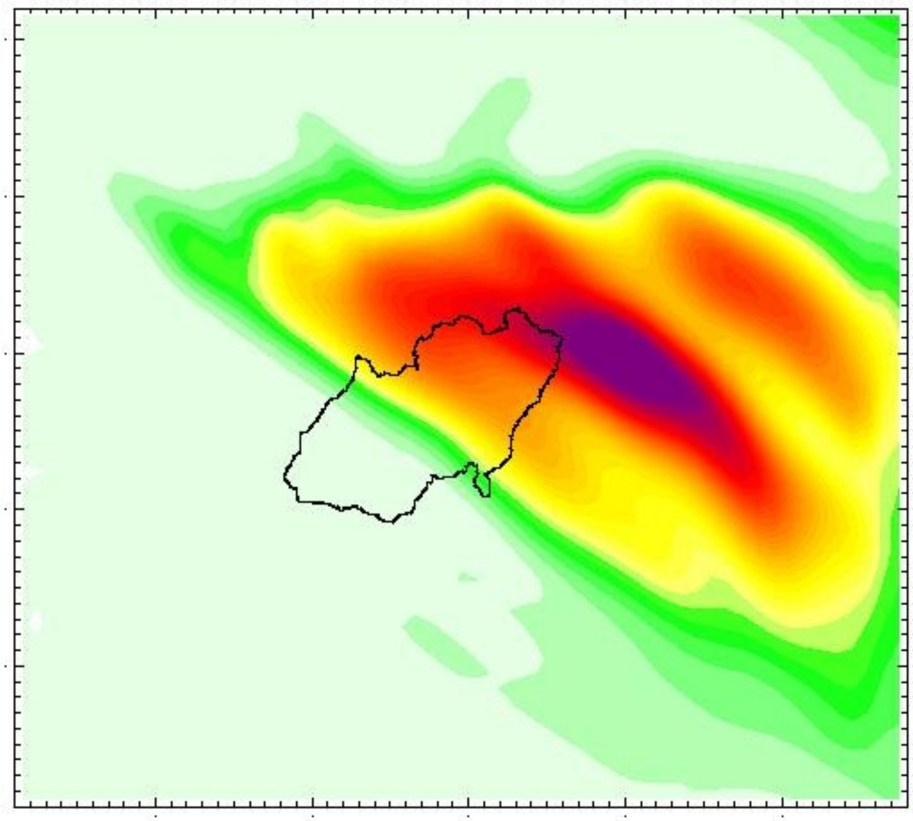
- MM5 documented and released (Grell, Dudhia and Stauffer (1994)
- Workstation version of MM5 in 1994
- Xiaolei Zou arrives-4DVAR
- MM5 V2 released--beginning of user support for the non-CRAY platform versions of code
- MM5 4DVAR released in 1997

1996--Predictability hypothesis verified!

Buffalo Creek, CO flash flood July 1996 3 h 48 min Spol rainfall



Buffalo Creek, CO flash flood, MM5 4 h rainfall 14 hour forecast from conventional, large-scale data



1998-99 Major Accomplishments

- Francois Vandenberghe---3DVAR system
- John Michalakes--massively parallel code version--portable to distributed-memory machines
- Idea of WRF, to be developed jointly by NCAR, NCEP, FSL, CAPS and others to replace MM5 and ETA models in future
- MM5 V3 released-improvements in physics and numerics

Growth of MM5 as world community model

"Around 1994 Dave Gill and Sue Chen started the workstation version of MM5 and Jim Steenburgh (then at U. Washington) set up an informal self-help mailing list for non-CRAY users. This workstation version was the first to run without need of a CRAY, and from that point the user base for MM5 grew exponentially. In the mid-90s, John Michalakes (Argonne National Lab) ported MM5 to distributed-memory platforms, mostly for AFWA with their IBM SP2's, using an ingenious code translation of his own design, making it possible to run on some of the world's largest supercomputers.

MM5 is now making way into PC usage and Intel-chip-based machines. Potential for a further growth explosion with such cheap computing."

Jimy Dudhia June 8, 1999

MM5 Developers in 1999

Nelson Seaman, Dave Stauffer, Tom Warner, Rick Anthes,
George Grell, Jimy Dudhia, Bill Kuo. June 1999