History of the Mesomonomster
Penn-State-NCAR Mesoscale Model MM0-MM5
Rick Anthes
Tom Warner Symposium
2 December 2011
Mesomoner 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

More or less circular boundary for 30x30 grid. Red points are interior to the critical radius, $R_c$. Blue points are the boundary points outside of $R_c$ which are needed in computing the tendencies for the points interior to the grid.

VERTICAL STRUCTURE

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>$\xi$</th>
<th>$\mu$ (m0)</th>
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<td>1</td>
<td>0</td>
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<td>$\psi, T$</td>
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<td>225</td>
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<td>$\psi, \phi$</td>
<td>2</td>
<td>450</td>
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<td>$\psi, T$</td>
<td>$\frac{3}{2}$</td>
<td>675</td>
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<tr>
<td>$\phi, \psi$</td>
<td>3</td>
<td>900</td>
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<tr>
<td>$\phi, \psi, \phi$</td>
<td>$\frac{3}{2}$</td>
<td>957.5</td>
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HORIZONTAL STRUCTURE - Northwest Section

LEGEND
- $x$ Exterior Boundary Point
- Interior Boundary Point
- Interior Point
- Center of Grid

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
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.
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
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

**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
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 emphasized
- 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 \((V,T,q,P_s)\)
- 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?

Ed Lorenz
1917-2008
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
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
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
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
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

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
War Story #7

Satellite Communications at PSU

"As the next communication upgrade we went to a satellite dish on the roof of the meteo building. The antenna belonged to NCAR, COMET I think, and was donated to us. We paid for the crane and the rest of the installation, but that increased speed and lowered the cost compared to the leased land line. When the internet came along, we ditched the antenna use, although no one wanted to pay to have it removed. So, as far as I know, the NCAR 10 foot boat anchor is still on the roof of Walker building as a memorial to the PSU NWP program."

Tom Warner, 14 June 1999

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
“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