THE NEW ENGLAND SEA BREEZE – MESOSCALE STRUCTURAL DETAILS

Frank P. Colby, Jr. *
University of Massachusetts Lowell, Lowell, MA 01854

1. INTRODUCTION

The Penn State/NCAR Mesoscale Model version 5 (MM5) was run for seven cases from 2001 in which a sea breeze develops along the eastern New England coast. The initial intent of the model runs was to determine the effect of grid size on the accuracy of the simulations, especially with respect to the timing and movement of the wind shift associated with the sea breeze circulation. The statistics are available in another paper (Colby, 2003). Here, some of the mesoscale details of the simulated sea breeze circulations are shown, demonstrating the ability of the model to handle the complexities in the flows.

2. MODEL CONFIGURATION

The MM5 was run for 24 hours of simulated time using 12 UTC Aviation Model, one-degree latitude/longitude output for boundary and initial conditions. The model was set up with 3 grids, as shown in Fig. 1. The outer grid had a 36 km grid size, and two-way interaction was used for the nested 12 km and 4 km grids. Simple ice physics (Dudhia, 1989) was employed and the MRF boundary layer parameterization (Hong and Pan, 1996) used. The Grell convective scheme (Grell, 1993) was applied in the 12 and 36 km grids, but no convective parameterization was used in the 4 km grid. The model was run with 24 sigma levels in the vertical, seven of which were below 1.5 km to allow the model to resolve the sea breeze. Tests with 40 levels showed no appreciable difference, other than a much longer running time, so it appears that the 24 level vertical resolution is completely adequate to resolve the sea breeze.

The model output was produced at one hour intervals, and processed into GrADS format (Grid Analysis and Display System – see http://grads.iges.org/grads for more details) using a Unix script.

3. MESOSCALE STRUCTURAL DETAILS

In each case, there were interesting details that were of interest in comparing the various model runs with each other and with the NCEP's Eta model on a 40 km grid. The initialization time for the Eta model runs was 12 UTC, the same as for the MM5 runs.

3.1 *July 9, 2001 – a Convergence Line*

Initial winds on this day were from the south, ahead of a weak surface trough that moved northeast across eastern Massachusetts from southern New Jersey at 12 UTC to eastern Massachusetts by 21 UTC. Showers broke out after this time in southern New Hampshire. The sea breeze circulation on this day started early along the east coast of Massachusetts before the larger scale circulation around the trough became dominant.

The model simulations all seemed to move the trough into eastern Massachusetts too slowly, thus allowing greater penetration of the sea breeze, and possibly allowing the sea breeze wind shift to take place sooner further inland. The surface wind began as a flow from the south, with an abrupt turn to easterly flow when the sea breeze started.

The 4 km grid shows a sea breeze beginning just off the coastline at 13 UTC, and fully formed at 14 UTC. The surface field is shown for the coastline in Fig. 2 for the 4 km grid at 15 UTC, showing a line of convergence over Cape Ann.

It is expected that as the land area on Cape Ann heated up, the initial sea breeze would be perpendicular to the coastline, given the weak ambient flow. None of the other cases demonstrated this detail, but the large-scale initial conditions were different in the other cases as well. Beyond noting that this convergence line is physically possible, there is no way to verify this pattern, since there are no observing locations on Cape Ann.

The sensible heat flux (Fig. 3) showed a local maximum over the Cape, and the temperature field, as seen in Fig. 2, showed a local maximum over the Cape as well. The sea breeze flows inland across the temperature gradient, just as would be expected. These patterns of sensible heat flux and temperatures were present in this form for at least three more hours, but the convergence line disappeared by 18 UTC as the sea breeze wind shift penetrated inland (see Figs. 4 and 5). This is an excellent illustration of one of the most difficult aspects of evaluating mesoscale simulations. The simulations often produce reasonable and physically possible patterns in the flow field that are impossible to verify without placing a dense grid of observing platforms within the domain.

The 40-km grid from NCEP's Eta model forecast light easterly flow reaching northeastern Massachusetts by 15 UTC and penetrating to central Massachusetts, before switching back to westerly by 18 UTC. The 15 UTC flow field is shown in Fig. 6.

---

* *Corresponding author address:* Frank P. Colby, Jr., Dept. of Env., Earth, & Atmos. Sci., University of Massachusetts Lowell, Lowell, MA 01854;
email: Frank_Colby@uml.edu

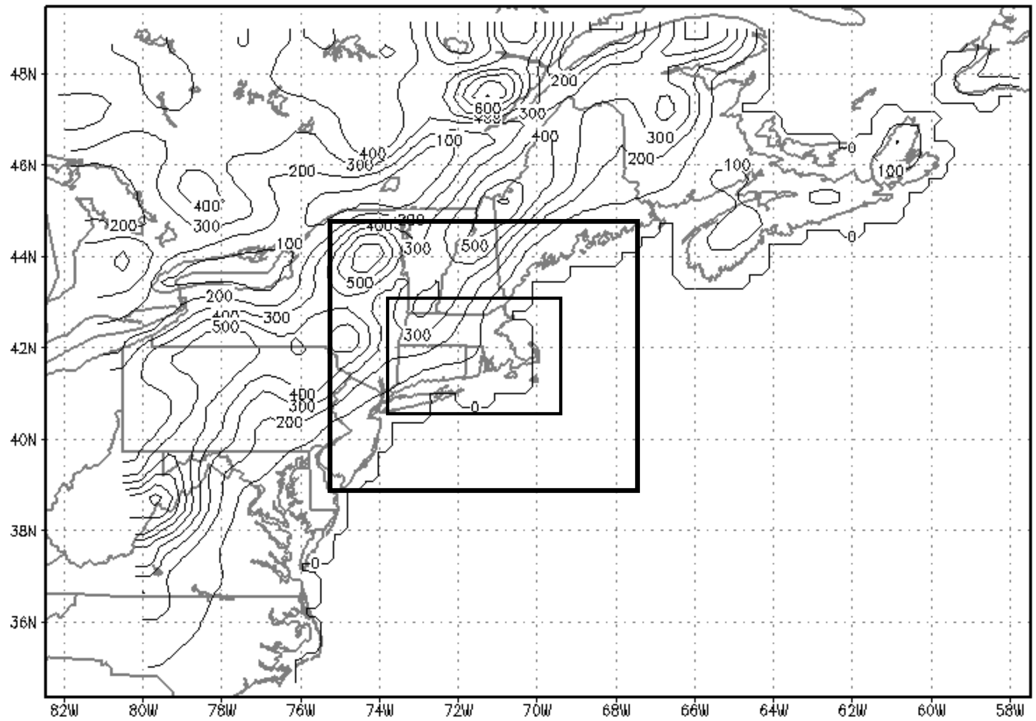

Figure 1. Map showing extent and location of the three different grids mentioned in the text. The outermost grid has a 36 km grid spacing, the intermediate grid has 12 km spacing, and the innermost grid has 4 km spacing.

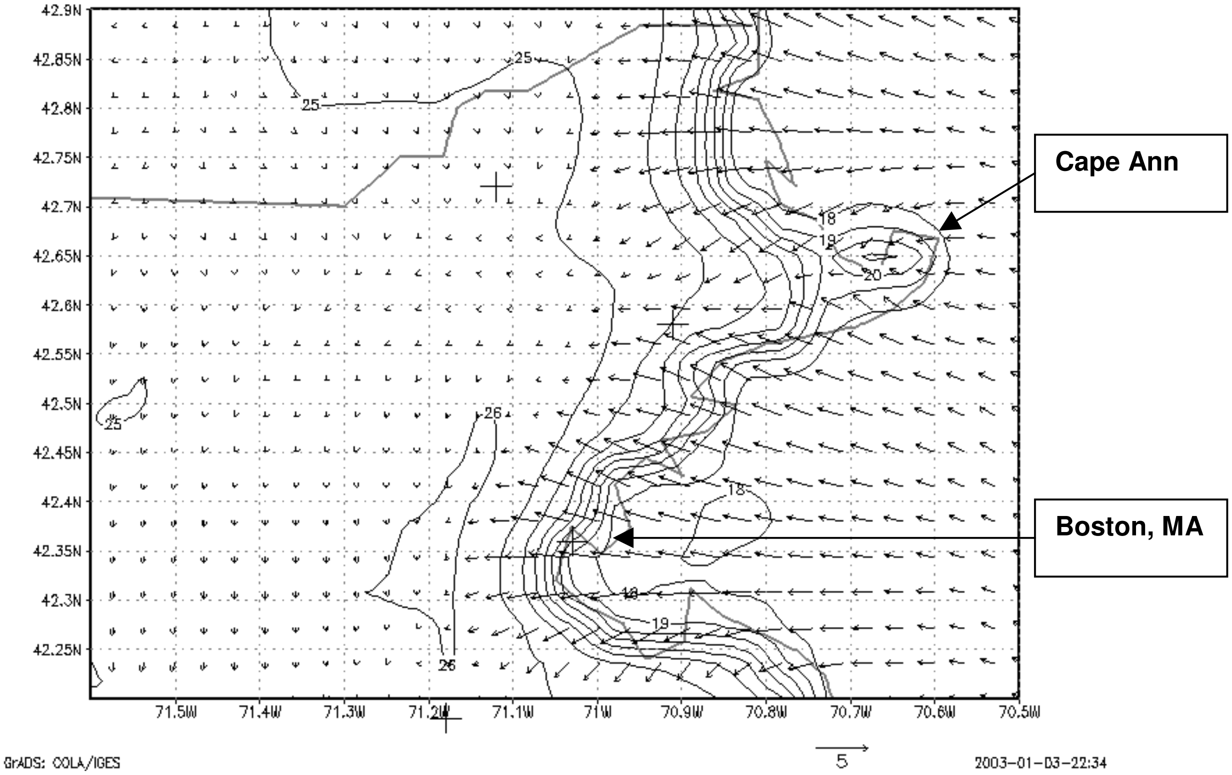

Figure 2. Output from triply nested model run for 4 km grid at 15 UTC, July 9, 2001. Winds are shown as arrows, with the length scaled to the wind speed (m/s) as shown in the lower right of each figure. Temperatures are contoured at 1 °C intervals. Boston, MA is located at the cross west of the arrowhead.

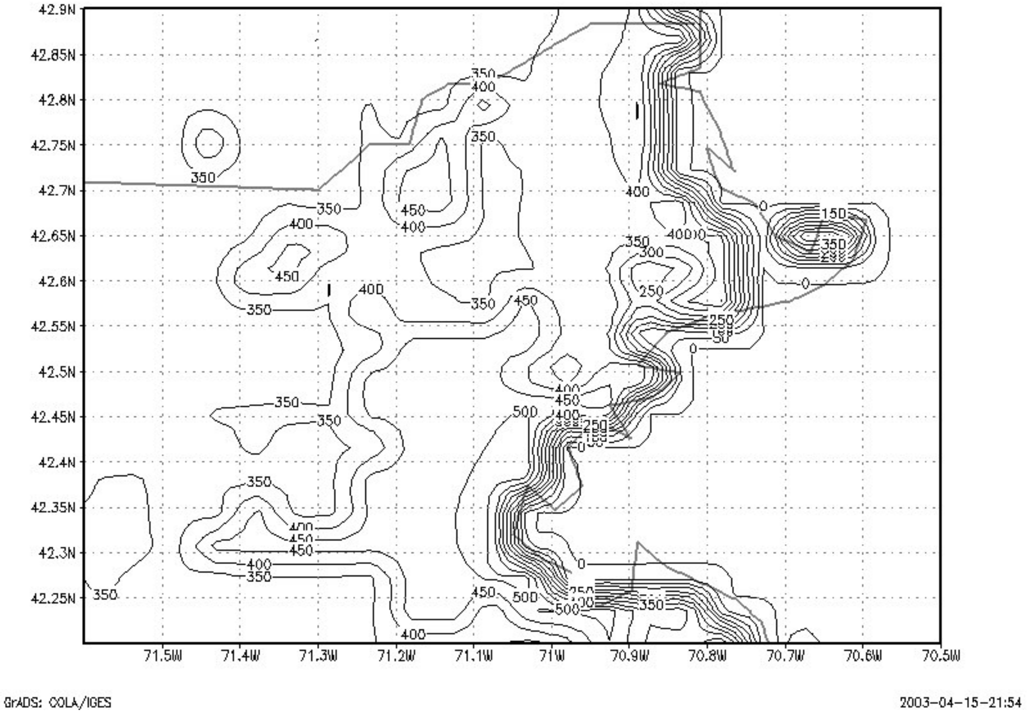

Figure 3. As in Fig. 2, except showing surface sensible heat flux in watts/square meter.

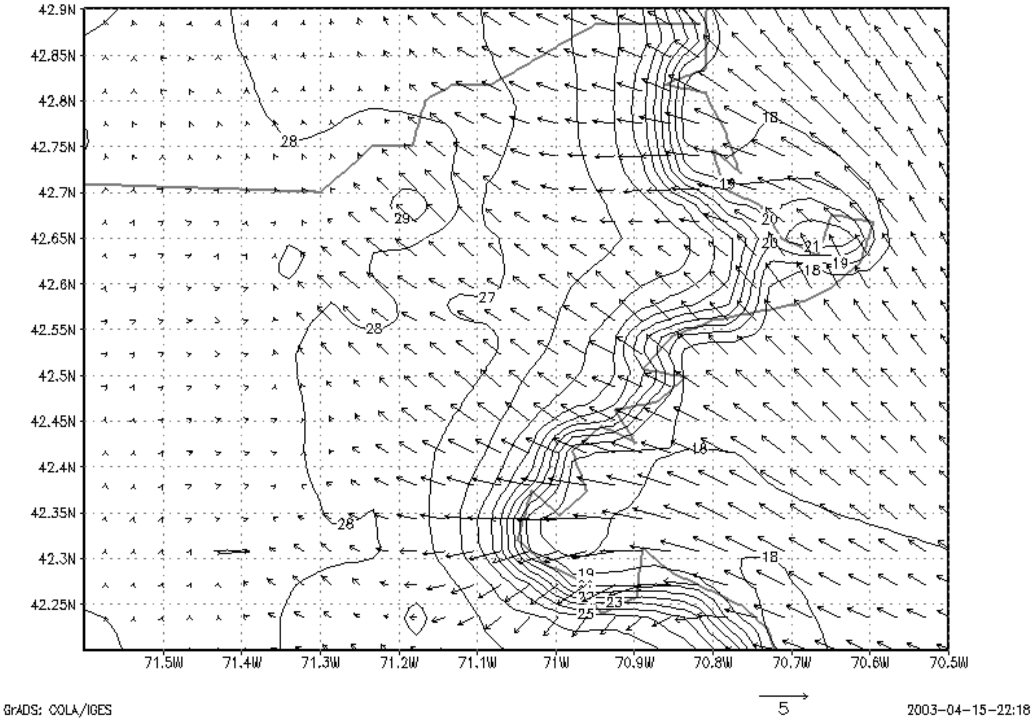

Figure 4. As in Fig. 2, except for 18 UTC.

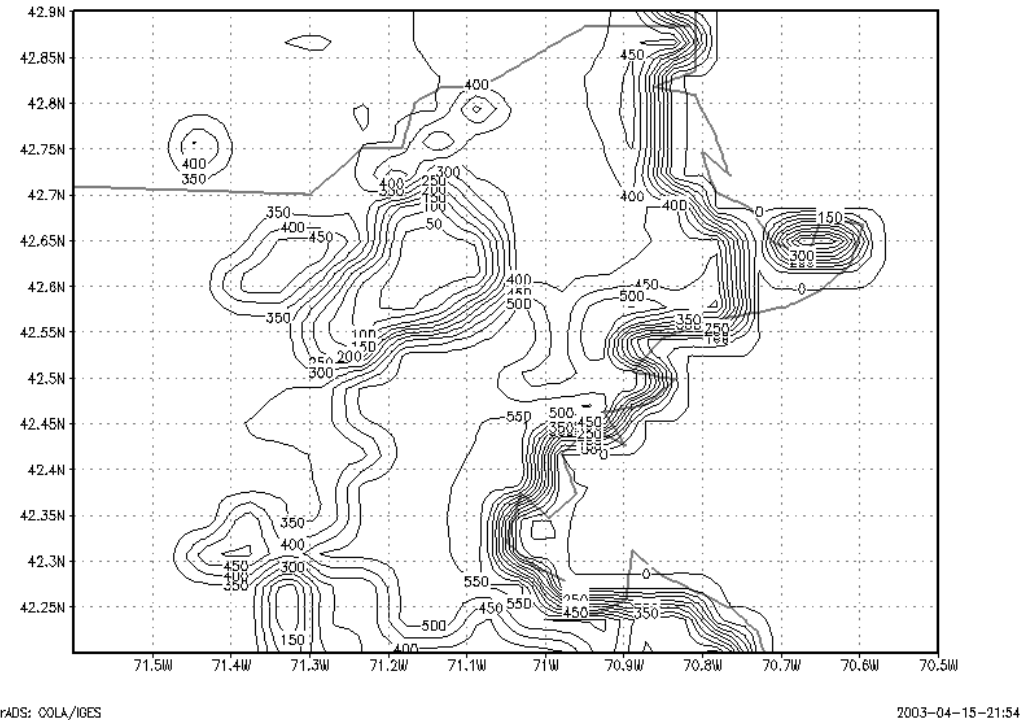

Figure 5. As in Fig. 3, except for 18 UTC.

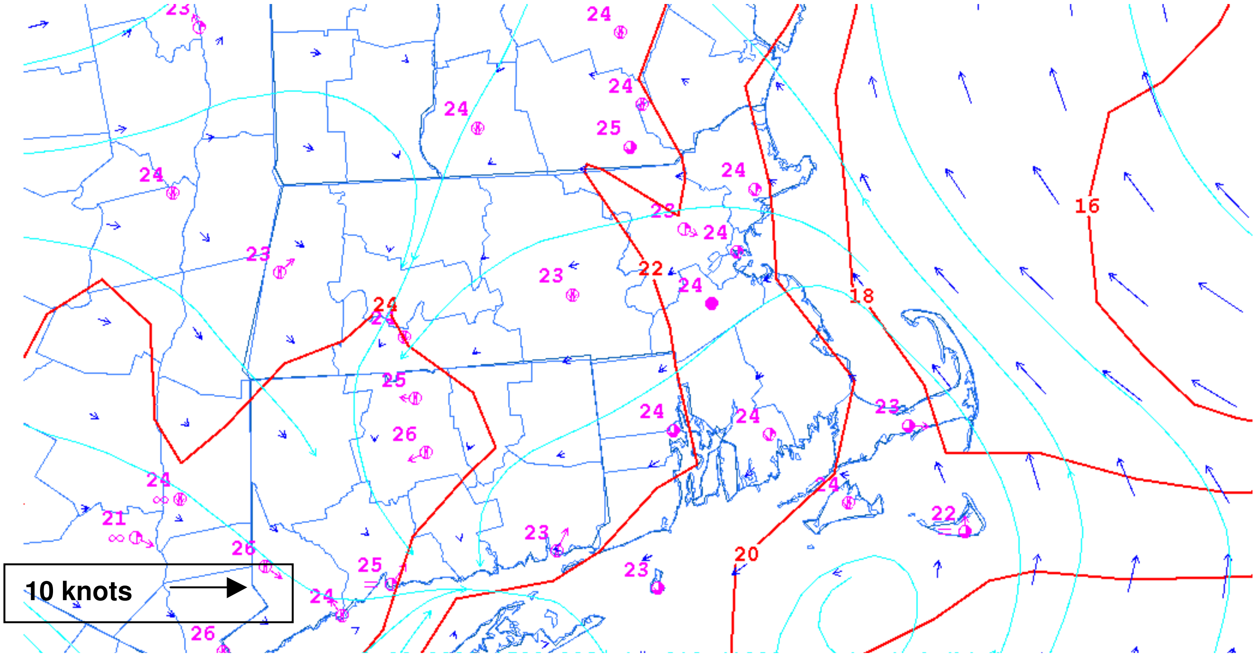

Figure 6. Map showing output from NCEP's Eta model with surface observations overlaid at 21 UTC, July 16, 2001. Only the temperature, wind and weather (if any) are plotted. The winds are plotted as arrows, or with a V in the station circle for variable wind directions. Model output winds are shown as arrows and streamlines, with the length of the arrow scaled for the wind speed (knots) as shown in the lower left corner. Model output temperatures are contoured at 2 °C intervals.

The easterly flow in central Massachusetts was not a sea breeze, given the temperature gradient shown on the figure. In this case, the Eta was unable to generate a sea breeze circulation.

3.2 *July 16, 2001 – Merged Flows and Showers*

The sea-level pressure gradient was strong enough on the morning of the 16th of July to drive surface winds of 4 – 6 knots from the northwest. As a result, the sea breeze wind shift occurred along the eastern coastline of Massachusetts between 16 UTC and 17 UTC. The sea breeze never reached very far inland, and only penetrated beyond the immediate coastline by 22 UTC. To the north, in southeastern Maine, thunderstorms occurred all day. A rain shower did develop in southeastern Massachusetts at 21 UTC, but dissipated by the next hour.

Figure 7 is a cross-section from the 4 km model run at 18 UTC. The cross-section starts in the ocean at about the same longitude as the tip of Cape Ann, runs east-west through Boston, MA, and ends about 40 km west of the coastline (see Fig. 8 for the position). The wind shift has already passed Boston by this time, and the colder air from over the ocean is visible as a cold wedge just east of Boston. The convergence along the wind shift generated upward vertical motion, and there is compensating downward motion just west of the wind shift, as well as diffuse downward motion to the east.

All of the model runs brought southerly or southeasterly flow into southeastern Massachusetts near 21 UTC, as the sea breeze from the southern coast of Massachusetts merged with the sea breeze from the east, and then turned southerly. Figure 8 shows a portion of the 12 km grid at 21 UTC, in which this merging of flows shows up clearly. This merging process also occurred in the Eta model run. Figure 9 shows the Eta forecast at 21 UTC along with the observed winds and temperatures, and it is clear that the winds in southeastern Massachusetts are far from being southerly, even though both model solutions suggested that they should be.

The 4 km grid is the only grid to forecast rain showers in this case, and it does so as of 20 UTC, within one hour of the time showers show up on the radar summary. The location is also in southeastern Massachusetts, close to where the radar data indicated showers. Figure 10 shows a portion of the 4 km grid at 20 UTC, while Fig. 11 shows a portion of the National Weather Service Radar Summary observations at 21:15 UTC, showing the rain shower over southeastern Massachusetts.

4. CONCLUSIONS

These simulations of the New England sea breeze

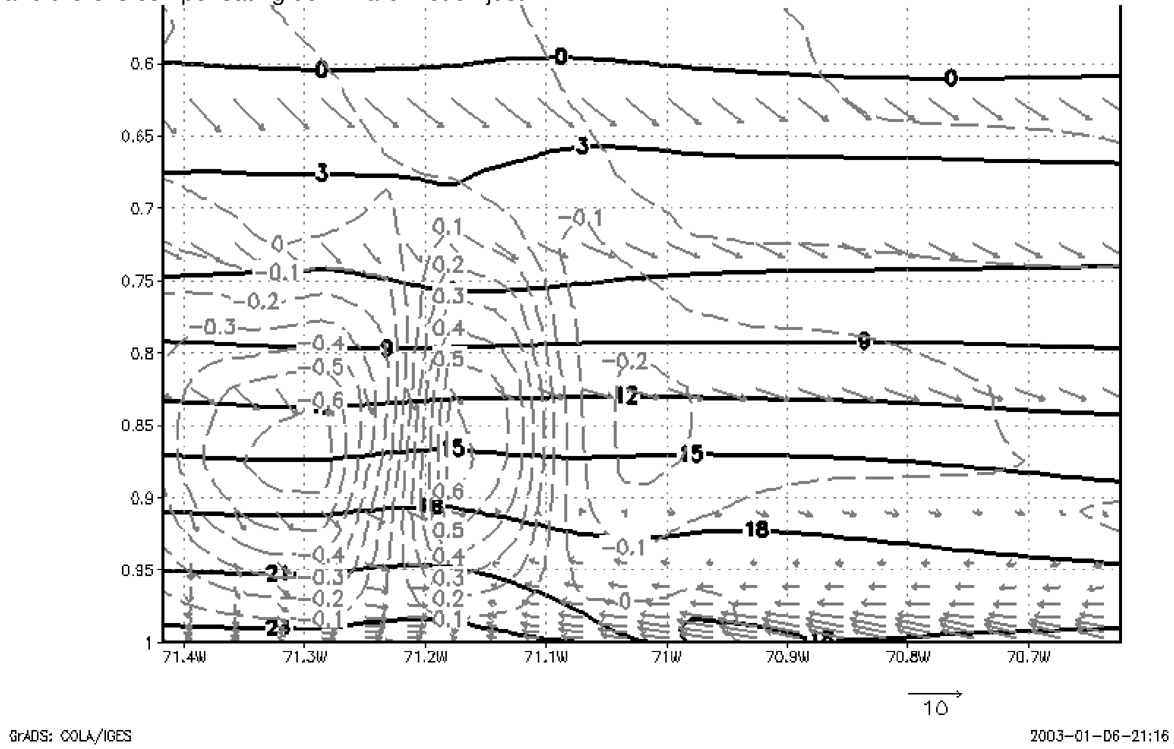

Figure 7. Cross-section from the 4 km grid, valid at 18 UTC, July 16, 2001. The vertical axis is in sigma (=p/surface pressure). Winds (m/s) are plotted as arrows, with a scale shown in the lower right. Temperatures (thick solid contours) are contoured at 3 °C intervals. Model vertical motion (dashed lines) is contoured at intervals of 0.1 m/s.

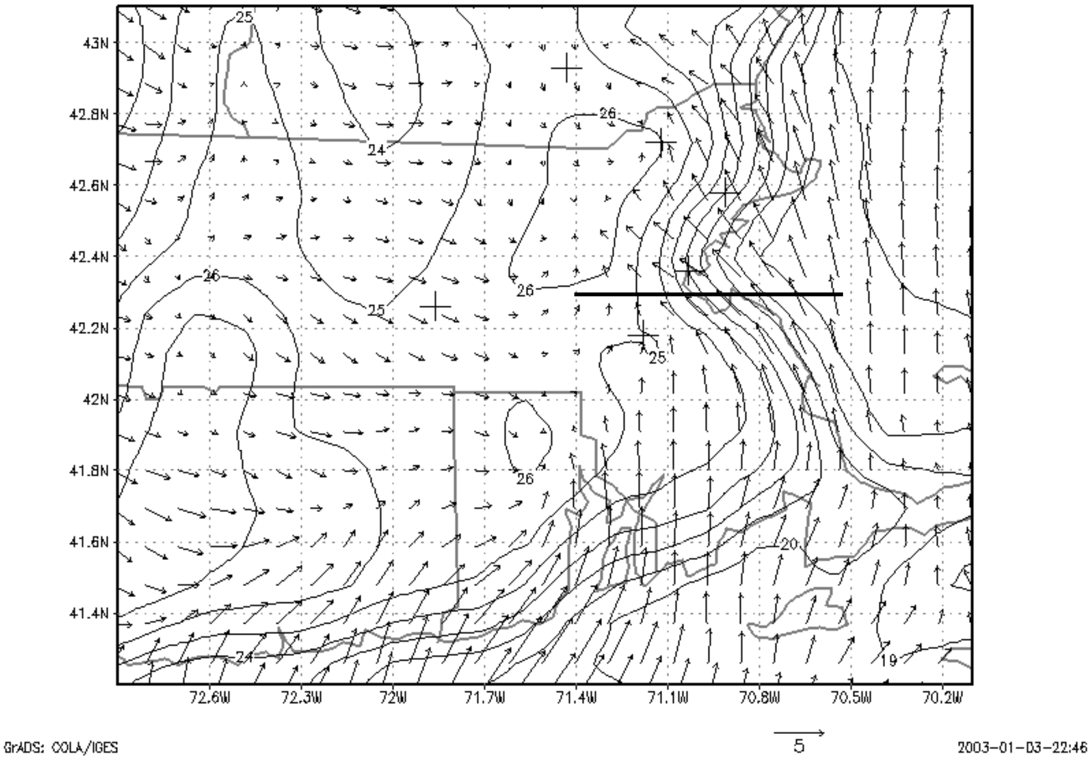

Figure 8. Output from MM5 model run as in Fig. 2, except for 21 UTC, July 16, 2001 from the 12 km grid. The solid line shows the position of the cross section in Fig. 6.

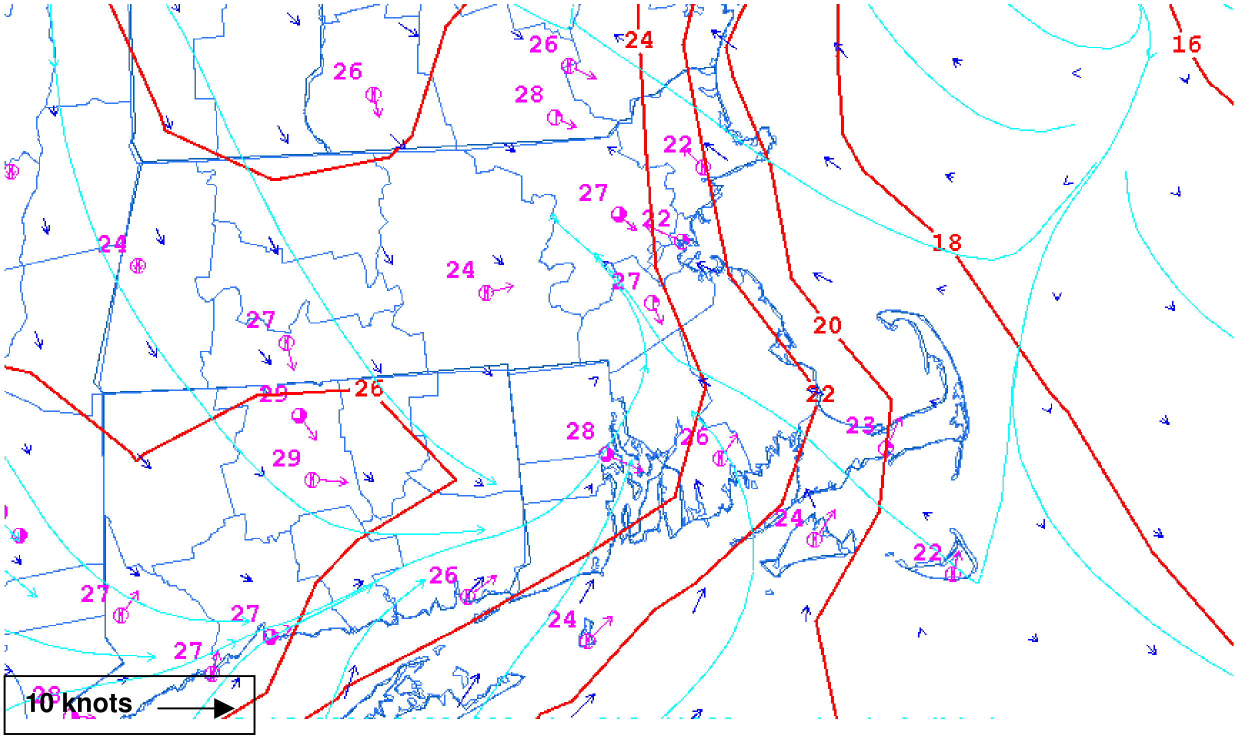

Figure 9. As in Fig. 6, except for 21 UTC, July 16, 2001.

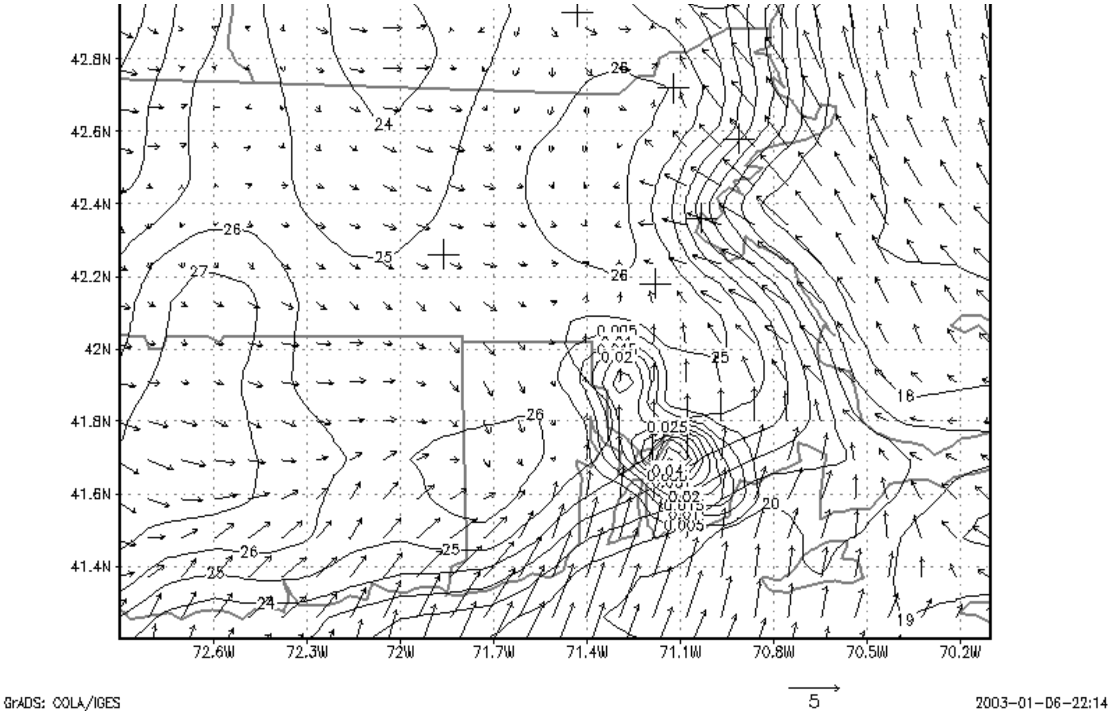

Figure 10. As in Fig. 8, except for 20 UTC, and with accumulated precipitation from the past hour contoured at 0.1 mm intervals.

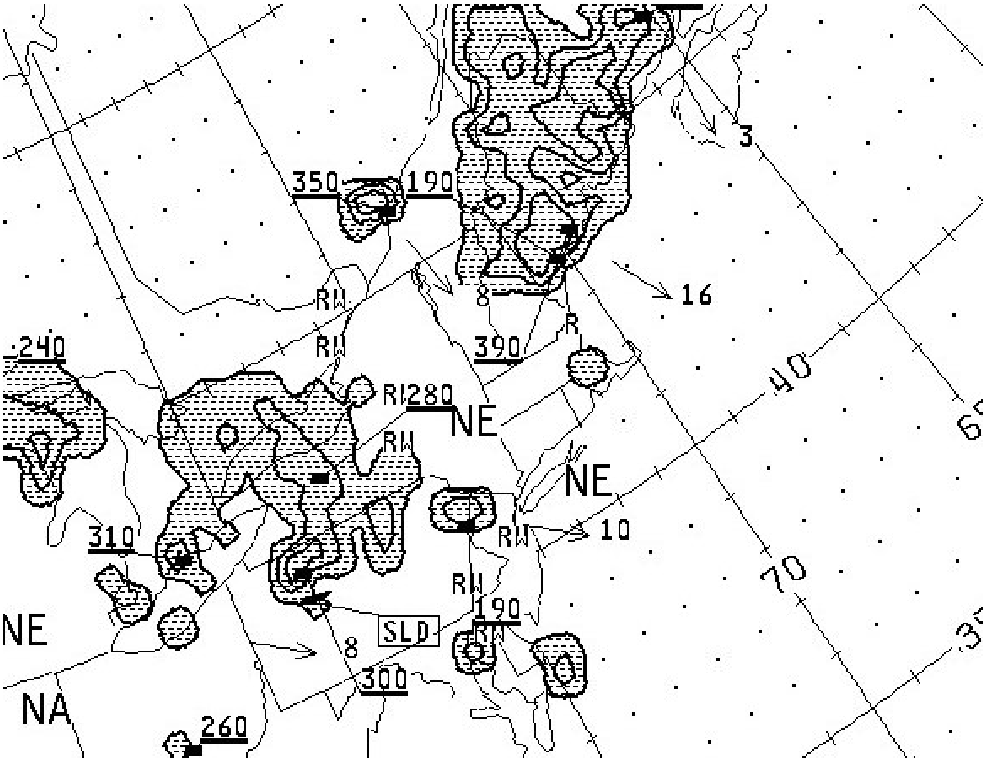

Figure 11. National Weather Service Radar Summary map from DIFAX broadcast, for 21:15 UTC, July 16, 2001.

circulations have proved to be illustrative of both the strong points of high-resolution mesoscale modeling as well as some of the pitfalls. The 4 km grids were able to resolve details in the flow fields that at times, were not even possible to determine from the observations. The convergence line over Cape Ann on July 9 is a good example of this. In the July 16 case, the presence of showers over eastern Massachusetts was forecast almost perfectly, as verified by radar observations.

Unfortunately, the flow fields were not always simulated correctly, as in the July 16 case of merged sea breeze circulations in south-east Massachusetts. The observations showed that both the NWS Eta model as well as the more detailed MM5 model brought the sea breeze wind shift inland too fast and too far.

This and other modeling results suggest that the surface energy balance and associated boundary layer parameterizations have a profound effect on the model simulations. Further research in this area is clearly needed.

5. Acknowledgements

This work has been helped considerably by scripts written by Mr. Matt Jones while a senior undergraduate, and Ms. Susanna Hopsch while a M.S. student.

6. References

Colby, F. P., Jr., 2003: Simulation of the New England sea breeze: the effect of grid spacing. *To Be Published in Wea. & Fore.*

Dudhia, J., 1989: Numerical study of convection observed during the Winter Monsoon Experiment using a mesoscale two-dimensional model. *J. Atmos. Sci.,* ***46,*** *3077–3107.*

Grell, G. A., 1993: Prognostic evaluation of assumptions used by cumulus parameterizations. *Mon. Wea. Rev.,* **121,** 764-787.

Hong, S.-Y., and H.-L. Pan, 1996: Nonlocal boundary layer vertical diffusion in a medium-range forecast model. *Mon. Wea. Rev.,* **124,** 2322–2339.