P4.1 Evaluation of RAMS Surface Wind Forecasts for the Chesapeake Bay Region During the Coastal Marine Demonstration Project

Jeffery T. McQueen[1]
NWS/Office of Science and Technology/SPB, Silver Spring, MD

Frank Aikman III and John G.W. Kelley
NOAA/National Ocean Service/CSDL, Silver Spring, MD

1. INTRODUCTION

Mesoscale meteorological model simulations have been performed over the Chesapeake Bay for individual case studies since the early 1980's (e.g.: Segal et al., 1982). The results agreed with observed sea and bay breeze wind regimes developing along the Chesapeake Bay (Scofield and Weiss, 1977). In addition, McQueen et al. (1997) showed that grid spacing of 5 km horizontal resolutions or finer were needed over the Bay region to properly simulate surface fluxes. Therefore, non-hydrostatic scale resolutions were required to attempt to capture the thermally and frictionally induced circulations which develop around the Chesapeake Bay and its tributaries.

During June and July 1999 and again in February and March 2000, the NOAA Air Resources Laboratory (ARL) and the National Ocean Service's(NOS) Coastal Survey Development Laboratory (CSDL) participated in the Coastal Marine Demonstration Project (CMDP, Aikman et al., 1999). The CMDP, sponsored by the National Oceanographic Partnership Program (NOPP), was begun to develop, improve and deliver atmospheric and oceanographic forecast products for the Chesapeake Bay and surrounding coastal regions. ARL contributed by employing its experience in predicting local-scale atmospheric flows using a modified version of the Regional Atmospheric Modeling System (RAMS) for air quality applications. This paper describes and evaluates an operational coastal marine prediction system using RAMS for the Chesapeake Bay (CBRAMS) and Mid-Atlantic coastal waters to predict atmospheric variables such as winds, temperature, moisture, convergence zones, visibility and precipitation. The CBRAMS predictions were used by the NOS oceanographic models to predict the Bay region water level and waves. These predictions represent an experimental attempt at non-hydrostatic atmospheric model forecasting of a coastal region. CB RAMS forecasts are also evaluated against the NWS operational Eta-32 model wind predictions to assess the conditions when value is added by running a customized local-scale model.

2. CMDP RAMS CONFIGURATION

The RAMS version 4a/4.2 originally developed at Colorado State University (Cotton et al., 1994) was used for the CMDP. The software developed at ARL allows the user to set up and initialize RAMS and perform simulations for a domain anywhere in the world using the ARL packed meteorological fields and global land and water surface datasets. This system was designed to be used for operational real-time simulations or research runs with an interface for quick configurations.

The CBRAMS 4 km grid was nested within a 16 km outer grid with two-way grid interactions. The domains with model topography are shown in Fig. 1. The full physics RAMS forecast includes non-hydrostatic physics, a second order closure boundary layer turbulent kinetic energy scheme, a surface soil and vegetation parameterization, explicit prediction of cloud micro-physical parameters (rain, snow, ice, aggregates, graupel and hail) and improvements for air-sea exchange. However, warm rain physics only were used for the first phase of CMDP to ensure early availability to the forecast community. A visibility computation for coasts was implemented using the Stoelinga-Warner (1998) algorithm. The Eta Data Assimilation System was used for initialization of local and regional scale features.

The model outputs were needed in real-time both to drive the water level and wave models and as guidance for local weather service and private industry specialized forecasts (see Titlow and McQueen, 1999). Therefore, the forecasts would have to be completed as soon as possible with the necessary resolution to predict the onset and timing of local-scale features such as river, bay and sea breezes. To do this, compromises were made for the configuration of precipitation processes. Model predictions were affected during convectively active days, however, the overall product was more useful since the predictions were available before the NWS marine forecasts were prepared. CBRAMS was run at 00 and 12 UTC each day on the NOS/CSDL 8 processor SGI Origin 2000 workstation with 30-36 hr forecasts completing in less than 3-6 hours from start time.

3. PRODUCTS

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*Corresponding author address: Jeffery McQueen, NOAA/NWS/OST/SPB,
1325 East-West Highway, Silver Spring, MD 20910
Email: Jeff.mcqueen@noaa.gov

CBRAMS fields were output hourly and converted to GRIB format for use by NOS water level and wave models. The GRIB files were also downloaded by WSI and the National Weather Service (NWS) Weather Forecast Offices (WFO) at Sterling, VA, Wakefield, VA and Mt. Holly, NJ for customized display and static and interactive plots posted to the ARL-Real Time Environmental Access and sYstem (READY) web page twice/day. Additional fields were added to the standard ARL-RAMS files for interactive visualization (e.g.:cloud water mixing ratio, moisture affected visibility, short and long wave radiation) with READY. The GRIB files were then transferred to the National Oceanographic Data Center (NODC) for access by the marine and forecast communities. Daily evaluations vs. the Wind Hotline mesonet were also created on the Wind Hotline web page (Titlow and McQueen, 1999).

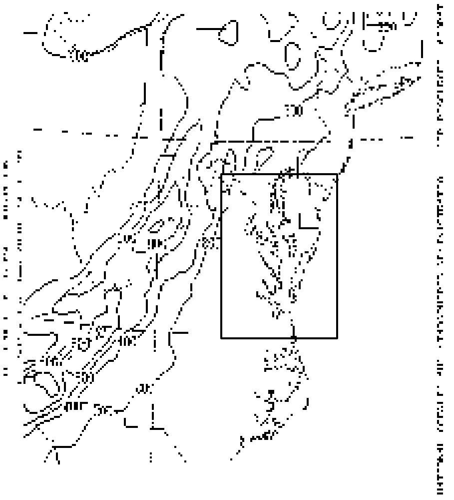

Fig. 1 CBRAMS 16 and 4 km domains.

For the first time, 4 km forecasts which incorporated these local-scale winds were used by hydrodynamic models for the Bay including the NOS Chesapeake Bay Estuarine Forecast System (CBEFS, Bosley and Hess, 1998) to predict water levels and the CBWAVES, a wind-wave height prediction model.

4. QUANTITATIVE EVALUATIONS

CBRAMS surface wind forecasts were compared to Eta-32 forecasts at three over-water sites (Thomas Point Light Buoy, (TPLM), Chesapeake Bay Observation System mid bay buoy (CBOS), Chesapeake Bay Bridge Tunnel C-MAN station (CBBT)) and an over-land reference site (Dulles International Airport (IAD). The locations of these sites and the west shore bay coastal and east shore coastal sites used for later wind error evaluation are shown in Fig. 4. The results of the comparisons were depicted in error box plots. Box plots are a good indicator not only of median error (middle line) but also the variability or spread of the error as indicated by the 10(lowest end of box) , 25, 50(median), 75 and 90 (upper end of box) % lines defining the box. The daily 00 UTC model cycles forecasts wind speed errors were averaged to create the error statistics. Light and variable wind measurement times (wind speeds less than 2 m/s) were not considered.

4.1 Afternoon Box Plot Errors

In Figs 2-5, only surface wind forecast errors during the afternoon hours are considered (18-00 UTC). This is the time when daytime heating would increase the thermal gradients between land and water and therefore local bay breeze forcings would typically occur (up-bay southerly flows over water and on-shore flows along the coasts) and when the largest differences between CBRAMS and Eta forecasts are expected to occur. Furthermore, wind error box plots are categorized for all wind direction and southerly wind direction categories. The over-water sites wind speed errors are shown in Fig 2. The afternoon CBRAMS wind speed bias is near zero and improved over the Eta wind speed underpredictions at the northern bay buoys(e.g.: at TPLM2, -1.2 m/s Eta median error for all afternoon wind directions and -1.3 m/s for southerly wind cases). Over the southern bay buoy (CBBT, fig 2b), CBRAMS wind bias are improved for all wind direction cases, however, the error variability is larger than Eta for both wind categories.

In figure 3, afternoon surface wind direction error for the over-water are presented. Here, the CBRAMS wind direction error is substantially smaller compared to Eta at the northern bay buoys (Fig 3a). CBRAMS wind direction error for the southerly wind category are further improved from the all wind classes prediction (median error reduced from 35.7 for Eta to 18.9° for CBRAMS at TPLM2). Eta predictions yield little differences in median error and error variability between all winds and southerly wind categories for TPLM2. Therefore, CBRAMS indicates a significant improvement in predicting the onset of the afternoon up bay breeze channeling which typically occurs in the summer afternoon. At the southern bay buoy, CBBT (Fig 3b), Eta and CBRAMS wind direction afternoon errors behave similarly implying that the Eta coarser resolutions are adequate. Both models show significant improvement for the southerly afternoon wind categories, implying that the bulk of the error for both models occurred in the prediction and timing of non-bay breeze or synoptically disturbed events. Since CBRAMS is initialized with Eta synoptic weather conditions, CBRAMS predictions would be forced by Eta synoptic weather conditions when this weather pattern is dominant.

4.2 Error Reduction

Comparison of CBRAMS error improvement over Eta in surface wind direction and speed are shown geographically as a percent change in Figs. 4-5. Only median error was used to evaluate CBRAMS percent model change from the median Eta error. CBRAMS wind direction percent error change over Eta for all afternoon wind directions and onshore winds are shown in Figure 4. A square next to a station indicates a positive improvement in wind direction error (error reduction) for CBRAMS predictions while a circle indicates an error increase in CBRAMS error compared to Eta. The size of the square or circle represents the percent change in the CBRAMS performance. For all afternoon wind directions (Fig 4a), a significant CBRAMS improvement is only seen at TPLM2, while a significant error increase is seen at the ocean influenced sites (KIPT and WAL) and a river site, LEWS. This implies that Eta adequately resolves the oceanic effect while CBRAMS introduces errors at river sites. In addition, large CBRAMS all-wind direction errors may be indicative of difficulties the model had in predicting convective and cloud-cover cases.

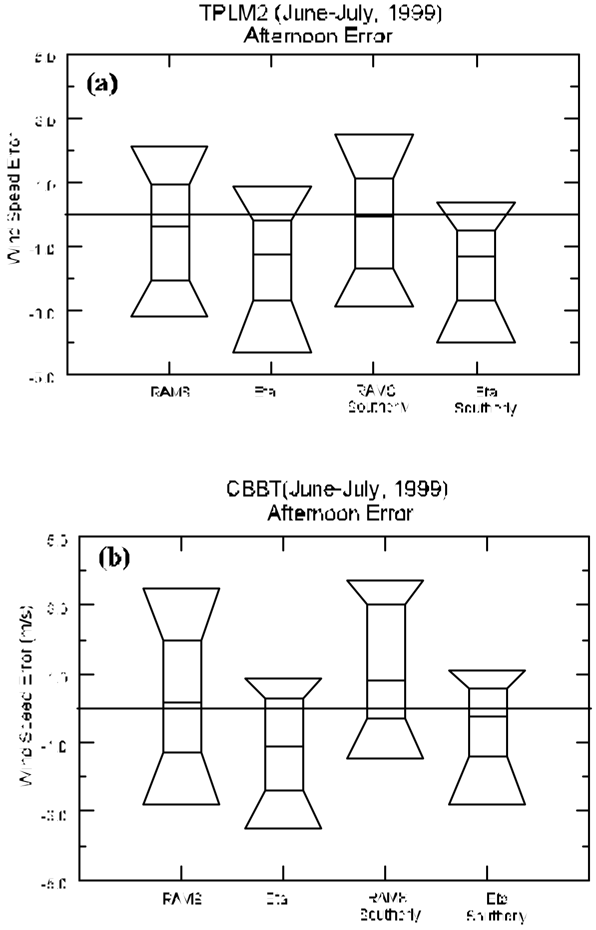

Figure 2. Eta-32 afternoon surface wind speed boxplot errors (m/s) compared against CBRAMS error boxplots at a) TPLM2 and b)CBBT. Box plots categorized for all winds and by southerly winds only.

For on-shore winds (Fig. 4b), CBRAMS improvement is seen at most sites with the largest improvement seen at the over-water and northern bay sites. It is in these regions of the Bay where CBRAMS increased resolution of the coastline and the water surface is particularly helpful. Percent improvement is smaller towards the southern, wider portions of the bay as the percent improvement decreases from 48% at TPLM2 to less than 10 % at CBBT. This also may be an indication that Eta resolution is adequate for the wider portions of the Bay and the coastal oceans.

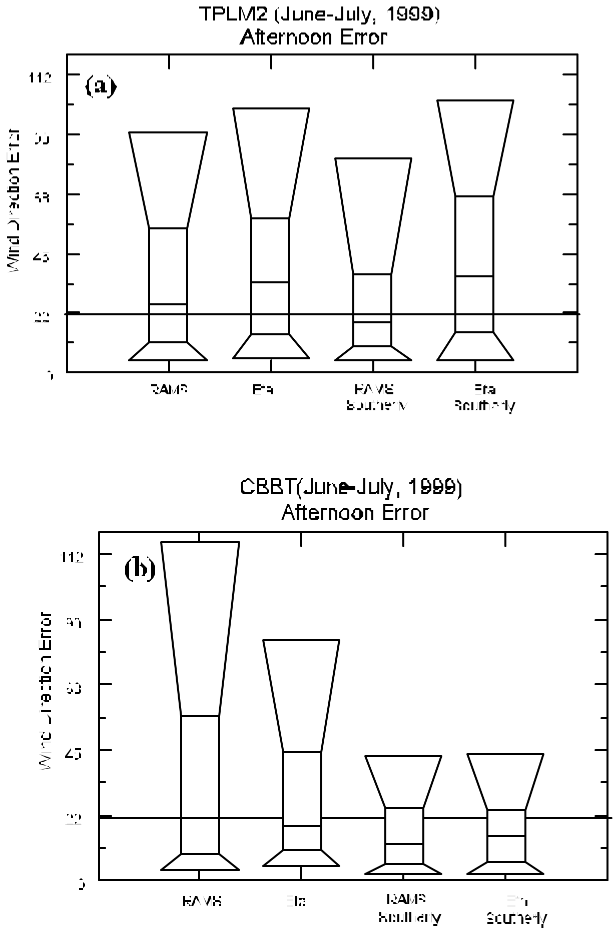

Figure 3. Same as Fig. 3 except afternoon wind direction box plot errors at a) TPLM2 and b) CBBT.

Surface wind speed bias error is shown in Fig. 5 for Eta (Fig 5a) and CBRAMS (Fig 5b). A square (circle) represents an over(under) estimate of wind speed. RAMS wind biases are near zero at all the over-water sites (TPLM2, CBOS, and CBBT) while Eta shows a characteristic speed underprediction over water. However, at the coastal river sites (TOLC, NHK, LEWS and WYE), CBRAMS overpredicts wind speed by overestimating the river breeze speed up effects. At other land and coastal sites, results are mixed. The smallest CBRAMS speed biases are at the over-water and coastal ocean sites where average wind speeds are stronger. Eta underpredicted wind speeds at most of these location especially TPLM2 and CBBT. Therefore, higher spatial resolution significantly improved the over-water wind prediction for the Chesapeake Bay estuary during the summer months especially in the narrower portions of the bay and over water.

5. CONCLUSIONS

CBRAMS for the CMDP has demonstrated that one to two day prediction of local-scale atmospheric phenomena (e.g.: bay breezes, channeling, increased over water wind speeds) is now possible with recent advances in computer architecture and parallel programming. Insights learned from this experiment will be valuable for future modeling over coastal environments.

Quantitative analysis showed that 4 km CBRAMS predicted the summertime up-bay channeling winds at TPLM2 and the CBOS buoy well with up to 54% wind direction error reduction over Eta predictions. Also, Eta predictions yield little differences in median error and error variability between all winds and southerly up-bay wind categories for the northern bay over-water sites.

For on-shore winds, the largest CBRAMS surface wind speed improvements occurred at over-water sites and in the northern narrower portions of the bay. The CBRAMS wind speed bias errors for over-water sites and for all wind directions cases were typically near zero. The Eta model forecasts consistently underpredicted wind speeds at the over-water locations. The absolute speed error were similar for both models (ranging between 1.5-2.0 m/s).

Both models show significant improvement for the southerly afternoon wind categories, implying that the bulk of the model error occurred in the prediction and timing of non-bay breeze or synoptically disturbed events. Also for all wind directions, CBRAMS errors were large and may be indicative of difficulties the model had in predicting convective and cloud-cover cases.

At the mouth of the Bay, wind direction predictions for southerly cases are much improved especially for CBRAMS where the median error falls to 10.9°at CBBT. For southerly wind cases, wind error and variability is reduced significantly for both models as well. The models may be behaving similarly in the southern and wider portion of the bay because the Eta model resolution is adequate there. The lower direction errors at CBBT for southerly wind cases imply that this flow regime can be predicted with higher confidence than other flows. The southern bay is often influenced by the summer time Bermuda high pressure pattern which results in southerly winds there.

Along river sites (e.g.: WYE, NHK and LEWS), CBRAMS strongly overpredicted (~+ 1 m/s bias) wind speed for all winds and on-shore winds cases. In addition, the absolute speed error for CBRAMS is much larger. During the demonstration, CBRAMS often predicted an up-river breeze wind speed acceleration when it in fact did not occur. CBRAMS probably over emphasized the river breeze effect because no river SST data was available and Bay temperatures were used instead. This would lead to an overestimate of the land-water temperature contrast as the Bay temperatures are colder than the shallower river temperatures. At ocean coastal sites, both Eta and CBRAMS adequately resolved the on-shore ocean breeze flows.

6. REFERENCES

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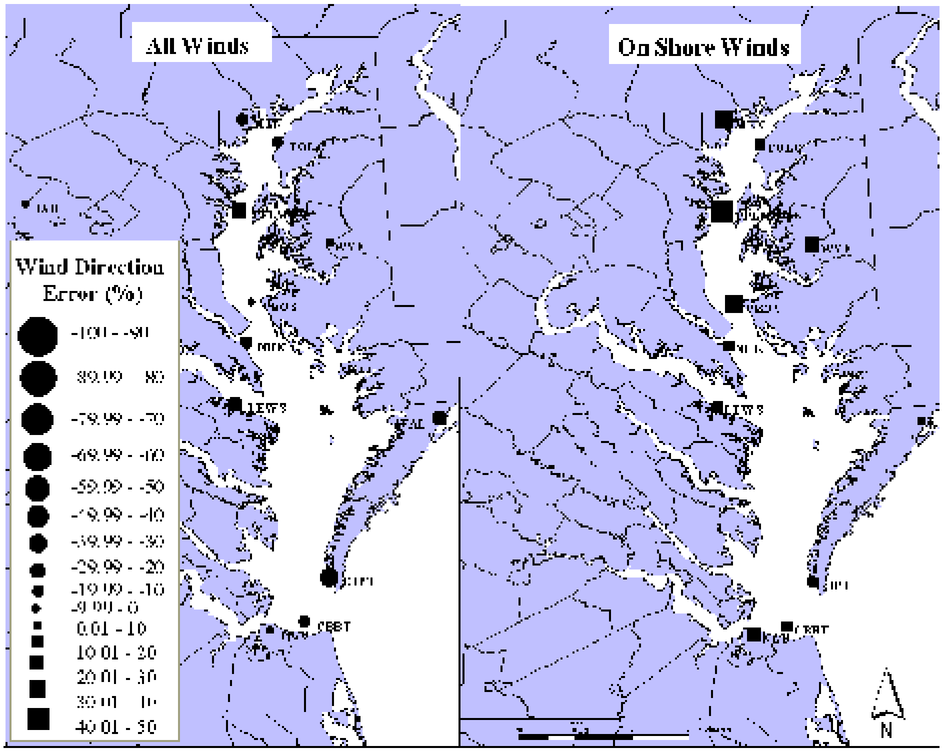

Figure 4. CBRAMS afternoon wind direction error reduction compared to Eta shown geographically as a percent change for a) All wind directions and b) for on-shore winds only A square (circle) indicates a reduction (increase) in wind direction error compared to Eta.

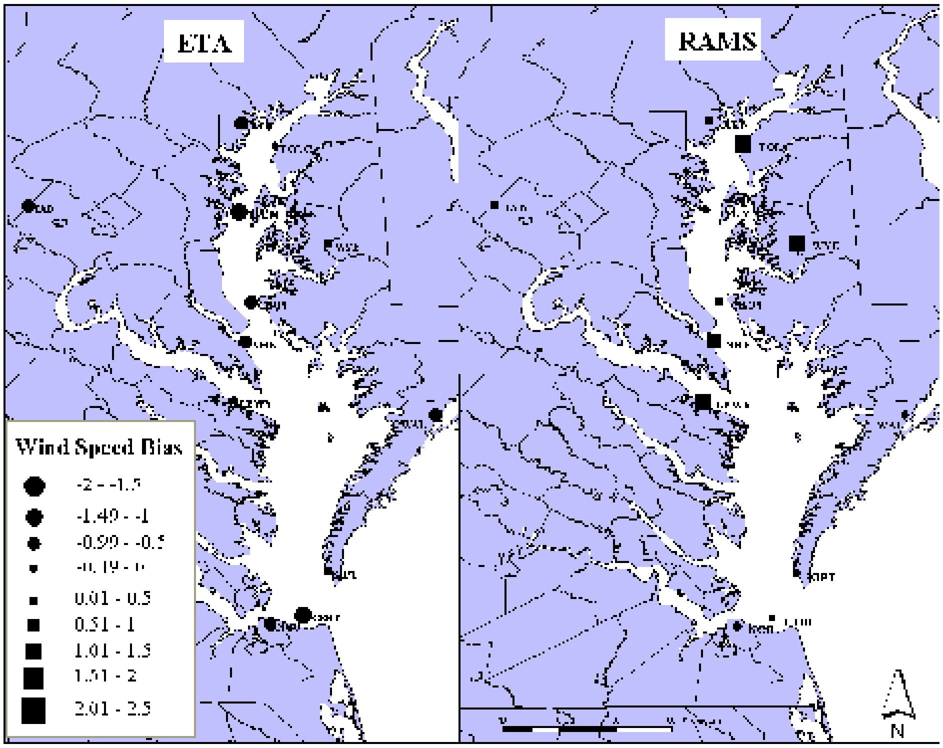

Figure 5. Wind speed bias error (m/s) shown geographically for both a) Eta and b) CBRAMS afternoon wind forecasts. A square(circle) indicates a positive (negative) wind speed bias.