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**Numerical Fog and Visibility Guidance in Coastal Regions**

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FIRST BULLETIN ON THIS SUBJECT

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This bulletin, prepared by Lawrence D. Burroughs and Jordan C. Alpert of the National Meteorological Center, describes the automated regional fog and visibility guidance for coastal regions of the United States. These forecasts are made with model output from a regional fog model developed by David Feit and Jordan Alpert. The fog model was implemented first for the Northeast Coast, effective with the 1200 UTC cycle on March 2, 1993. Eventually, regions along the Gulf of Mexico Coast and the West Coast (including the Gulf of Alaska) will be added. Other regions will be considered later.

Each implementation of a new region will be announced by a National Technical Information Message (NTIM), which is available under AFOS product identifier WSHPNSNMC (World Meteorological Organization [WMO] header NOFS41 KWBC), and amendments to this TPB.

Mary M. Glackin
Chief, Services Development Branch

# NUMERICAL FOG AND VISIBILITY GUIDANCE IN COASTAL REGIONS

by Lawrence D. Burroughs and Jordan C. Alpert,
Development Division, National Meteorological Center[1]

## 1. INTRODUCTION

A major concern to National Weather Service (NWS) marine forecasters is the problem of forecasting advection fog at sea. Previously, fog forecasts based on statistical methods were issued over the open ocean only (Burroughs, 1989; National Weather Service [NWS], 1989); until now, no system existed to provide similar guidance in coastal and offshore areas.

The Ocean Products Center (OPC) of the National Meteorological Center (NMC) has developed a partially diagnostic and statistical model designed to provide fog and visibility guidance in coastal and offshore regions. The first region for which forecasts are produced is along the Northeast Coast of the United States. It was implemented with the 1200 UTC cycle on March 2, 1993. The Regional Fog Model is transportable from region to region, (i.e. only the size of the region and its location varies, but not the model itself). The fog model will provide guidance for the West Coast (including the Gulf of Alaska) and the Gulf of Mexico Coast. The guidance is available on AFOS as four graphical products, and will also be available in the future in GRIdded Binary, or GRIB, files.

## 2. MODEL DESCRIPTION

To simulate the formation of fog and stratus, time dependent changes of temperature, water vapor, and liquid water content are predicted by the fog model. It consists of a variable horizontal region size and seven vertical layers between the earth's surface and 2 kilometers (km). Computations are based on standard finite difference techniques. Horizontal velocity fields in space and time for the forecast period are obtained from the Aviation (AVN) version of NMC's Global Model (Kanamitsu et al., 1991) for both the 0000 and 1200 UTC cycles. The AVN velocities are used to advect heat, moisture and liquid water in the Regional Fog Model. For the East Coast region, a 20 by 20 subset of the Regional Analysis and Forecast System (RAFS) C grid (NWS, 1985) is used. There are seven vertical layers between the lowest, at 25 m above the sea surface, and the top of the model, which is close to 2 km. The five highest vertical levels are designed to approximately coincide with the first five sigma levels of the AVN model, starting with fog model level 3. The fog model level 2, at 25 m, is the level used to determine visual ranges and fog conditions (see Fig. 1).

The initial conditions for the fog model are obtained from the Spectral Statistical Interpolation (SSI) analysis (Derber et al., 1991). The boundary conditions for potential temperature, specific humidity, u- and v-wind components, and surface pressure are obtained from the AVN model. A buffer zone is used on lateral boundaries to facilitate a smooth transition between the AVN and the Regional Fog Model. At the boundary grid points, only values from the AVN are used. At the first gridpoint in from the boundary, a mix of two-thirds of the AVN boundary value and one-third of the fog model value is used. At the second gridpoint in, a mix of one-third AVN and two-thirds fog model is used. At all other interior points, only fog model values are used. Boundary values are updated by the fog model advective scheme only if there is advection from the fog model interior domain to the boundaries. Otherwise, the lateral boundaries are interpolated linearly in time from the

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AVN model output at 12-h intervals. The sea surface temperatures at the lower boundary are the same as those contained in the AVN model. These are held constant for the duration of the fog model run. The AVN vertical sigma coordinate is interpolated to the fog model's height coordinate. Horizontal interpolation is used to transform the AVN gaussian grids to the fog model's domain.

Physical processes included in the fog model are eddy diffusion, horizontal advection, and fog droplet fallout. Fluxes of heat and water vapor between the ocean and fog model layer 1 are calculated by taking into account the air density, heat capacity at constant pressure, and the exchange coefficients for sensible heat and moisture. Fog model diffusion, at interior model levels, is handled by computing exchange coefficients for potential temperature, specific humidity, and liquid water, following Blackadar (1962). The model physics are made simple with the goal of executing quickly, so that many ocean areas could be included. Predictions to 48 hours take less than 1 minute on the NMC CRAY computer. The fog model is designed to handle advection fogs which occur when warm moist air is advected over cooler water (April - September on the East Coast). These fogs generally occur when conditions are stable or near neutral, not unstable. Thus, this model doesn't handle steam fogs or "Arctic Sea Smoke", which occur when the water is warmer than the air being advected over it; this would require more complex physics and higher model resolution. The system uses a wet-bulb adjustment. Imbalances in the hydrologic cycle are left to the next time step to correct.

A simple parameterization of droplet fallout is used which contains three categories of droplet sizes. Terminal velocities are associated with each droplet category, and a percent by mass of liquid water content is given to each category. This permits the flux of liquid water loss to be calculated. This, in turn, allows the fog cloud to dissipate over time. However, radiation effects are not included at this time. For complete details on the model, see Alpert and Feit (1990).

## 3. POST-PROCESSING

Liquid water content from the fog model is converted to visibility in the post-processing step. An algorithm, which relates liquid water content to visibility, was developed from the results of a study done by Wiener et al. (1961). Visibility at sea ranges from 0 to 13 km (the maximum range to the horizon from the bridge of most ships). Fog is reported if visibility is 1 km (0.5 n mi) or less. A liquid water content of 0.04 grams/cubic m is required to produce a visual range of 1 km. When the liquid water content is greater than 0.5 $gm^{-3}$, the droplet sizes become too large for fog, drizzle, or light rain, and the visual range begins to increase. Fog can occur, but it is no longer the main obstruction to visibility. The liquid water content is damped above 0.5 $gm^{-3}$, so that fog will rarely be displayed, although visual ranges of 5.5 km (3.0 n mi) may be depicted.

## 4. AVAILABILITY

The Regional Fog Model visibility guidance is available as a set of four graphics for AFOS users, and will eventually be available to the NWS Alaska Region and to Family of Services' Numerical Products Service/Direct Connect Service subscribers in four GRIB files. The implementation date for the production of the GRIB files will be announced in a National Technical Information Message (AFOS product identifier WSHPNSWSH; WMO header NOUS41 KWBC).

The domain of the Regional Fog Model is a small subset of the RAFS expanded C grid (discussed in Section 2). Where there are data from the model, the visibilities range from 0 to 13,000 m. Where there are no data, 30,000 m is used. Eventually, as other regions are added, they will be included in the various output products.

Output from the fog model is available year-round. The fog season for the East Coast guidance is April 1 - September 30.

### a) AFOS graphics

The fog guidance is available on AFOS at 12-hour intervals from 12 through 48 hours from both the 0000 and 1200 UTC cycles, for a total of four AFOS graphics per cycle. The graphics based on the 0000 UTC cycle will be available at approximately 1000 UTC; the 1200 UTC guidance will be available around 2100 UTC. The AFOS product identifiers for the four fog graphics are:

NMCGPH02W - 12HR CST FOG FCST
NMCGPH04W - 24HR CST FOG FCST
NMCGPH06W - 36HR CST FOG FCST
NMCGPH08W - 48HR CST FOG FCST

The AFOS graphics are displayed on the North American background (B02). Use of this background allows for other regional fog output to be added to these graphics. Figure 2 shows a sample AFOS graphic from the fog model, at a 1:1 zoom level (full size, as transmitted). It is recommended that a 9:1 zoom be used when viewing the fog model graphics on an AFOS Graphics Display Module (GDM), as shown in Fig. 3.

Beside showing visual ranges of 0.5 n mi (fog) and 3.0 n mi and the model boundaries, a statistically derived climatological barrier is also shown on the AFOS graphics. The barrier was taken from a study by Burroughs (1987). Fog rarely occurs to the east of the barrier, while it frequently occurs to the west - especially in the spring and summer months. To account for this, visibility restrictions are severely damped east of the barrier. This doesn't mean lowered visibilities can't occur there; however, when lowered visibilities are present, they occur in isolated heavy showers or thunderstorms which cannot be resolved by the fog model, and, in general, lowered visibilities will rarely occur in that part of the model domain.

The plotted visibilities are in nautical miles to conform to forecast requirements contained in Weather Service Operations Manual D-51 (NWS, 1986). The two visibilities highlighted show where visual ranges go below 3 n mi and where fog is likely. Both must be included in forecast discussions issued by NWS offices with marine responsibility if they are forecast to occur.

Currently, the four fog graphics are only available on the Eastern Region's Regional Distribution Circuit (RDC) of the AFOS network. The graphics will be made available to other RDCs as more fog guidance is developed for additional coastal regions.

### b) GRIB files

GRIdded Binary (GRIB) files were approved for use by the World Meteorological Organization (WMO) in 1985. They are designed to be efficient vehicles for transmitting large volumes of gridded data over high-speed telecommunication lines using modern protocols. Stackpole (1992) gives complete information on GRIB as it is used by NMC. To conform to WMO and NMC standards, meters are the units used in the GRIB file output from the fog model.

The WMO headers for the fog GRIB files will be:

FXUS42 KWBC - 12 h Coastal Fog Model GRIB Forecast
FXUS44 KWBC - 24 h Coastal Fog Model GRIB Forecast
FXUS46 KWBC - 36 h Coastal Fog Model GRIB Forecast
FXUS48 KWBC - 48 h Coastal Fog Model GRIB Forecast

When implemented, the GRIB files will be available to the NWS Alaska Region and on the Family of Services' Numerical Products Service and the Direct Connect Service. A decoder will be necessary to use these files. NMC can furnish a decoder - contact Automation Division (301-763-8115) for more information.

## 5. EVALUATION/VERIFICATION

Evaluations of the skill of the Regional Fog Model for the East Coast region are shown in Fig. 4, parts a and b. Fig 4a gives results for a sample from May through July 1990. At the time, the model was only being tested out to 36 hours, so there is no result for 48 hours. Fig 4b presents an off-season evaluation for a one week period, beginning February 28, 1992. In general, the model does somewhat worse off-season than during the fog season (April-September for the East Coast). The results are quite good and are typical for most years. However, during the prime fog season for 1992, the model did worse than expected. The reasons for the decrease in skill is being investigated. Preliminary results indicate a combination of changes to the global model and an unusual weather year may have contributed to the decrease in skill. The patterns appeared to be correct in size and shape, but offset from the actual areas of lowered visibilities and fog.

## 6. OPERATIONAL CONSIDERATIONS

The fog model is designed to predict advection fogs and, therefore, will give the best results during the months of April through September (warm season) when advection fogs are most prevalent. The model is run year round, and adjustments to the post-processor have been made to account for the over-prediction of liquid water during the months of October through March (cool season).

The fog model has no radiation parameterization at this time, and dissipation of the fog cloud is slowed as a result. This is an improvement which will be added in the future. It also has limited knowledge of convective activity or non-convective rain production. These parameters are available from the AVN. This information will be added as an upgrade to the model which will allow it to discriminate better between fog, rain, and shower situations.

Forecasters should be aware that the fog model generally produces too much fog and too large an area of lowered visibilities - especially during the cool season. It also tends to make the fog persist longer than it should because of the lack of a radiation parameterization. This deficiency will be rectified soon.

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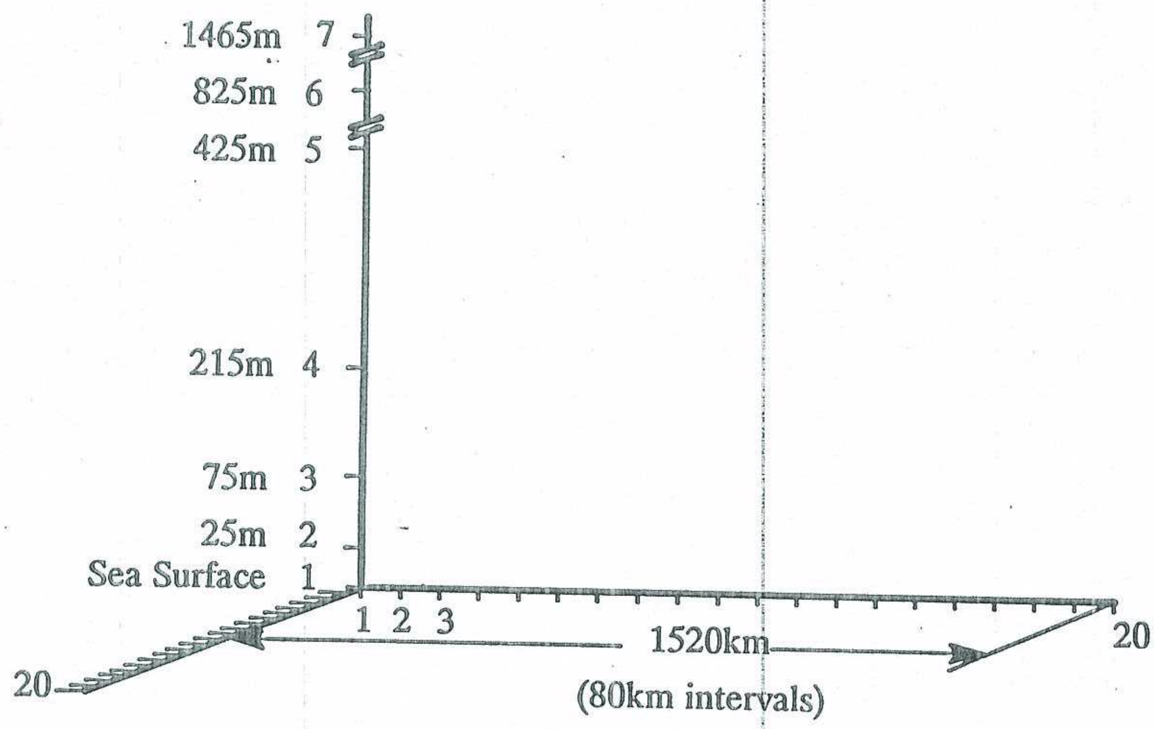



Figure 1. Regional Fog Model horizontal and vertical grid dimensions for the region along the Northeast Coast of North America. For other regions, the vertical grid remains the same, but the horizontal grid dimensions and locations will change.

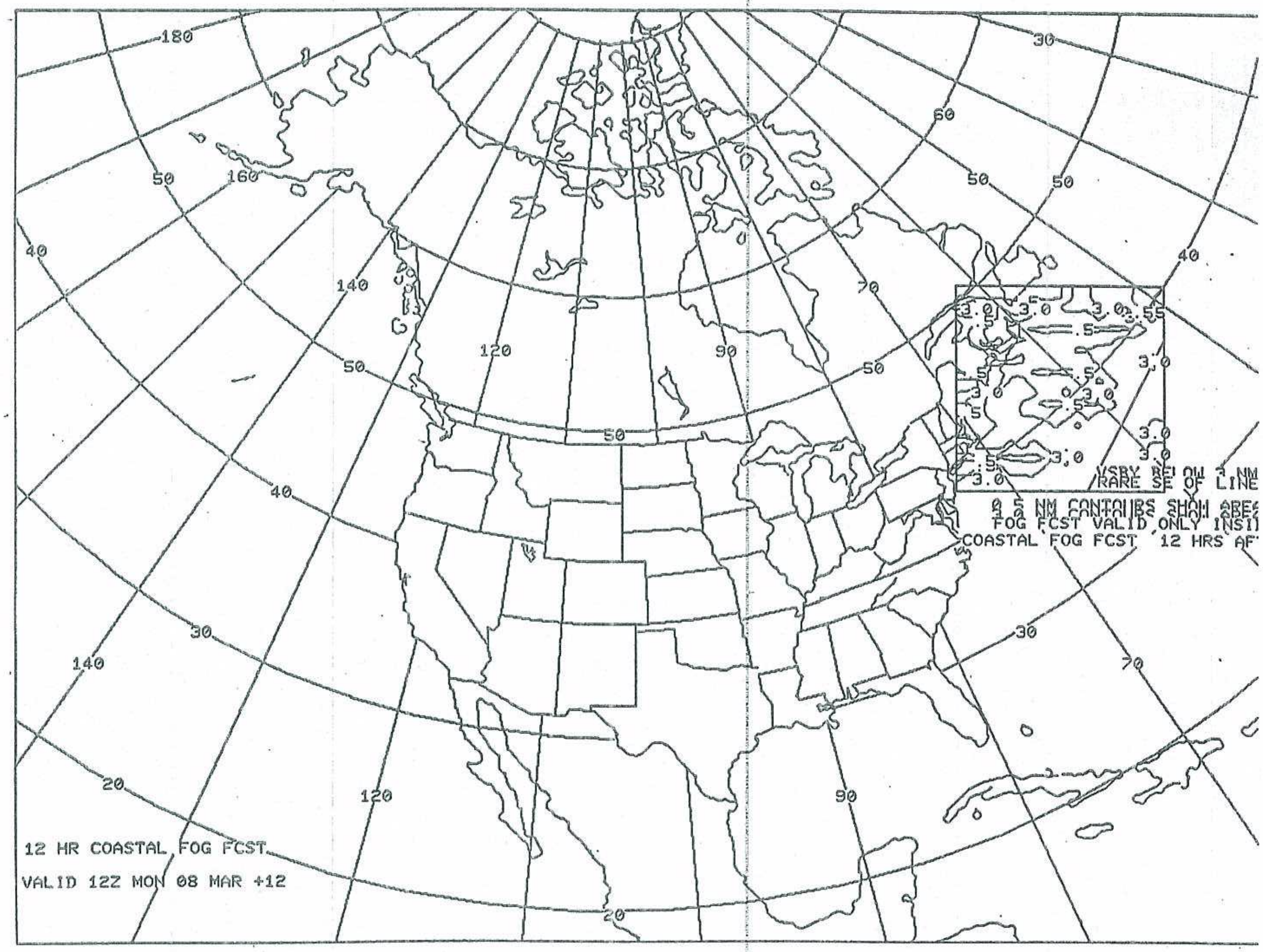



Figure 2. Sample AFOS graphic NMCGPH04W (24 h Coastal Fog Model Forecast) at 1;1 zoom ratio ("unzoomed"). A 9:1 zoom of this same graphic is shown at the recommended 9:1 zoom ratio in Figure 3 , with a full explanation of the graphic.

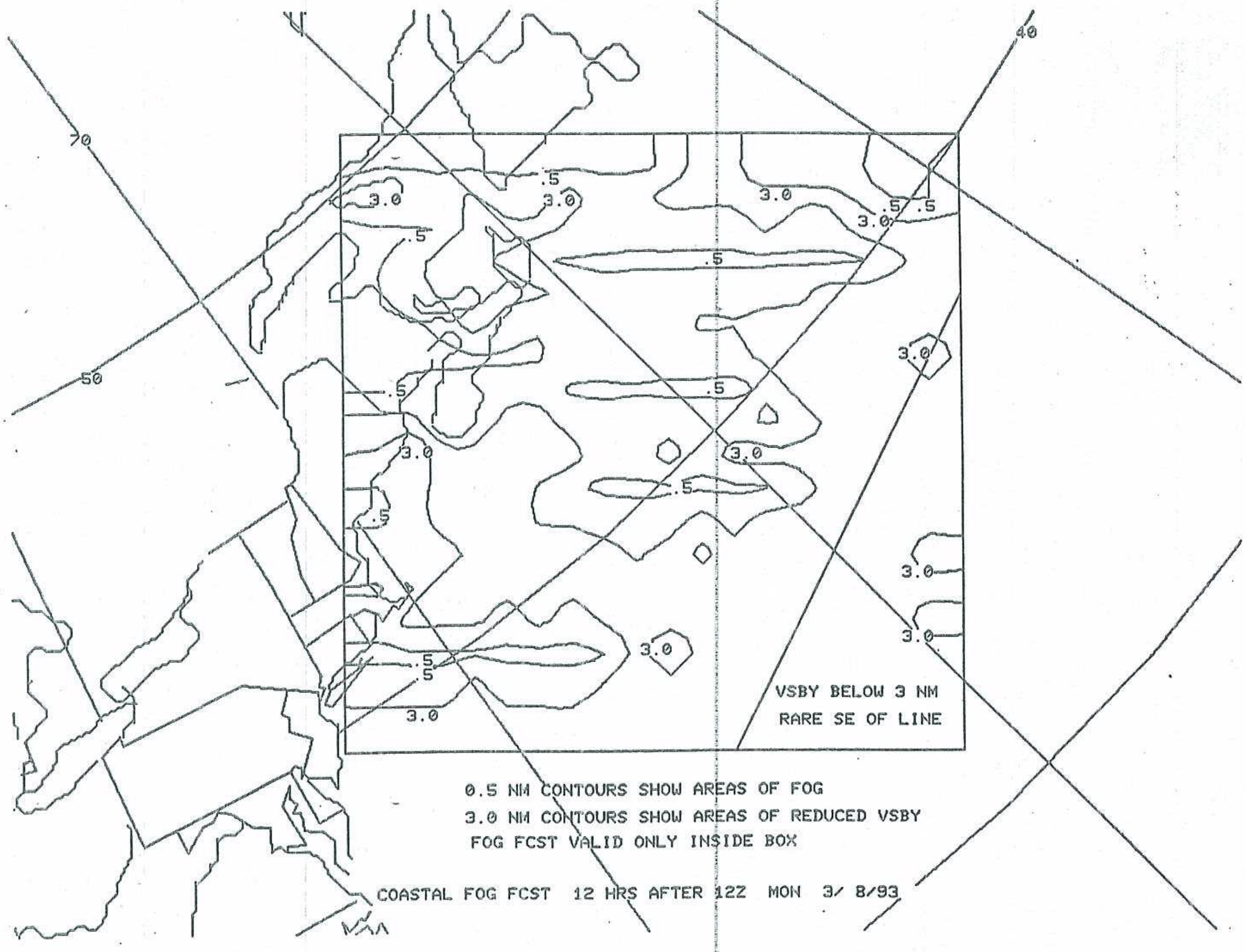
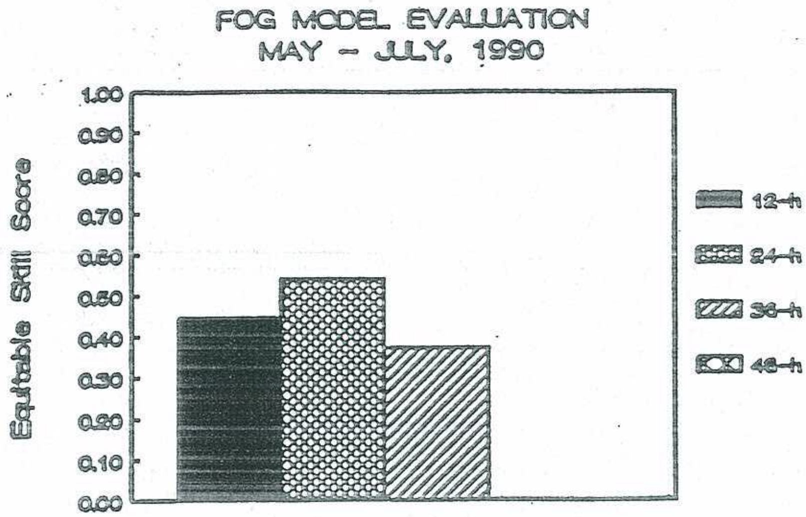



Figure 3. Sample AFOS graphic NMCGPH04W, at 9:1 zoom ratio. Boxed area shows the valid region for the Regional Fog Model along the East Coast of the United States and Canada. The diagonal line in the lower right corner delineates where lowered visibilities and fog are climatologically rare. Contours are in nautical miles.

a)




b)

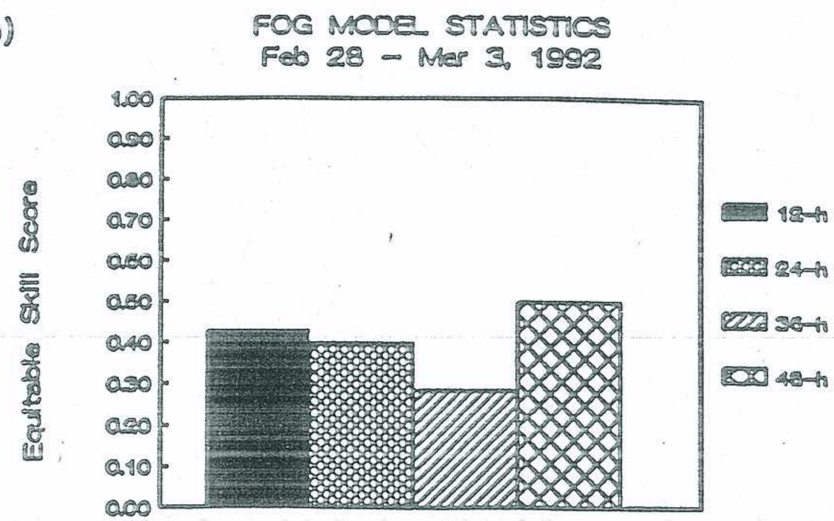



Figure 4. Skill score results for the Northwest Atlantic region of the Regional Fog Model. Fig. 4a shows results for May through July 1990. At that time the model was only run though 36 hours. Fig. 4b presents results from a small off-season sample from February 28 - March 3, 1992.