# Description of Field-Selected Algorithms for National Blend of Models (NBM)

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[For comments, please use the Working Version]

## 1. Introduction

The **Analysis and Nowcast Branch (AFS11)** within the Analyze, Forecast, and Support (AFS) Office of the National Weather Service (NWS) developed and conducted a field

[1] The questions developed based on field input (e.g., field surveys, stakeholder feedback)
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survey on the National Blend of Models (NBM) in collaboration with the Digital and Graphical Information Support Branch (AFS13). AFS11 released in Fall of 2022, a Report on the Evaluation of NBM, and described their work on the verification and validation of the NBM v4.0 and the newer version (v4.1) as an effort to address the needs of the field through case studies. Also in 2022, the **NBM Development Team of the Meteorological Development Laboratory (MDL)** collected NBM v4.1 Stakeholder Feedback. Based on the input collected from the field and stakeholders and conclusions obtained from the AFS11 report, it was determined that there were several algorithms and other details of the NBM that were either not well-documented or not well-understood. The need to document these specific algorithms of the NBM was also brought up during the FY23 AFS Annual Operating Plan (AOP) Meeting.

The purpose of this document, which is the result of the collaboration between AFS11 and the NBM Development Team, is to help provide plain language summaries to the field offices so that they can better understand how certain algorithms work in parts of the NBM. This document is to complete the AFS11 FY23 milestone, *"Development and field-distribution of documents that explain the rationale behind the basic NBM algorithms and methodologies for its forecast operations"*. To accomplish this goal, we collected summary responses from the NBM developers and collected additional documentation or training sources which are highlighted in each section below. In addition, NBM has a NOAA Virtual Lab (VLab) forum, v4.1 Master Documentation, and the v4.1 Service Change Notice (SCN) containing additional resources regarding the model. AFS11 analyzed various information from the field's input (e.g., field surveys, stakeholder feedback) and came up with a list of questions that the field wanted to ask. The NBM Development Team provided answers to the questions. And, both teams provided discussions on the outcome while AFS11 performed the final editing. Please note that this list will be updated later when needed or requested to accommodate additional needs for documentation, which did not show up during our initial need-collection phase.

## 2. How are the Percentiles Computed?

A percentile is a value from a sample data or population describing the percentage amount of values that are less than the percentile value. The units of a percentile value are the same as the units of the sample data or population. A common example is the 50th percentile (i.e., the median), which is a value of a dataset where half of the values are less than the value. Conversely, this means that the other half of the values are greater than the 50th percentile. Another example is the 75th percentile, a value in which 75% of the data values are less than.

In the NBM, percentiles are computed explicitly from a sample of forecast values. The following procedure is performed per grid point:

1. Sort an array of values in ascending order (i.e. from smallest to largest). Computationally speaking and programmed in Fortran, the sorted values are stored in a 1-dimensional array where the index (i.e., the location in the array) of the smallest value would be 1 and the largest value would have an index equal to the size of the array (i.e., the last value).

2. Determine the value of the index location of the N-th percentile via the following expression: IDX = (N/100) * M, where IDX is the index location associated with the N-th percentile; N is the percentile value; and M is the total number of values.

3. Further evaluation of IDX is required. If IDX is a whole number, the N-th percentile is the value stored in the array at location IDX. If IDX is a real value, then we use the Fortran intrinsic functions FLOOR and CEILING to find the lower and upper index values that bound IDX. For example if index location is IDX = 23.4, then FLOOR(IDX) = 23 and CEILING(IDX) = 24, then we can perform a linear interpolation of between the values at the 23rd and 24th index locations to determine the N-th percentile value.

## 3. What is Quantile Mapping & Dressing (QMD)?

QMD is a bias correction technique that leverages the entire distribution of events in the form of Cumulative Distribution Functions (CDFs) for a given variable over some N-day training period for the model forecast system and for the analysis (truth). Given today's forecast value at that grid point, one can determine the associated quantile from the forecast CDF and then replace the forecast with the analyzed value associated with that same quantile. Quantile mapping adjusts for bias conditioned on the forecast precipitation amount, and it does so in a way that avoids the collapse of spread common with regression approaches when there is little relationship between the forecast and observed . It should be noted here that the "D" in QMD represents the dressing of the quantile-mapped value. At this time, no dressing is performed in the QMD system. National Centers for Environmental Prediction (NCEP) Central Operations (NCO) has a strict reproducibility requirement, which doesn't allow random noise for exact solutions, and we were forced to turn off the dressing in NBM v3.2. A walkthrough demonstration of the Quantile Mapping Correction Procedure is available here.

**Precipitation**

The NBM produces calibrated precipitation guidance that is generated using the QMD correction technique for the Alaska, CONUS, Hawaii, Oceanic, and Puerto Rico National Digital Forecast Database (NDFD) domains and initialized daily at 0000, 0600, 1200, and 1800 UTC. Probabilistic guidance in the form of percentiles of QPF (1 through 99); probability exceedance thresholds; and a single deterministic value (the mean of QMD values per grid point) is generated for precipitation duration periods of 6-, 12-, 24-, 48-, and 72-hours, out to Day 11. The probability exceedance thresholds change per the precipitation duration period.

Precipitation QMD uses a Multi-Model Ensemble (MME) composed of 200 models from 17 deterministic and ensemble modeling systems, at the shortest lead times. Gamma distribution parameters are estimated from training data for each modeling system and for the analysis. Each model or ensemble member is quantile mapped using their modeling system CDF to the analysis CDF. The MME size is inflated by using a 3x3 (9 point) stencil whereby the forecast and model CDF at each stencil point is quantile-mapped to the analysis CDF of the center grid point.

Please see the "Configuration and Technical Details of Blend Precip QMD v4.1" documentation for more detailed information on the QMD procedure for precipitation.

**Maximum/Minimum 2-m Temperature**

Calibrated, probabilistic 18-hour maximum and minimum 2-meter temperatures are generated from the same quantile mapping technique for Alaska and CONUS NDFD domains and initialized daily at 0000, 0600, 1200, and 1800 UTC. The forecast projections that these products are available for vary by the initialization cycle and are roughly equivalent to a "daytime maximum temperature" and "nighttime minimum temperature".

While the overall calibration technique is the same as precipitation, the probability distribution is different. Temperatures are generally normally distributed and therefore we use a Gaussian distribution where we compute the mean and variance of the variable in order to estimate the CDF for each modeling system and analysis using the previous 60 days of model forecasts and analyses. Stenciling and Savitzky-Golay smoothing are turned off for temperature quantile mapping.

| Maximum Temperature | | |
|---|---|---|
| | **Alaska** | **CONUS** |
| Probability of Thresholds | ≤ -40℉, ≤ -20℉, ≤ 0℉, ≤ 32℉, ≤ 50℉, ≥ 70℉, ≥ 80℉, ≥ 90℉ | ≤ 0℉, ≤ 28℉, ≤ 32℉, ≥ 80℉, ≥ 90℉, ≥ 100℉, ≥ 110℉, ≥ 120℉ |
| Percentiles | 1 through 99 | |
| Single Value | Deterministic, Standard Deviation | |
| **Minimum Temperature** | | |
| | **Alaska** | **CONUS** |
| Probability of Thresholds | ≤ -40℉, ≤ -20℉, ≤ -10℉, ≤ 0℉, ≤ 10℉, ≤ 28℉, ≤ 32℉, ≥ 80℉ | ≤ -40℉, ≤ -20℉, ≤ -10℉, ≤ 0℉, ≤ 10℉, ≤ 28℉, ≤ 32℉, ≥ 80℉ |
| Percentiles | 1 through 99 | |
| Single Value | Deterministic, Standard Deviation | |

**24-Hour Maximum 10-m Wind Speed/Gust**

Calibrated, probabilistic 24-hour maximum 10-meter wind speed and gust are generated from the same quantile mapping technique for the CONUS NDFD domain and initialized daily at 0000, 0600, 1200, and 1800 UTC. Similar to precipitation, the distribution wind speed and gust values are best defined by a Gamma distribution. Gamma distribution CDFs are generated using the previous 120 days of model forecasts and analyses. This is an extension of the 60-day training sample found in temperature and precipitation products to attempt to better capture seasonal transitions. Stenciling and Savitzky-Golay smoothing are turned off for wind quantile mapping.

| Maximum Wind Speed | |
|---|---|
| Probability of Thresholds | ≥ 11 kts, ≥ 17 kts, ≥ 22 kts, ≥ 34 kts, ≥ 48 kts, ≥ 64 kts |
| Percentiles | 1 through 99 |

| | |
|---|---|
| Single Value | Deterministic, Standard Deviation |
| **Maximum Wind Gust** | |
| Probability of Thresholds | ≥ 22 kts, ≥ 34 kts, ≥ 41 kts, ≥ 48 kts, ≥ 56 kts, ≥ 64 kts |
| Percentiles | 1 through 99 |
| Single Value | Deterministic, Standard Deviation |

## 4. How is the Initial Interpolation to the NBM grid performed?

Most model inputs are not on the native NBM grid, which is a Lambert Conformal, 2.5 km 2345 x 1597 grid in the Continental United States (CONUS), and come in a variety of shapes and sizes. For global grids that are coarser than 23 km, the NBM uses a data gridding program (wgrib2's) new grid interpolation function (code in Appendix #1) to place them on a uniform grid that can be ingested by the Model Output Statistics (MOS)-2000 software. MOS-2000 can only read in three types of map projections, Lambert Conformal, Polar Stereographic, or Mercator. Therefore, a pre-interpolation step using wgrib2 must be done on inputs that aren't available on one of those map projections. We don't put these inputs on the NBM regional grid at this point to reduce the computational power needed for some of the basic post-processing that needs to be done, such as time interpolation, computing max/min fields, obtaining probability of precipitation from total precipitation, etc. Most elements are interpolated using bilinear interpolation, with the exceptions of Accumulated Total Precipitation (APCP) fields using budget interpolation, and ceiling/visibility grids using nearest neighbor.

High resolution inputs, such as the High-Resolution Rapid Refresh model (HRRR) or North American Mesoscale (NAM) Nest, are read directly into the MOS-2000 software, because they exist on WCOSS on one of those previously-mentioned map projections. While even these high-resolution inputs are not on the native NBM grid at this point, it still saves computational power to leave them on their native grid before performing our basic post-processing computations.

For the final step before moving onto other aspects of the Blend, like bias-correction with analysis data, an internal software code is again used to interpolate all model data to the NBM grid for that region. As noted above, depending on the element, the interpolation used is either bilinear, budget, or nearest neighbor. The codes used do not attempt to downscale or use a smartinit to interpolate this data.

## 5. How are the Weights Determined: Mean Absolute Error (MAE) Versus Expert Weights

The basic rule of thumb is to use dynamic Mean Absolute Error weighting for elements that have a gridded analysis field available that we can use to "update" the weights on a daily basis. Once a day, forecasts from all input models in the NBM are compared against the verifying UnRestricted Mesoscale Analysis (URMA) analysis to compute a bias delta and an MAE. This computation is done separately at all grid points, to better capture local biases. In order to keep a "memory" of the previous trend in bias delta and MAE, a decaying average equation is used to adjust the bias delta (equation in Appendix #2) and MAE (equation in Appendix #3) computed from yesterday's "update".

Here's a list of fields that are computed using MAE weights (equation in Appendix #4), as of Blend v4.1, and the analysis used to correct it:

- URMA
    - Temperature, including Daytime Maximum and Nighttime Minimum
    - Dewpoint
    - Wind Speed and Gust
    - Sky Cover
    - Significant Wave Height (Except Oceanic, which uses Wave Watch 3 Analysis)
- Multi-Radar Multi-Sensor System (MRMS)
    - Maximum Hourly Reflectivity
- Rapid Refresh modeling system (RAP) analysis field
    - Transport Wind Speed
    - Mixing Height
- Global Data Assimilation System (GDAS) (For Oceanic and Global domains)
    - Temperature
    - Relative Humidity
    - Wind Speed
    - Geopotential Height

Expert weighting is done when no analysis exists, and a subjective weight is needed to give more weight to models where it is accepted that their performance is better than other models being blended. The weight choices are determined based on knowledge of past performance of the different inputs and typically change with forecast projection to account for models dropping out of the blended solution. Unlike the MAE weights which vary day to day, the expert weights are static and are only changed when implementing a new version, if necessary. The NBM team has compiled spreadsheets showing what the weights are for various elements in v4.0 and v4.1. The team is aware of a handful of discrepancies within these spreadsheets, including inputs that don't add up to 100 or sum to a value greater than 100; these will be fixed in a future version, but they are not a detriment to the products.

For both MAE and expert weighting, if an input is missing for any given NBM cycle, its weight is not used and is "distributed proportionally" to other inputs. For example, if an element has an expert weighting of 50% Global Forecast System (GFS), 25% Global Ensemble Forecast System (GEFS), and 25% ECMWF (officially, Integrated Forecasting System or IFS), and if ECMWF is missing, that lost 25% weight is distributed proportionally to the GFS and GEFS. In this simplified example, the weights would become 66% GFS and 33% GEFS.

## 6. How are Winter Products Computed?

The Winter Weather system in Blend v4.1 was expanded from 18 members to 100 members. Due to current software limitations, 100 members is the most that can be accommodated. Each input provides a dominant precipitation type where precipitation has occurred since the last time step. This is then applied to the direct model output QPF and computer Snow-to-Liquid ratio (SLR), if the precipitation type is snow, to determine an accumulated snow or ice amount. For ECMWF, GEFS, and Short Range Ensemble Forecast (SREF) inputs, the raw precipitation field is replaced by the bias-corrected QMD precipitation.

**Snow Liquid Ratio (SLR)**

We compute a SLR based on the model's vertical profile to change the QPF forecast to snowfall accumulation. The final SLR is a combination of four different methods. First, the Cobb method (Cobb and Waldstreicher, 2005) which takes into account vertical motion and humidity to better describe the snow crystal types to inform the SLR. Second, the Method for Max Temperature Aloft simply applies the maximum temperature in the model's vertical profile to an equation to derive SLR. Third, the Weather Prediction Center's Roebber method (Roebber et al., 2003) takes into consideration cloud microphysics along with the vertical profile present in the model.

Finally, the 850-700 mb thickness method (Bourguin, 2000) which estimates the SLR based on the thickness of the vertical profile. The exact configuration of methods and weights applied to each input's SLR is shown on slide 16 of the snow documentation noted above.

**Snow / Ice Amounts**

For deterministic snow/ice amounts, an expert weighting system is used, as described in a previous section. The probabilistic percentiles and thresholds, however, are essentially "equally weighted". All 100 members are used to create a single CDF, from which percentiles and thresholds from that CDF are derived. So, if one is looking at a 20% probability of a 24-hour snow amount exceeding 1 inch, this can be understood as 20 of the 100 members in the system forecasted at least 1 inch of snow in that 24-hour window. This may, however, create an inconsistency with respect to the deterministic snowfall amount which is expert-weighted. For example, let's assume the HRRR is one of those 20 models that forecasted over an inch of snow, but it's showing 6 inches of snow. Since the HRRR is weighted very heavily in the NBM deterministic product, the final deterministic snowfall accumulation is likely to be higher than one expects given the probabilistic product showing a 20% chance of more than 1 inch of accumulation. The same is true of the percentile product, the 50th percentile could be very different from the deterministic expert weighted forecast because of how the weights are applied.

**Consistency between Deterministic and Probabilistic Products**

The discrepancy between deterministic and probabilistic answers from a blended solution is a complicated problem to solve. There are instances in the forecast process where a single model, or handful of models, better represents the upcoming scenario. For a true probabilistic ensemble, with a large variety of inputs providing different solutions, better performing models will get dampened because the probability space in the NBM doesn't treat any inputs different from the rest. In the NBM's probabilistic space, all inputs are seen as just-as-likely of a solution as any other input. However, the NBM still has a deterministic blended product for a lot of these variables because of the need to convey that some inputs are trusted more than others, and the need to generate a single forecast out of a multi-model ensemble is still desired. Work is ongoing on how to best approach ingesting 100+ different inputs, understanding that some of those inputs are traditionally more trusted than others, but still keeping the probability space scientifically valid.

## 7. How are Other Products Computed?

**Wet Bulb Globe Temperature (WBGT)**

Wet Bulb Globe Temperature (WBGT) indicates heat stress to humans and animals, accounting for temperature, wind, humidity, and intensity of solar radiation (as determined by sky cover, latitude, and sun angle), and is calculated as described in Dimiceli and Piltz (2011) or Dimiceli et al. (2011) as a combination of the dry-bulb temperature, wet-bulb temperature, and black globe temperature (a measure of incoming solar radiation).

WBGT is calculated for the CONUS, HI (Hawaii), PR (Puerto Rico), and GU (Guam) domains. Rather than being calculated for each individual model input and then blended, WBGT is calculated from final NBM inputs: bias-corrected, MAE-weighted Temperature, Dew Point, Sky Cover, 10-m Wind Speed, and MSLP (NBM Oceanic domain 50th percentile MSLP is interpolated onto each regional grid). Static data for each domain are also used - these include terrain, albedo, surface roughness, and timezone for each NBM gridpoint. NBM WBGT code is based on code currently used in NDFD.

**Fire Weather Elements**

NBM v4.1 contains a variety of fire weather elements. Mixing Height is calculated using a modified Stull Method that accounts for the buoyant effects of moisture. In a change from previous NBM versions, Mixing Height and Transport Wind Speed are now bias-corrected to the RAP analysis. Transport Wind Direction is calculated based on average U and V winds between the surface and the Mixing Height. Ventilation Rate is simply the product of the bias-corrected, MAE-weighted Mixing Height and Transport Wind Speed.

Two fire weather indices are calculated: the Haines index, a moisture and stability index used to assess the probability that a fire will become large or erratic, and the Fosberg Fire Weather Index, a surface-based index representing flame length and fuel drying. Downward short-wave radiation flux at the surface is blended from direct model output. Please note that the Haines index will likely be discontinued as an operational forecast element in the future in favor of other forecast elements that more accurately predict moisture and instability combinations that lead to extreme fire behavior.

More detailed information on the fire weather elements can be found below.

- Mixing Height
  - **Technique used:** Two techniques depending on model (see "Included Models" below). Five models use a modified Stull method, while the other seven models use Planetary Boundary Layer (PBL) height as a proxy for mixing height. For the modified Stull method, an environmental virtual potential temperature sounding is compared to a fire parcel virtual potential temperature sounding, with the mixing height being the point where the two soundings cross. Fire parcel temperature perturbation is 0.5 K above the surface temperature. Mixing height is expressed as height above ground level. Mixing Height is smoothed using a 25-point smoother for the GFS model only.
  - **Included models using modified Stull method:**
    - Global Forecast System (GFS); Rapid Refresh modeling system (RAP); RAP Extended Run (03z, 09z, 15z, 21z) (RAPX); North American Mesoscale model (NAM); NAM Nest (NAMH)
  - **Included models using PBL height:**
    - High-Resolution Rapid Refresh model (HRRR); HRRR Extended run (00z, 06z, 12z, 18z) (HRRRX); Weather Research and Forecasting (WRF) – Advanced Research WRF (WRF-ARW); High Resolution Window Forecast System (HIRESFV3); WRF Member 2 (WRF-MEM2); Deterministic ECMWF (ECMWFD); Ensemble ECMWF (ECMWFE)
  - **Bias correction:** Bias-corrected to RAP analysis. Due to an issue with previous low bias, no negative bias correction is allowed (bias correction is only performed when it will increase the Mixing Height value)
  - **Weighting (Expert or MAE):** MAE-weighted
- Transport Wind Speed
  - **Technique used:** Average wind speed magnitude from surface to mixing height
  - **Included models:** GFS, RAP, RAPX, NAMH, NAM, HRRR, HRRRX, WRF-ARW, WRF-MEM2, HIRESFV3, ECMWFD, ECMWFE
  - **Bias correction:** Bias-corrected to RAP analysis. Due to an issue with previous low bias, no negative bias correction is allowed (bias correction is only performed when it will increase the Transport Wind Speed value). Transport Wind Speed is also checked against the NBM 10-m wind speed to ensure Transport Wind Speed is never less than the 10-m wind speed.
  - **Weighting (Expert or MAE):** MAE-weighted
- Transport Wind Direction

- **Technique used:** Average U and V winds from the surface to the mixing height are calculated for each model input, then the transport wind direction is calculated from the vector of the equal-weighted, blended $U_{avg}$ and $V_{avg}$ winds
    - **Included models:** GFS, RAP, RAPX, NAMH, NAM, HRRR, HRRRX, WRF-ARW, WRF-MEM2, HIRESFV3, ECMWFD, ECMWFE
    - **Bias correction:** No
    - **Weighting (Expert or MAE):** No, equal-weighted U and V inputs used
- Ventilation Rate
    - **Technique used:** Product of transport wind speed and mixing height
    - **Included models:** GFS, RAP, RAPX, NAMH, NAM, HRRR, HRRRX, WRF-ARW, WRF-MEM2, HIRESFV3, ECMWFD, ECMWFE
    - **Bias correction:** Uses bias-corrected inputs - Ventilation Rate is the product of the bias-corrected, MAE-weighted NBM Mixing Height and Transport Wind Speed
    - **Weighting (Expert or MAE):** Uses MAE-weighted inputs
- 6-hour max Haines Index
    - **Technique used:** Haines Index is a fire weather index with moisture and stability components, calculated using the method described by [Haines (1988)](). Elevation criteria for using low (up to 999 feet MSL), mid (1,000-2,999 MSL), or high (3,000+ feet MSL) Haines index is determined by the NBM gridpoint's elevation in Unified Terrain.
    - 6-hour max is determined by first calculating an hourly Haines index for each input model, then blending and equally weighting these hourly values, then choosing a 6-hour max from the blended values.
    - **Included models:** GFS, RAP, RAPX, NAMH, NAM, HRRR, HRRRX, WRF-ARW, WRF-MEM2, HIRESFV3, ECMWFD, ECMWFE
    - **Bias correction:** No
    - **Weighting (Expert or MAE):** No, equal-weighted
- 6-hour max Fosberg Fire Weather Index
    - **Technique used:** Fire weather index intended to represent expected flame length and fuel drying. Calculated using the method described by [Fosberg (1978)]().
    - **Included models:** NBM blended, MAE-weighted 2-m Temp, 2-m dewpoint, and 10-m wind speed
    - **Bias correction:** Yes - uses bias-corrected inputs
    - **Weighting (Expert or MAE):** Yes - uses Mean Absolute Error Weights inputs
- Solar Radiation

- **Technique used:** Blend of direct model output for downward short-wave radiation flux (w/m**2). Note that the NBM valid forecast time corresponds to the end of the forecast time period covered by the model inputs
- **Included models:** HRRR, HRRRX, RAP, RAPX, GFS, NAMH
- **Bias correction:** No
- **Weighting (Expert or MAE):** No, equal-weighted

### Freezing Spray

Freezing Spray is a product derived from the final blended 2-meter temperature, 2-meter dewpoint, 10-meter wind speed, sea surface temperature, and significant wave height elements. Using these elements, two methodologies are used to compute icing rates independently, Overland and Stallabrass. After we have the icing rate computed from each method, an average of the two is taken which becomes our final icing rate. Finally, that icing rate is changed into a category based on the thresholds below.

| **Icing Rate Threshold (X [cm/hr])** | **Icing Amount** |
|---|---|
| X < 0.1 | No Icing |
| 0.1 ≤ X < 0.7 | Light Icing |
| 0.7 ≤ X < 2.0 | Moderate Icing |
| X ≥ 2.0 | Heavy Icing |

### Aviation

- Ceiling Height and Visibility
    - Short-term forecasts to 36 hours are from the Gridded Localized Aviation MOS Program (LAMP) (one hour offset in cycle time).
    - Gridded LAMP (GLMP) uses direct model output from both GFS and HRRR as well as recent observations.
    - Forecasts beyond 36 hours are a gridded analysis of station forecasts based on both GFS and NAM.
    - Forecasts over water are from RAP and GFS.
- Cloud Base
    - A weighted average of several NWP cloud height diagnostics

- Three Cloud Layers (primary, secondary, tertiary)
    - Bases, amounts, and tops are provided for each layer.
    - The Technique is Aviation Weather Center's (AWC's) Digital Aviation Services (DAS) logic.
    - The RAP 3-D cloud fraction is the foundational model info driving this field.
    - Cloud layer primary is consistent with ceiling height when a ceiling of < 5000 ft is forecast.
- In Flight Icing
    - Repackaged AWC Forecast Icing Potential (FIP)

**Thunderstorm Coverage**

Rather than following the traditional approach of blending model outputs to create NBM thunderstorm coverage, blending two existing operational thunderstorm products seemed to be the most straightforward approach to generating a more robust thunderstorm coverage product. By intelligently synthesizing Gridded LAMP's (GLMP) Lightning potential product with the NBM's Thunderstorm product, the NBM can generate hourly thunderstorm coverage through 36 hours (over that hour) for every cycle covering the CONUS, Alaska, Hawaii, Puerto Rico, and Oceanic domains. The product closely follows AWC's three defined probabilistic categories of thunderstorm coverage: Isolated (10-20%), Scattered (30-50%), and Numerous (60-100%). A summary of the steps taken to generate this product can be found in NBM V4.1 Thunderstorm Coverage Development document.

## 8. What is the timing of NBM products? Are all products available for all cycles?

The timing and availability of the NBM varies by product, region, and cycle. The tables below provide a general guide to availability of data, with the timing numbers listed with respect to the start of the dissemination process. The transmission and ingestion of the individual fields will add further delay to when they are available in the Graphical Forecast Editor (GFE). More details of the QMD timing is given in "QMD Run Availability in NBM".

- *A live data feed (past couple of days of data) of Core and QMD NBM is available on NOAA's Operational Model and Distribution System (NOMADS) under blend.YYYYMMDD/[core, qmd, text]*

- *A full archive going back to about May 2020 of operational NBM data is available on our* [*Amazon Web Services (AWS) big data project*] *[*now part of [NOAA Open Data Dissemination(NODD)] database*] under* ***blend.YYYYMMDD/[core, qmd, text]***.
- *An additional location of archive data is at the* [*MDL Big Data Archive Viewer*]

| **Core NBM** | |
|---|---|
| Cycles | Timing (UTC) |
| 00 | 00:55 - 01:00 |
| 07 | 08:05 - 08:10 |
| 12 | 12:55 - 13:00 |
| 18 | 18:40 - 18:50 |
| 19 | 20:00 - 20:10 |
| 01, 02, 03, 04, 05, 06, 08, 09, 10, 11, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23 | HH:30 - HH:45 |

| **Winter NBM** | |
|---|---|
| Cycles | Timing (UTC) |
| 01 | 02:05 - 02:15 |
| 07 | 08:00 - 08:05 |
| 13 | 14:05 - 14:15 |
| 19 | 20:00 - 20:10 |
| 00, 02, 03, 04, 05, 06, 08, 09, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21, 22, 23 | HH:30 - HH:35 |

| **Quantile Mapping and Dressing (QMD) NBM [Alaska/CONUS/Oceanic)]** **Regions listed in expected arrival order* | |
|---|---|
| Cycles | Timing (UTC) |
| 00 | 06:50 - 07:20 |
| 06 | 12:50 - 13:40 |
| 12 | 18:50 - 19:20 |
| 18 | 00:50 - 01:30 |
| **QMD NBM [Puerto Rico]** | |
| 06 | 12:40 - 12:45 |
| 18 | 00:40 - 00:45 |

| **Oceanic NBM** | |
|---|---|
| Cycles | Timing (UTC) |
| 00 | 01:00 - 01:10 |
| 07 | 08:10 - 08:20 |
| 12 | 13:00 - 13:10 |
| 19 | 20:10 - 20:20 |

| Significant Wave NBM | |
|---|---|
| Cycles | Timing (UTC) |
| 00 - 23 | HH:10 - HH:15 |

| Global NBM | |
|---|---|
| Cycles | Timing (UTC) |
| 00 | 11:30 - 1135 |
| 12 | 23:30 - 23:35 |

| Text NBM | |
|---|---|
| Cycles | Timing (UTC) |
| 01 | 02:20 - 02:30 |
| 07 | 08:10 - 08:20 |
| 13 | 14:20 - 14:30 |
| 19 | 20:10 - 20:20 |
| 00, 02, 03, 04, 05, 06, 08, 09, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21, 22, 23 | HH:30 - HH:40 |

To explain the variances in product arrival times, is typically explained by the quantity and volume of new model inputs that are being processed for a particular cycle. The more that needs to be pre-processed, the longer the product as a whole takes to complete. With the NBM winter products, the hours that process the European Center for Medium Range Weather Forecasts (ECMWF) Ensemble will take the longest to complete.

Other reasons for runtime variability include:

- System issues (e.g., slow node or crashed job) on the Weather and Climate Operational Supercomputing System (WCOSS)
- Advanced Weather Interactive Processing System (AWIPS) processing and/or Satellite Broadcast Network (SBN) bandwidth issues

Downstream impact of a failure within the current cycle's jobflow

## 9. What are the Sources of Biases and Associated Limitations, and what are possible ways to alleviate them?

**Lack of climatology input for QMD Temperature and Wind**

- In the QMD system, both Temperatures and Winds do not have a climatology to correct to. For Temperatures, there is only a 60-day training period used for bias correction. This training period and lack of climatology causes issues during transitional seasons of spring and fall. The training sample is filled with data from the previous two months where it's usually really cold in the winter, or really warm in the summer.

- When the first heat wave of the spring comes, the Blend's QMD temperature suite is usually too cold because the training sample is filled with cold data. The QMD wind system typically has less struggles with transitional seasons because it has a longer, 120-day training period, which covers more possibilities than the temperature system but can miss extremes if they are rarer than the training period can capture.
- We discussed in the AFS11's Report on NBM Evaluation (Summary and Conclusions) that "The bias correction relying on the training dataset for the last 60 days wouldn't allow the adaptation of the algorithms to weather pattern changes. The optimum periods need to be calculated scientifically or intelligently so that, for example, major transient events (such as cold fronts, heat waves, or cold outbreaks) can be represented without being filtered out by the averaged training dataset. [NBM Requirements #7a,b]. Therefore, by addressing this requirement, the bias for temperature could be alleviated.
- We also discussed in the AFS11's NBM Evaluation Report (Summary and Conclusions) that "Deterministic wind speeds and wind gusts, which can be overestimated especially in complex terrain, need to be improved based on science, rather than engineering (e.g., overall enhancement of the winds to compensate for the average bias). …. The best way is to improve the input wind elements from the upstream models, but within the NBM those algorithms can be formulated based on science and statistically trained with the aid of AI/ML". [NBM Requirements #5a,b]

**METeorological Aerodrome Reports (METAR), replaced at co-located gridpoint**

- At the nearest grid point where a METAR is providing data, the URMA value is overwritten by this data. While this is seen as a positive thing for aviation needs, where the forecast at the METAR location is important, it can cause the gridpoint of the METAR to stand out from the surrounding grid points due to differences with the URMA analysis.
- We discussed in the AFS11's Report on the NBM (Summary and Conclusions) that "Future consideration should be given to how best to balance and present verification results from both point-based METAR verification, and analysis-based verification in order to properly represent error characteristics."

**Biases found in analysis fields**

- Any biases present in our verifying analysis (URMA, etc.) will be heavily reflected in bias corrected products and the final Blend product. Some examples of this are wind speeds and gusts generally being too low in URMA, i.e., “hot spots” (values in a large area being vastly different than surrounding regions) in temperature and wind analysis from URMA causing similar features in Blend forecasts, and mixing height bullseyes near shallow or dry lakes due to issues with the RAP analysis.
- We discussed in the AFS11’s NBM Evaluation Report (Summary and Conclusions) that “The most effective way to alleviate these issues is to address them in those upstream models. AFS11 developed requirements for some of those key systems (RTMA/URMA, HRRR, HREF) to help the developers address the issues.”

**Rare scenarios captured by a few or none of the input models**

- The Blend is not a dynamical model, and localized scenarios that don’t happen frequently are difficult or impossible to capture in the Blend’s current form. There are times, for example, where only a single model that’s included in the Blend captures a strong cold pool at the surface, resulting in low surface temperatures. The bias correction methods currently used in the Blend make it very difficult to tell the system that a particular case is handled best by one particular model. This is where forecaster experience is key. A forecaster has the ability to identify this, and adjust the Blend’s forecast to better align with the scenario.
- However, while this is probably inevitable at this point, the purpose of the NBM is to avoid custom adjustments by forecasters (a.k.a. grid editing). Therefore, we still need to try to find a scientific way (e.g., in model-specific weighting based on real-time performance) to implement these rare but important scenarios within the NBM algorithms as much as possible.

**Expert weighted products**

- Even though expert weights are determined with consultation of a group of Meteorologists, they can’t capture the best performing model in every scenario. One set of weights are applied to an entire domain, without consideration of regional biases or success of any particular model.
- Moreover, this “expert weighting” is by nature potentially inconsistent and depends largely on the expert capability and sample size, and thus an objective science-based weighting will have to be developed.

## 10. Conclusion and References

**Conclusion:**

The NBM is a national suite of calibrated forecast guidance based on a blend of both NWS and non-NWS multi-scale numerical weather prediction model output and post-processed statistical model guidance. The goal of the NBM is to create a highly accurate, skillful, and consistent starting point for the gridded forecast within the field offices.

As with intricate frameworks such as the NBM, there are often specifics that are not well documented, and thus can leave forecasters with uncertainty as to what the algorithms within the blend are doing to create their forecasts. This document, a collaborative effort between AFS11 and the NBM developers, was focused on addressing specific comments from the field that highlighted the need to better explain some of these algorithms within the NBM. The topics covered included:

- How are the Percentiles Computed?
- What is Quantile Mapping & Dressing (QMD)?
- How is the Initial Interpolation to the NBM grid performed?
- How are the Weights Determined: Mean Absolute Error (MAE) Versus Expert Weights?
- How are Winter Products Computed?
- How are Other Products Computed?
- What is the timing of NBM products? Are all products available for all cycles?
- What are the Sources of Biases and Associated Limitations, and what are possible ways to alleviate them?

The developers of the NBM continue to work hard to make ongoing improvements for the forecaster's needs. This includes plans to upgrade the latest version 4.1 (Master Documentation) implemented early in 2022 to version 4.2 tentatively scheduled to be December 2023, and beyond that time a version 4.3. As with previous new versions, master documentation as well as service change notices (SCNs) will be created so that the field is aware of the details of the latest upgrades.

AFS11 has been collecting the field's needs on the NBM and developing requirements to help developers alleviate the deficiencies based on the needs. AFS11 is also evaluating the needs through case studies, represented in terms of the requirements, in order to refine and supplement the requirements. AFS11 will continue to survey the field for any additional needs for the NBM.

**Reference List:**

- AFS Acronym List
- Analyze, Forecast, and Support (AFS) Office of the National Weather Service (NWS)
- AFS11's Report on the Evaluation of the National Blend of Models (NBM)
- NBM v4.1 Stakeholder Feedback
- NBM NOAA Virtual Lab (VLab) Forum
- NBM v4.1 Master Documentation
- NBM v4.1 Service Change Notice
- NBM V4.1 Thunderstorm Coverage Development document
- NOAA's Operational Model and Distribution System (NOMADS)
- Amazon Web Services (AWS) big data project
- MDL Big Data Archive Viewer
- Model Output Statistics (MOS)-2000 software
- Dynamic Mean Absolute Error weighting
- Expert Weights for elements
- Demo of Quantile Mapping Correction Procedure
- Configuration and Technical Details of Blend Precip QMD v4.1
- Winter Weather system in Blend v4.1
- Method for Max Temperature Aloft
- Operational Mixing Height Determination by Stull (1991)
- Haines Index by Haines (1988)
- Fire Weather Index by Fosberg (1978)
- Icing rate computation by Overland and Stallabrass
- AFS11's science requirements for NBM

# 11. Appendices

## Appendix 1: wgrib2 grid interpolation generic command

GRID="nps:255.0000:60.0000 210.0000:593:23812.5000 2.5320:400:23812.5000"

```
$WGRIB2 -match "2 m above ground|10 m above ground|PRES:surface|TCDC:entire|APCP|GUST" \
	$g1 -new_grid_winds grid \
	-new_grid_interpolation bilinear \
	-if ":(APCP):" -new_grid_interpolation budget -fi \
	-new_grid ${GRID} $g2 >> $pgmout 2>errfile
```

## Appendix 2: Bias Delta Decaying Average Equation

$$B_t = (1 - \alpha)\, B_{t-1} + \alpha\, (F_{t-1} - OBS_{t-1})$$

B = Bias, $\alpha$ = “Decaying Weight”, F = Forecast, OBS = Observation

## Appendix 3: Mean Absolute Error Decaying Average Equation

$$MAE_t = (1 - \alpha)\, MAE_{t-1} + \alpha\, |BCFCST_{t-1} - OBS_{t-1}|$$

MAE = Mean Absolute Error, $\alpha$ = “Decaying Weight”, BCFCST = Bias-corrected Forecast, OBS = Observation

## Appendix 4: Mean Absolute Error Weighting Equation

$$W_m = a_m^{-1} \left( \sum_{k=1}^{K} a_k^{-1} \right)^{-1}$$

W = Weight for member “m”, a = most recent $MAE_t$ for member “m”, K = total number of models being blended