MM5 Modeling Report

Alaska MM5 Modeling for BART
Southern Alaska

Prepared for:

Members of the Alaska BART Coalition:

Agrium Inc.
Alyeska Pipeline
Anchorage Municipal Light and Power
ConocoPhillips Alaska, Inc.
Tesoro Alaska Company

October 2007

Project No. 013474

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Prepared by:

Geomatrix Consultants, Inc.
3500 188th Street SW Suite 600
Lynnwood, Washington 98037

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MM5 MODELING REPORT
Alaska MM5 Modeling for BART
Southern Alaska

1.0 INTRODUCTION

In 1999, the U.S. Environmental Protection Agency (EPA) announced a major effort to improve air quality in national parks and wilderness areas. The Regional Haze Rule (RHR) calls for federal agencies and States to work together to improve visibility in certain identified national parks and wilderness areas – also known as "Class I" areas. The objective of the RHR is to achieve natural visibility conditions in these federally protected lands by the year 2064. The rule requires the States to develop and implement air quality protection plans to reduce the pollution that causes visibility impairment.

The Alaska Department of Environmental Conservation (ADEC) is developing a plan to protect visibility and comply with the intent of the Regional Haze Rule. A component of this plan is the implementation of the federal Best Available Retrofit Technology (BART) rules in Alaska. On behalf of ADEC, the RMC conducted CALPUFF simulations of Alaskan BART Eligible sources. The simulations were performed to evaluate whether these eligible sources are subject to a BART Determination based on predicted impacts to visibility within Alaska Class I areas. BART Eligible sources are exempt from performing a BART determination if their impacts are below screening criteria set by ADEC, EPA, and the Federal Land Managers (FLMs). Non-exempt sources must perform a technology review and propose BART for each emission unit that comprises the BART Eligible source.

The Western Regional Air Partnership (WRAP) is a consortium of federal, state, and tribal agencies charged with implementing regional planning processes to improve visibility in all western Class I areas. The WRAP has formed the Regional Modeling Center (RMC), consisting of the University of California at Riverside (UCR), ENVIRON International Corporation, and the University of North Carolina (UNC).

Starting in 2004, the RMC undertook an effort to perform the meteorological modeling necessary for the development of Section 309 SIPs/TIPs, and begin the analysis for the Section 308 SIPs/TIPs. This effort produced a one-year meteorological simulation of Alaska using the Fifth Generation Mesoscale Model (MM5), developed and maintained by the Pennsylvania State University (PSU) and the National Center for Atmospheric Research (NCAR). The

modeling was documented in a Draft Modeling Protocol[1] and a Draft Report[2]. The RMC used MM5 to simulate the calendar year 2002, using two computational domains with 45 and 15 km grid spacing, respectively.

The RMC used the CALPUFF modeling system to assess the impacts from BART Eligible sources in Alaska based on one year of 15 km MM5 data. The CALPUFF model grid spacing was 2 km, significantly different than the MM5 grid spacing of 15 km. In addition, because only one year was simulated, BART exemption simulations performed by WRAP used the highest modeled visibility impact, not the 98th percentile impact as is recommended under EPA rules.

Several members of the ad-hoc Alaska BART Coalition (a collection of corporations with BART-eligible sources) contracted with Geomatrix Consultants (Geomatrix) to perform a refined MM5 simulation of Alaska, as well as post-process the MM5 data and prepare CALMET files in support of future CALPUFF modeling. Geomatrix in turn sub-contracted the MM5 portion of the project to 3TIER, Inc., although Geomatrix participated in the model application. This report describes the MM5 modeling 3TIER and Geomatrix performed.

The resulting 3-year MM5 dataset, with grid spacings of 45, 15 and 5 km, is now available. A 3-year MM5 dataset with an inner 5-km mesh size domain will be a major step towards allowing ADEC and/or the BART Eligible sources in Alaska to refine the previous RMC modeling analyses and employ the more robust 98th percentile change to extinction as the BART exemption criterion. This MM5 dataset (and the use of the 98th percentile change to extinction) may also be used during the technology review phase of the BART process, given that the federal rules allow for an evaluation of the degree of visibility improvement associated with each technology scenario being considered as possibly BART. A separate Air Quality Modeling Protocol has be developed and submitted to ADEC that covers aspects pertaining to CALMM5, CALMET, and CALPUFF.

For an overview of the Meteorology of Alaska, or a more detailed description of the MM5 modeling system, refer to the RMC Draft Modeling Protocol and Draft Modeling Report.

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[1] Draft Modeling Protocol, PRELIMINARY WRAP ALASKA VISIBILITY MODELING, October 15th, 2004. Available at http://pah.cert.ucr.edu/aqm/308/docs/alaska.

[2] Draft Report, ALASKA MM5 MODELING FOR THE 2002 ANNUAL PERIOD TO SUPPORT VISIBILITY MODELING, September 2005. Available at http://pah.cert.ucr.edu/aqm/308/docs/alaska.

2.0 THE METSTAT ANALYSIS PACKAGE

ENVIRON has developed a statistical analysis software package to calculate and plot a collection of statistical quantities. The package is comprised of a FORTRAN program to generate observation-prediction pairings and to calculate the statistics, and a Microsoft Excel macro to generate the plots. The statistics it calculates are described in Section 3.1, and the METSTAT package itself is further described in Section 3.2, of the RMC's Draft Modeling Report[2].

3.0 MM5 SETUP

Geomatrix produced a draft Alaska MM5 Modeling Protocol, circulated it to interested parties, and integrated the responses into a final Alaska MM5 Modeling Protocol[3], a copy of which can be found in Appendix A. A much abbreviated listing of MM5 modeling techniques follows. Refer to the Alaska MM5 Modeling Protocol (Appendix A) for more information and discussions. A sample "mmlif" file (MM5 control file) is given in Appendix B.

3.1 DATA SOURCES:

- ds090.0, "NCEP/NCAR Global Reanalysis Products" (NNRP), used for boundary conditions
- ds464.0, "NCEP ADP Global Surface Observations", and ds353.4, "NCEP ADP Global Upper Air Observation Subsets", used to re-analyze the ds090.0 data for nudging
- ds277.7, "NOAA Optimum Interpolation 1/4 Degree Daily Sea Surface Temperature (SST) Analysis", used for sea surface temperature
- National Weather Service Climate Prediction Center "Daily Snow Cover for the Northern Hemisphere" dataset[4], used for snow cover

3.2 MODELING DOMAIN:

- Polar Stereographic projection, centered at 59ºN, 151ºW (see Figure 1)
- D01: 109×90 points, 45 km grid spacing
- D02: 106×88 points, 15 km grid spacing, one-way nest

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[3] Alaska MM5 Modeling Protocol, ALASKA MM5 MODELING FOR BART IN SOUTHERN ALASKA. Geomatrix, 3500 188th Street SW, Suite 600, Lynnwood, WA, May 2007.
[4] See http://www.cpc.noaa.gov/data/daily_snow

- D03: 106×130 points, 5 km grid spacing, one-way nest
- 40 sigma levels from the surface to 50 millibars, concentrated near the surface

3.3 PHYSICS OPTIONS:

- Two set-ups, "winter" and "summer", to allow winter-time diagnosing of sea ice from SST (requires 5-layer LSM) and summer-time use of the OSU LSM (recommended by Univ. of Alaska Fairbanks).
- Sea ice and snow cover turned off in "summer" set-up.
- Reisner II cloud microphysics
- Grell cumulus parameterization, with no shallow convection
- ETA PBL model
- RRTM radiation model
- SST varying in time
- Polar physics option
- Solar slope and topography shadowing effects (5 km domain only)

3.4 NUDGING:

- 3-hourly interval for analysis nudging of the 45 and 15 km domains
- Only temperature and water vapor nudged below the PBL

3.5 MM5 APPLICATION:

- Run in independent six-day segments on a Linux cluster (some using OpenMP)
- The first 12 hours and last 12 hours of each run are not used, but were retained
- Simulation started on December 15, 2001, to allow for sufficient "spin-up" for future photochemical or visibility modeling

4.0 DEVIATIONS FROM THE MM5 PROTOCOL

The only deviation from our revised Alaska MM5 Modeling Protocol (May, 2007) involves the dates chosen to switch from the "winter" to "summer" MM5 set-ups. The RMC modelers based their choice of dates on sea ice concentration data, as measured by satellites. They chose May 30, 2002 as the switch-over day "because most of the domain was free of sea ice by this time." Similarly, October 13, 2002 was selected as the day to switch back to the "winter" set-

up, "because sea ice with a concentration of 100% reached land in the north of the domain on that day."

In our Protocol, Geomatrix proposed to select the switch-over days for 2003 and 2004 using similar criteria. The RMC reports did not specify any objective method for determining these days; they were presumably subjective determinations based on visual inspection of the plots available on the internet.[5] Geomatrix initially selected June 13, 2003 and June 7, 2004 as the "winter" to "summer" switch-over days, based on visual similarity of the sea ice distribution near Alaska. Similarly, Geomatrix initially chose October 16, 2003 and October 20, 2004 as the "summer" to "winter" switch-over days. Because there was little day-to-day variation in the sea ice coverage near these dates, the actual switch-over dates were selected to coincide with the beginning of a 6-day MM5 run, for convenience. Using the "sea ice coverage" criteria, the first "summer" MM5 runs were initially 2002052812, 2003061212, and 2004060612; and the first "winter" MM5 runs were initially 2002101012, 2003101512, and 2004101912,. Recall that the first 12 hours of an MM5 run are not used, so the actual switch-over occurred at 00 UTC on May 29, 2002, etc.

After MM5 was run for all three years and its output transported to Geomatrix' Linux cluster, the METSTAT program was run for each month. There was a very noticeable cold bias in the spring of each year. For example, the average temperature bias for the 5 km domain for May was -5.03 K in 2002, -4.1 K in 2003, and -4.36 K in 2004. Plots for the 15 km domain of observed and predicted domain-average temperatures, bias, root-mean-square (RMSE) and index of agreement (IOA) are shown in Figure 2. Clearly, the simulation after the switch-over date of May 29, 2002 is much improved. Interestingly, it is difficult to see the switch-over date in the wind statistics (Figure 3). The humidity statistics (Figure 4) show a positive bias during the time of the negative temperature bias, despite being specific humidity instead of relative humidity. A similar low bias existed for May of 2003 and 2004, as well as April of all three years (not shown).

Instead of using the "sea ice coverage" criterion used by RMC, Geomatrix chose to use a new criterion that can be paraphrased as "when the 15 km domain-averaged overnight low temperatures are consistently above freezing." This criterion is also somewhat subjective, as the date was chosen by eye, based on the METSTAT plots of temperature. Because there is only a slow variation from day to day, we selected the closest start date of a 6-day MM5 run,

[5] ftp://sidads.colorado.edu/pub/DATASETS/PASSIVE_MICROWAVE/POLAR_STEREO/DATA/SEAIC

again for convenience. This criterion resulted in the selection of the first "summer" runs as 2002042812, 2003040812, and 2004040712.

The cold bias of the MM5 model for the period was greatly reduced by using the "summer" set-up. Temperature biases for the 5-km domain for May improved from -5.03 to -0.11 K for 2002, from -4.10 to -0.38 K for 2003, and from -4.36 to -0.31 K for 2004. Although a more modest improvement, the wind speed bias improved by around 25% for May by using the "summer" set-up instead of "winter": from -0.95 to -0.69 m/s for 2002, from -0.91 to -0.77 m/s for 2003, and from -0.89 to -0.63 m/s for 2004. Wind speed RMSE improved as well, but only by about 0.15 m/s (less than 10%). METSTAT plots for May 2002 using the revised switch-over date (April 29, 2002) are shown in Figures 5 to 7.

No readily apparent biases exist for the "summer" to "winter" switch-over in October. In fact, the two criteria "sea ice coverage" and "freezing overnight lows" both produce nearly the same switch-over dates. The first "winter" MM5 runs remain the same, namely 2002101012, 2003101512, and 2004101912.

5.0 SURFACE STATISTICAL ANALYSIS FOR ALASKA

A statistical evaluation of the MM5 surface fields was performed using the METSTAT analysis package and the NCAR ds472.0 dataset. This dataset contains hourly observations from airports and other sites in the U.S. and Canada. Variables of interest include wind speed/direction, temperature, dew point, and precipitation. METSTAT plots for the entire 36-month modeling period can be found in Appendix C.

Emery[6] has proposed a series of performance "benchmarks" to assess model performance. These are not intended as pass/fail criteria, but rather to put the current statistical results in perspective compared to about 30 other meteorological simulations. Benchmark values are given in Table 1, along with 3-year average statistics for both the 5 km and 15 km domains.

Additionally, the RMC Draft Modeling Report[2] introduced a second set of "benchmark" values, the WRAP Performance Envelope. These were taken from the performance of the WRAP 2002 annual MM5 simulations of the continental U.S., using only the western sub-domains. These sub-domains include the Rockies and the Sierra Nevada, which, unlike several of the

[6] Emery, C.A., E. Tai, and G. Yarwood. 2001. Enhanced Meteorological Modeling and Performance Evaluation for Two Texas Ozone Episodes. Prepared for the Texas Natural Resource Conservation Commission, by ENVIRON International Corporation, Novato, CA.

eastern sub-domains in the continental U.S. MM5 runs, contain terrain much more similar to the terrain in Alaska.

These two benchmarks are plotted as lines on a scatter plot. With the benchmark generally being an "absolute value should be less than" goal, these plots are often called "soccer" plots. When the statistic plotted falls within the soccer "goal," the benchmark "goal" is met. Soccer plots of wind speed, wind direction, temperature, and humidity for both the 15 km and 5 km domains are shown in Figures 8 to 11. There has been some variability in the axes of the soccer plots presented in various WRAP/RMC reports in the past. For example, the Draft MM5 Modeling Report[2] did not show wind speed bias or wind direction bias. A new kind of soccer plot showing the Index of Agreement (IOA) is shown in Figure 12. Because the benchmark for IOA is to *exceed* a critical value, here the "goal" is to be outside the inner box -- to miss the goal, as it were.

Most of the points fall within the WRAP Performance Envelope, indicating the current MM5 simulations feature about the same accuracy as the WRAP MM5 simulations in the mountainous west. It is clear that the wind speed RMSE is higher in the winter than in the summer, just as the magnitude of the wind is higher in the winter than in the summer. October and November feature the largest wind direction bias for the 15 km domain, falling outside of the WRAP Envelope. Interestingly, the mean wind direction error for the 5 km domain is larger than for the 15 km domain. This may be due to the relative absence of terrain in the larger 15 km domain.

The current MM5 simulations feature a warm bias in the December, January and February, and a cool bias in the March and April. Although few points meet the benchmark, almost all points fall within the WRAP Envelope. The humidity performance is excellent, with all points meeting the benchmark. This is partially due to the lower over-all values of specific humidity in Alaska, as compared to parts of the continental U.S., where the benchmarks were developed.

Compared to the WRAP RMC 2002 MM5 runs for Alaska, the current runs feature overall similar performance statistics. The wind speed RMSE and wind direction error is higher, yet the wind speed bias is smaller, compared to the RMC runs (wind speed RMSE is not shown in the RMC Draft Modeling Report, but is shown in the RMC Draft Modeling Protocol). Wind direction errors for the RMC runs were generally around 30º, but are generally around 50º for the current runs. The higher wind speed RMSE and wind direction error might indicate that the synoptic-scale weather fronts in the current simulations are less well-timed.

January 2004 is the month with the highest wind speed RMSE of the three-year run. The time series of wind speed statistics for both the 15 km and 5 km domains for this month are shown in Figure 13. MM5 does well at capturing the overall gross features of the wind speed events. The spurious yet brief high wind speed event in the 5 km domain near the middle of the month is probably an artifact of the METSTAT program, as there are some missing data (enough that RMSE was not calculated) for a few hours in the middle of the day. In general, the RMSE of wind speed increases as the wind speed itself increases. Perhaps of most interest to dispersion modelers, the periods of low wind speeds generally show a slight under-prediction, which would lead to a conservative over-prediction of concentrations.

7.0 SUMMARY AND CONCLUSIONS

Geomatrix prepared a meteorological dataset for southern Alaska based on a 3-year simulation using the MM5 numerical weather prediction model. The simulations were performed retrospectively using a historical reanalysis of the weather during 2002 through 2004 using grid mesh sizes of 45, 15 and 5 km. Geomatrix also conducted an evaluation of the simulations using the METSTAT statistical package. Some conclusions from the evaluation are as follows:

- Model performance was sensitive to the assumed transition from winter to summer modeling techniques. We found a criterion based on consistent predicted surface temperatures above freezing to be a better indicator of this transition than the sea-ice coverage dataset.

- Overall model performance was similar to the WRAP MM5 simulations for 2002 and to the statistical benchmark envelope found for other MM5 studies in the western United States

- The reduction in mesh size from 15 km to 5 km improved the biases in wind speed, wind direction, temperature, and humidity predictions. However when paired in time, the hourly scatter in the predictions was slightly higher for the 5-km mesh size simulations.

We believe the 3-year MM5 dataset with an inner 5-km mesh size domain is a major step towards allowing ADEC and/or the BART Eligible sources in Alaska to refine the previous BART modeling analyses based on a single year and a less refined grid. In addition, the MM5 dataset should be sufficient to support the use of the more robust 98th percentile change to extinction as the BART exemption criterion as recommended by EPA.

TABLES

TABLE 1

THREE-YEAR MEAN STATISTICS

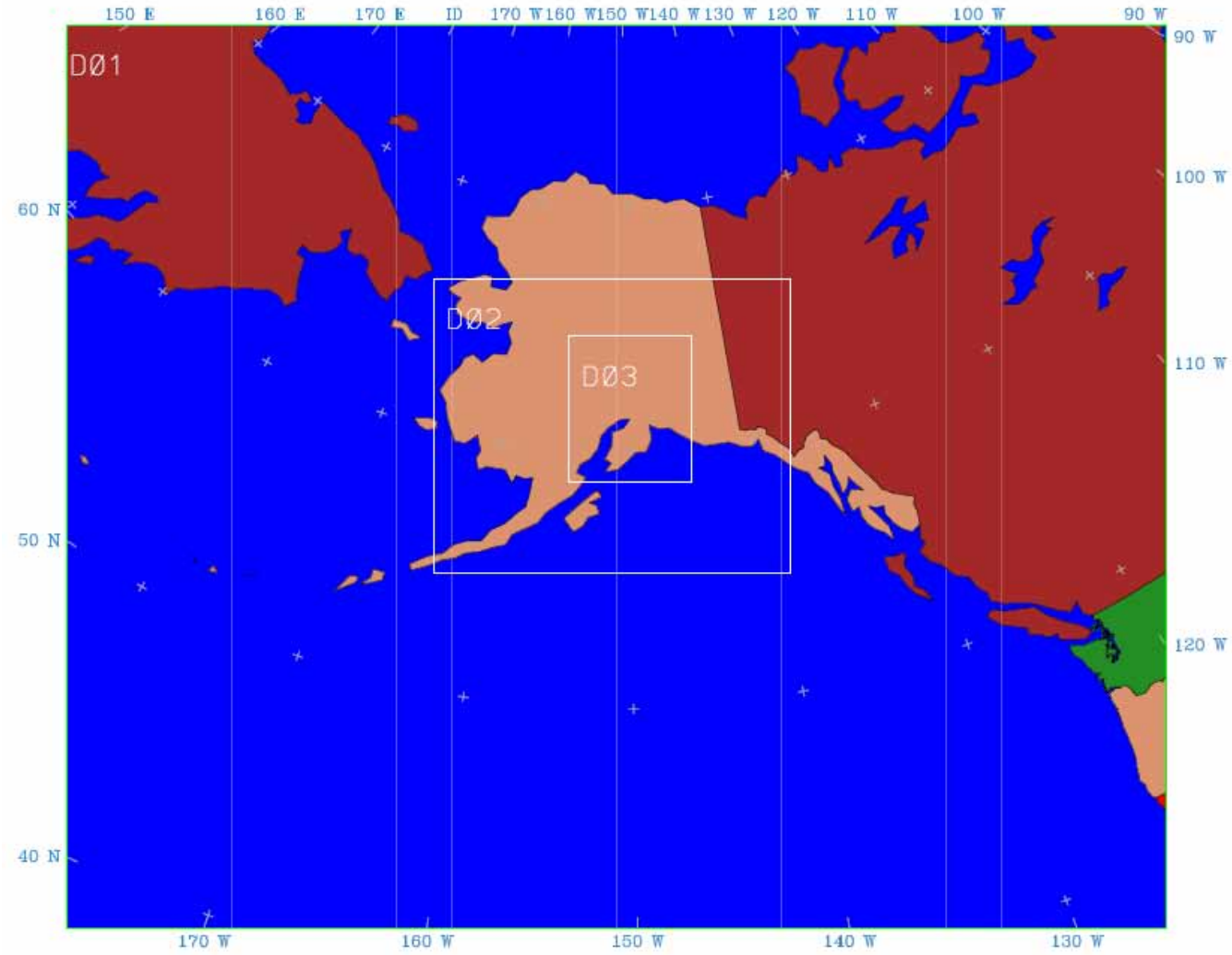
Alaska MM5 Modeling for BART
Alaska

Concentrations in [measurement units]

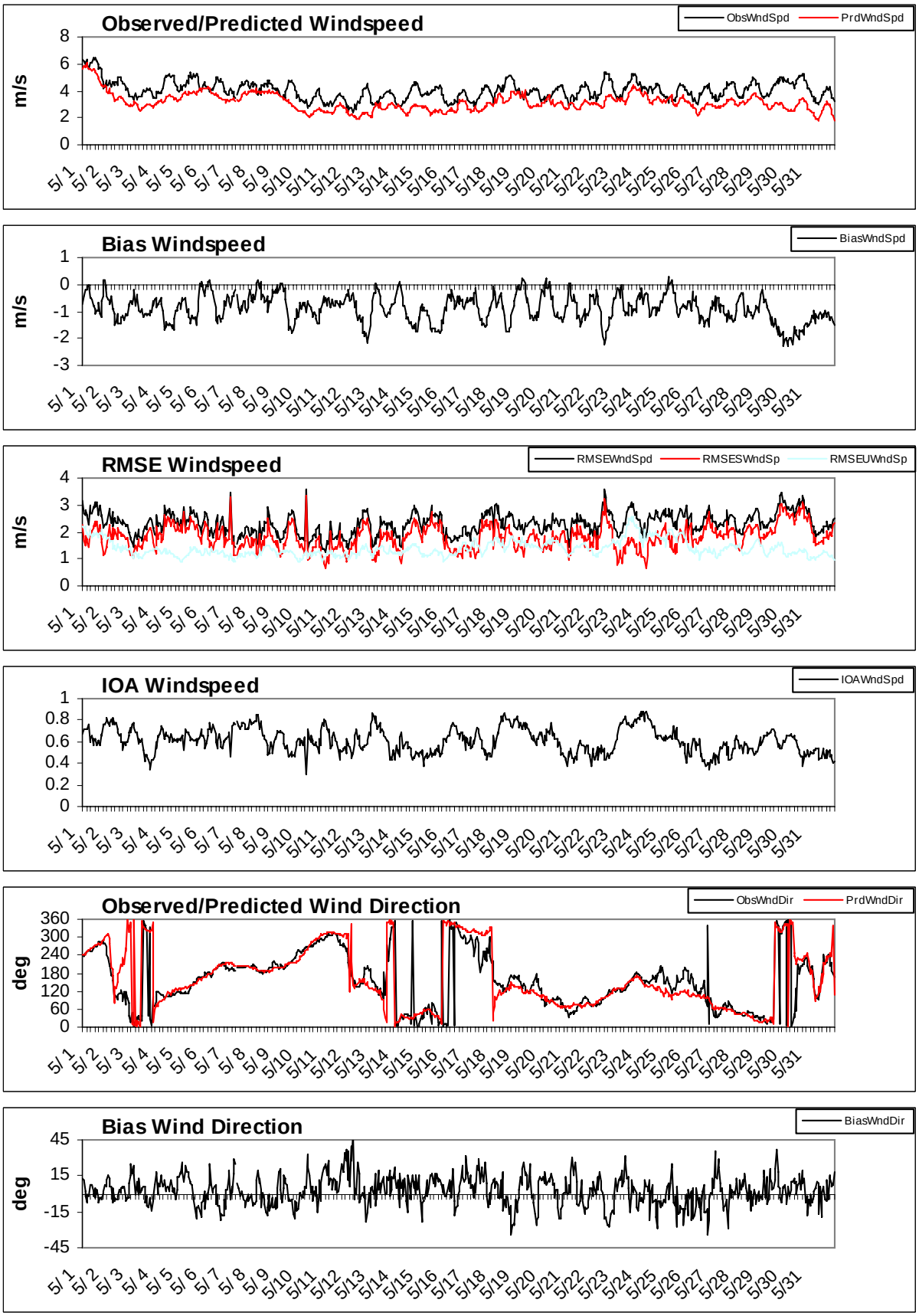
Parameter	Statistic	5 km Domain	15 km Domain	Benchmark[(a)]
Wind Speed (m/s)	RMSE	2.33	2.38	≤ 2
	Bias	-0.16	-0.40	≤ ±0.5
	IOA	0.64	0.69	≥ 0.6
Wind Dir (deg)	Error	54.1	49.5	≤ 30
	Bias	-0.43	6.32	≤ ±10
Temperature (K)	Error	2.64	2.22	≤ 2
	Bias	-0.12	0.31	≤ ±0.5
	IOA	0.84	0.91	≥ 0.8
Humidity (g/kg)	Error	0.70	0.70	≤ 2
	Bias	0.31	0.50	≤ ±1
	IOA	0.72	0.79	≥ 0.6

(a) Values taken from Emery et al. (2001)[7]

FIGURES



GEOMATRIX	MM5 DOMAINS: D01 – 45KM, D02 – 15KM, D03 – 5KM GRID MESH SIZES Alaska MM5 Modeling for BART Alaska	Project No. 13474.000 Figure **1**

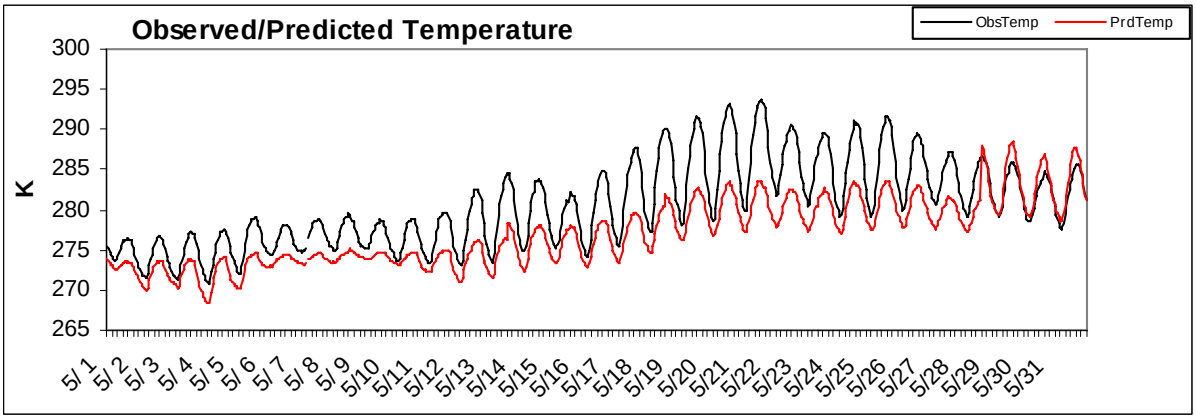


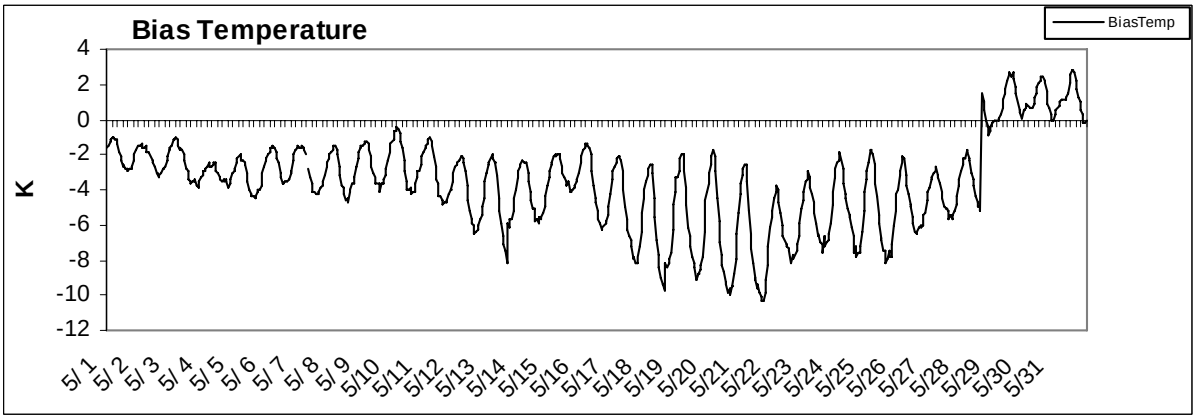
GEOMATRIX

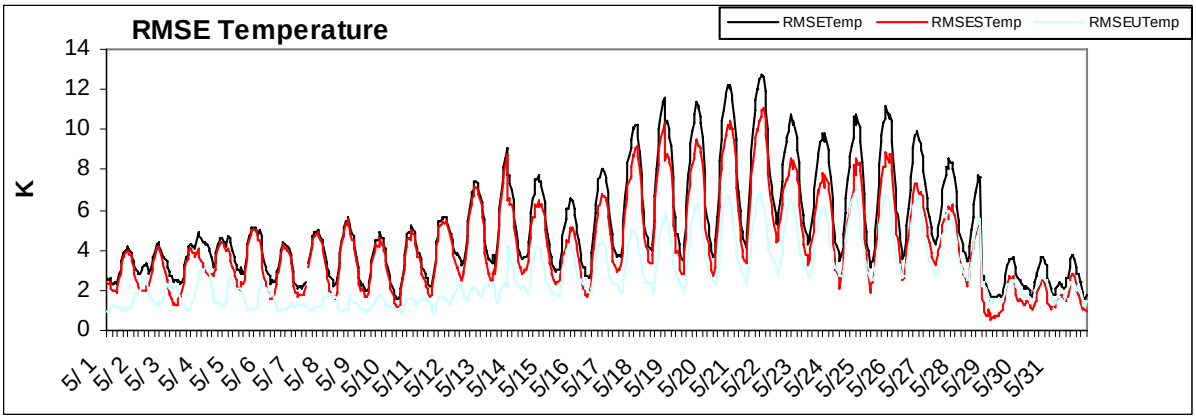
15 KM DOMAIN AVERAGE WIND STATISTICS FOR MAY 2002,
USING ORIGINAL SWITCH-OVER DATE OF MAY 28, 2002
Alaska MM5 Modeling for BART, Alaska

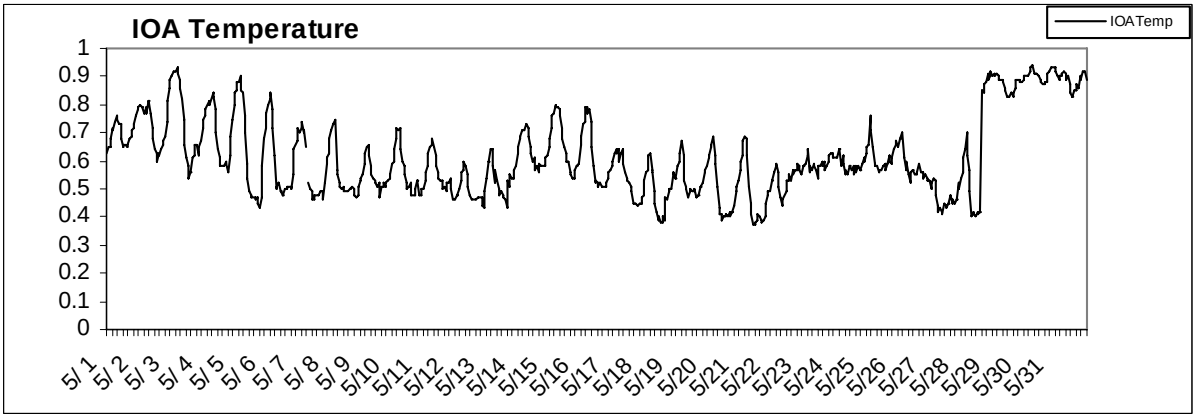
Project No.
13474.000

Figure
2







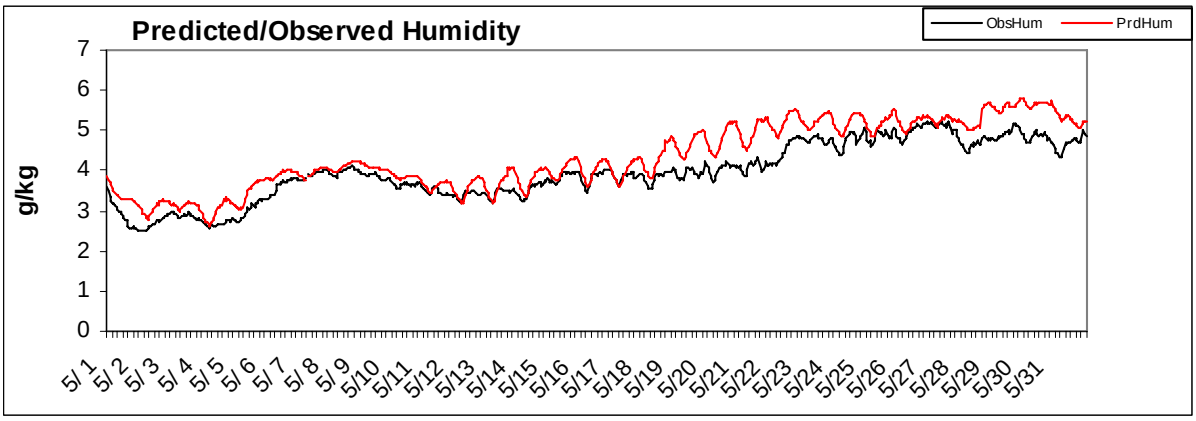


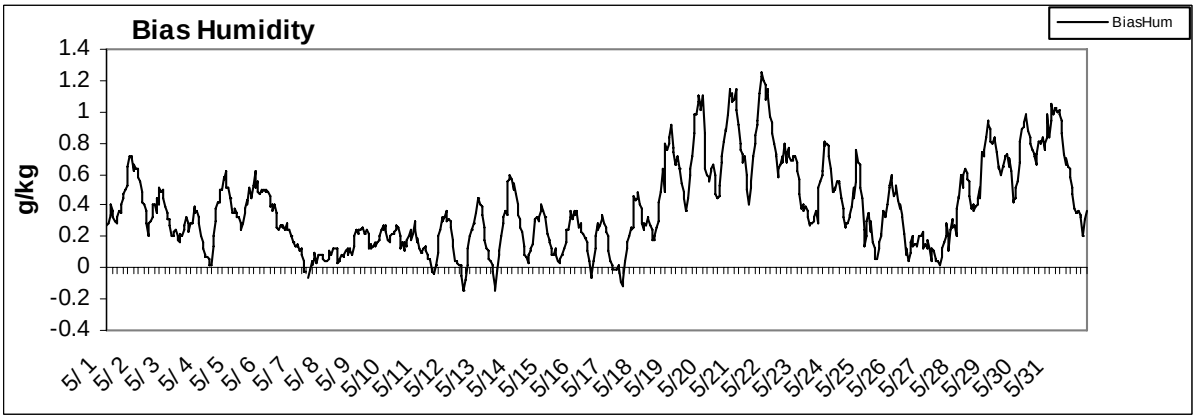
GEOMATRIX

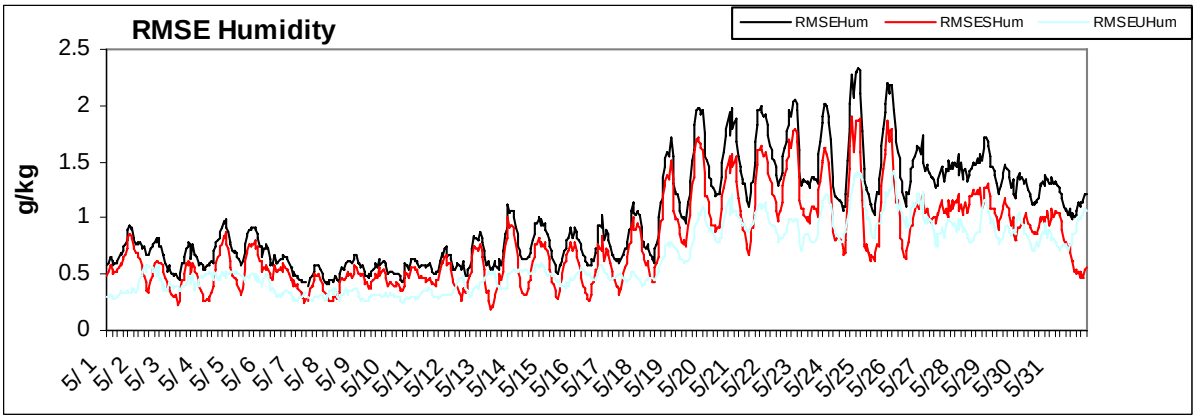
15 KM DOMAIN AVERAGE TEMPERATURES STATISTICS FOR MAY 2002, USING ORIGINAL SWITCH-OVER DATE OF MAY 28, 2002
Alaska MM5 Modeling for BART, Alaska

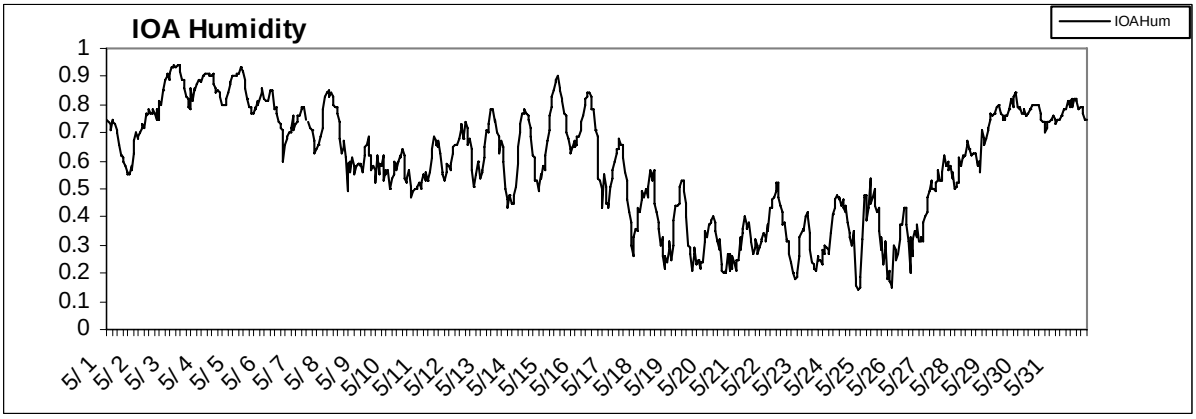
Project No.
13474.000

Figure
3









GEOMATRIX

15 KM DOMAIN AVERAGE HUMIDITY STATISTICS FOR MAY 2002,
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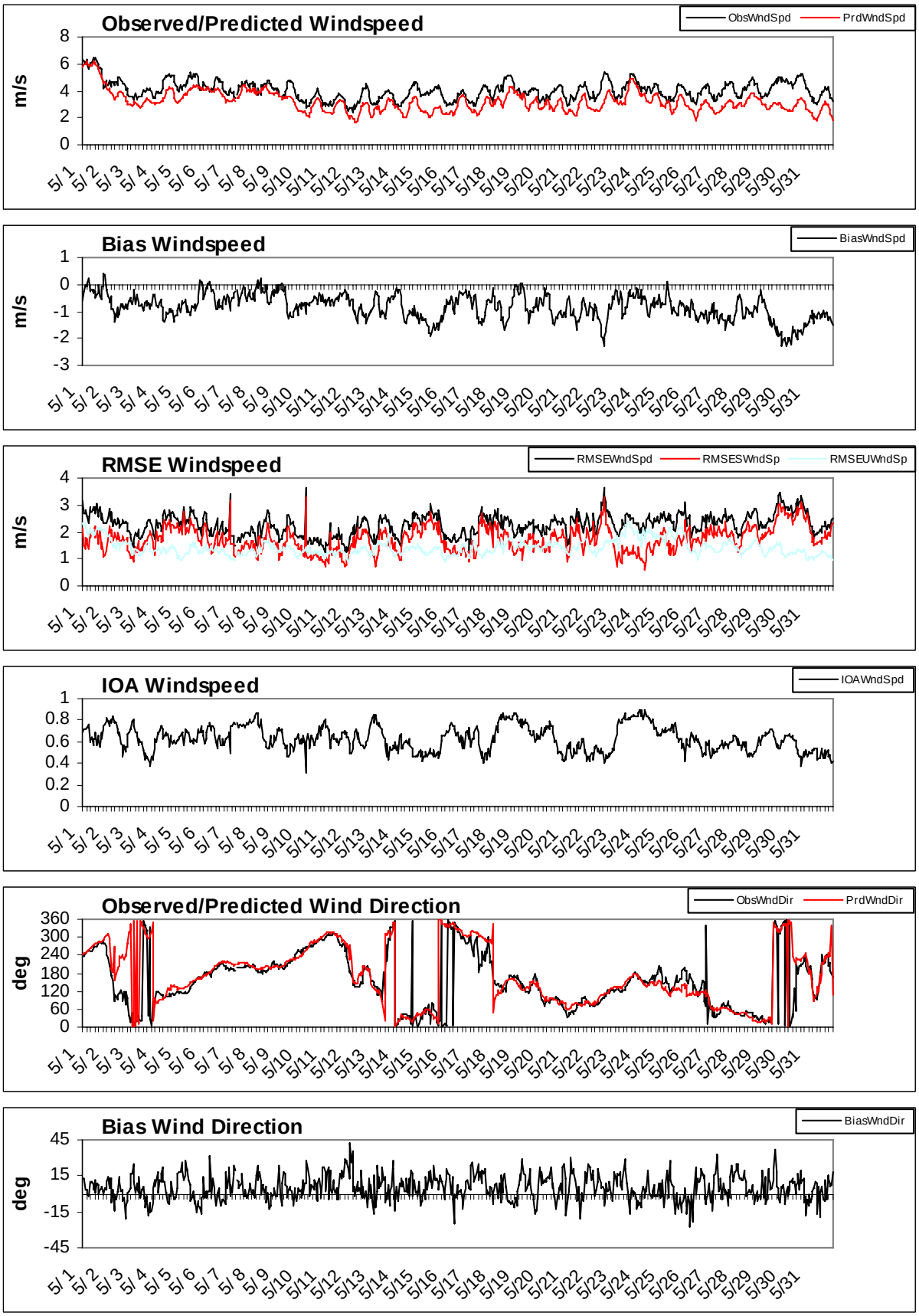
Alaska MM5 Modeling for BART, Alaska

Project No.
13474.000

Figure
4

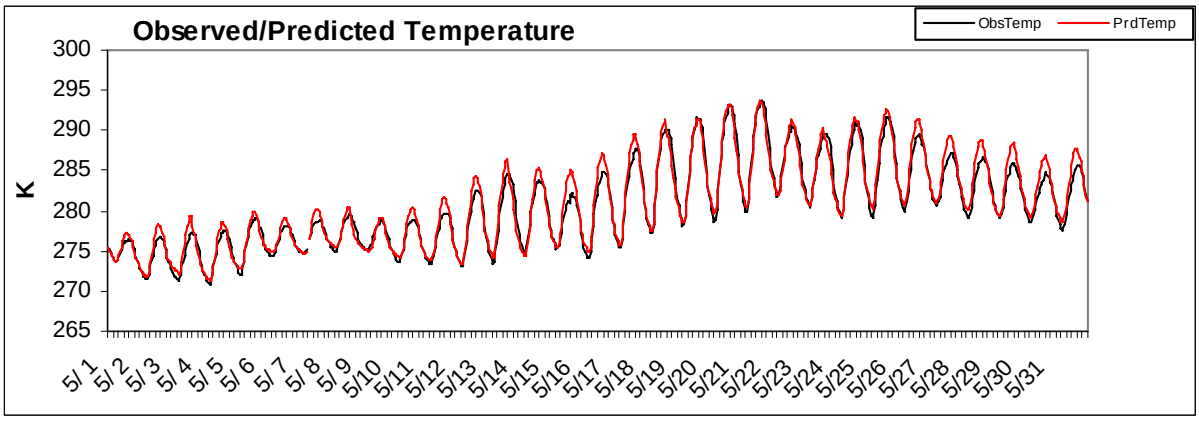


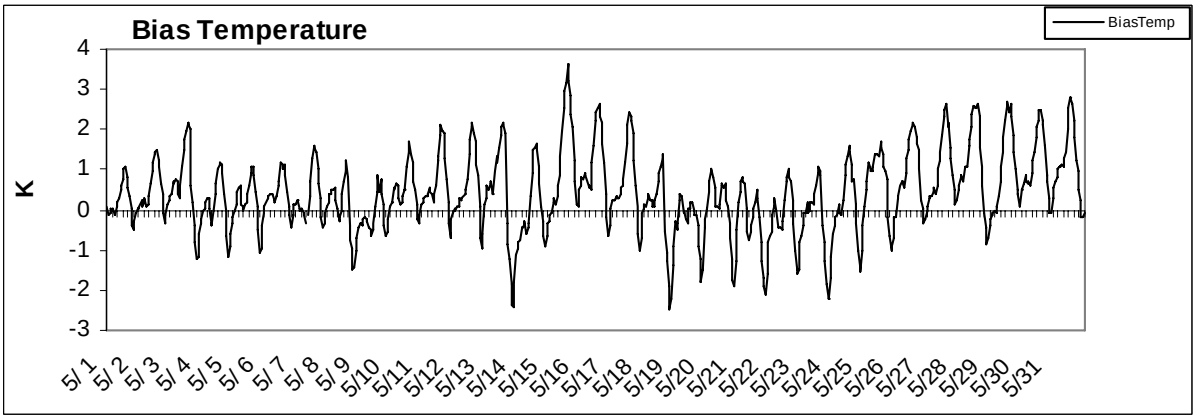
GEOMATRIX

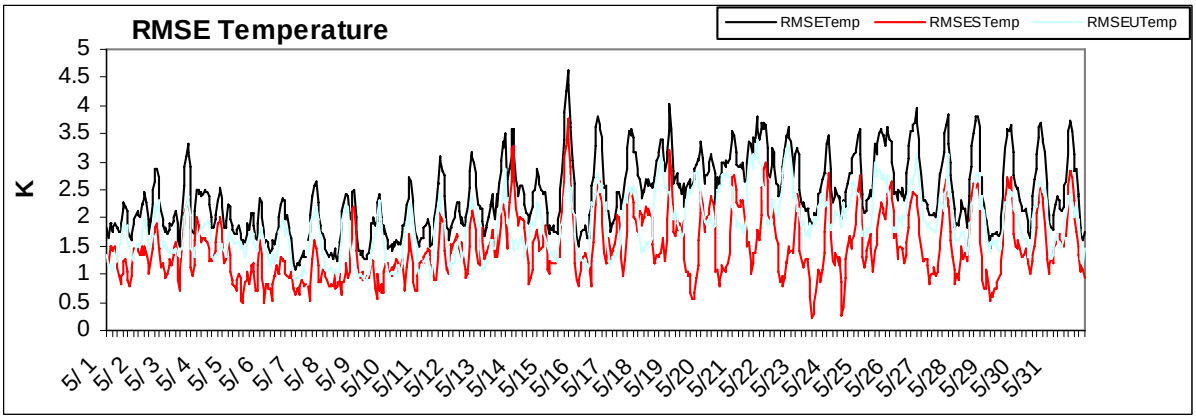
MM5 DOMAINS: D01 – 45KM, D02 – 15KM, D03 – 5KM GRID MESH SIZES
Alaska MM5 Modeling for BART
Alaska

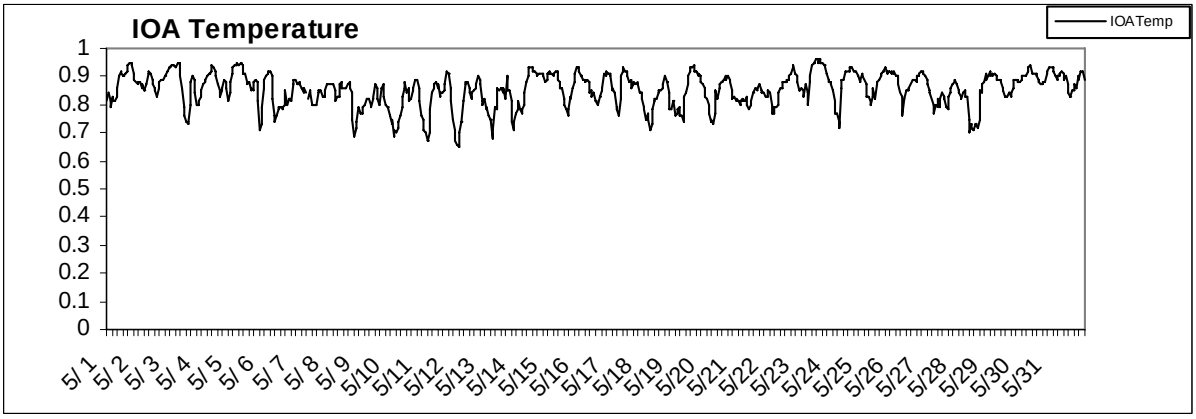
Project No.
13474.000

Figure
5

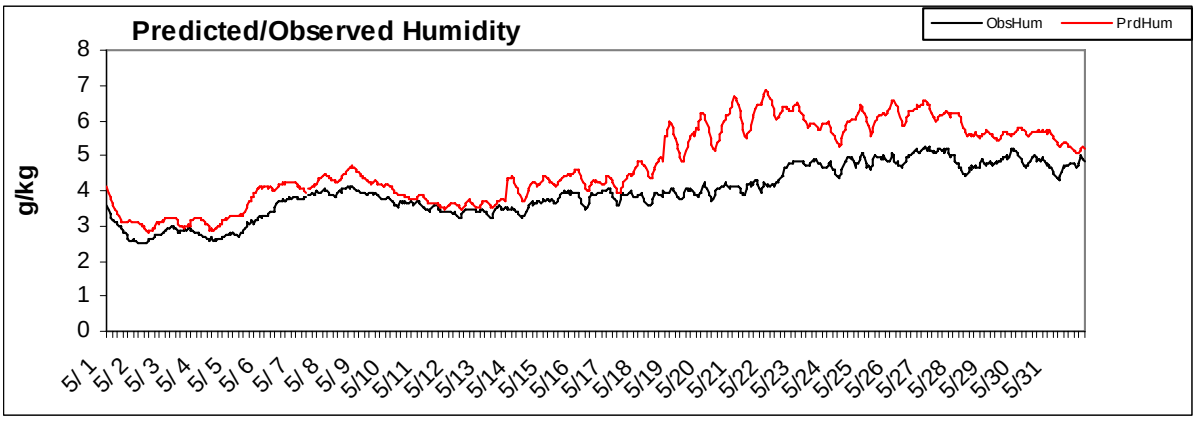


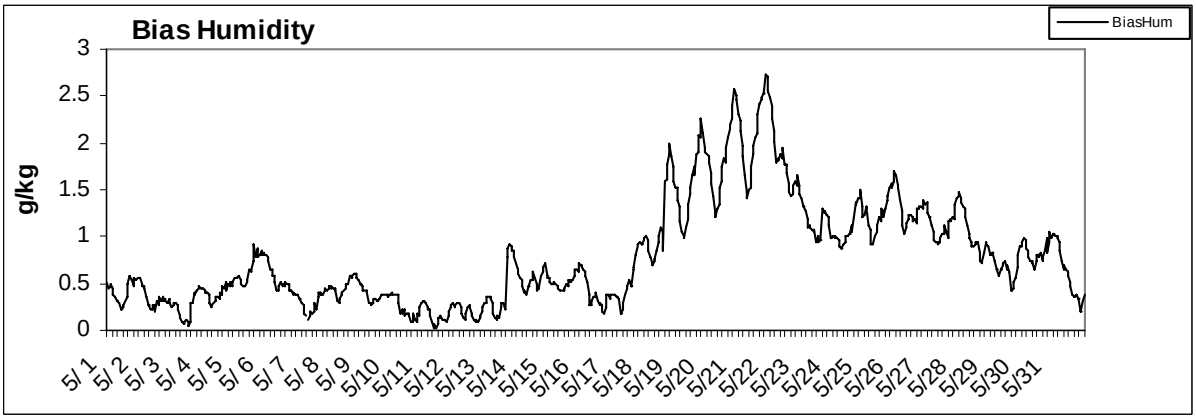


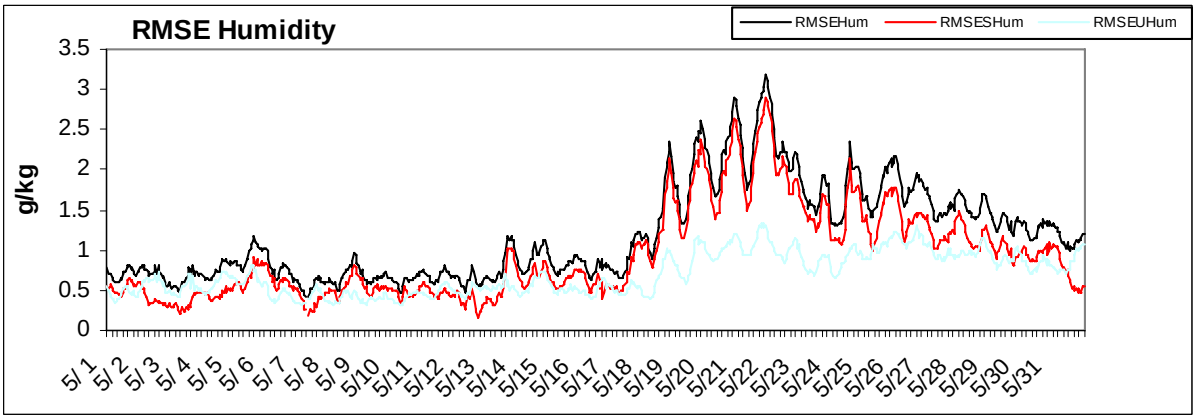


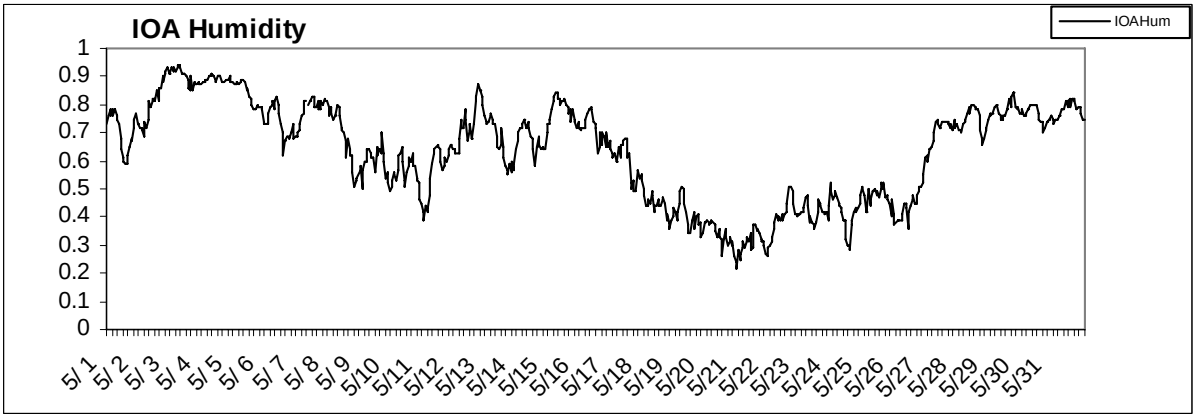


GEOMATRIX	15 KM DOMAIN AVERAGE TEMPERATURES STATISTICS FOR MAY 2002, USING REVISED SWITCH-OVER DATE OF APRIL 28, 2002 Alaska MM5 Modeling for BART, Alaska	Project No. 13474.000 Figure **6**

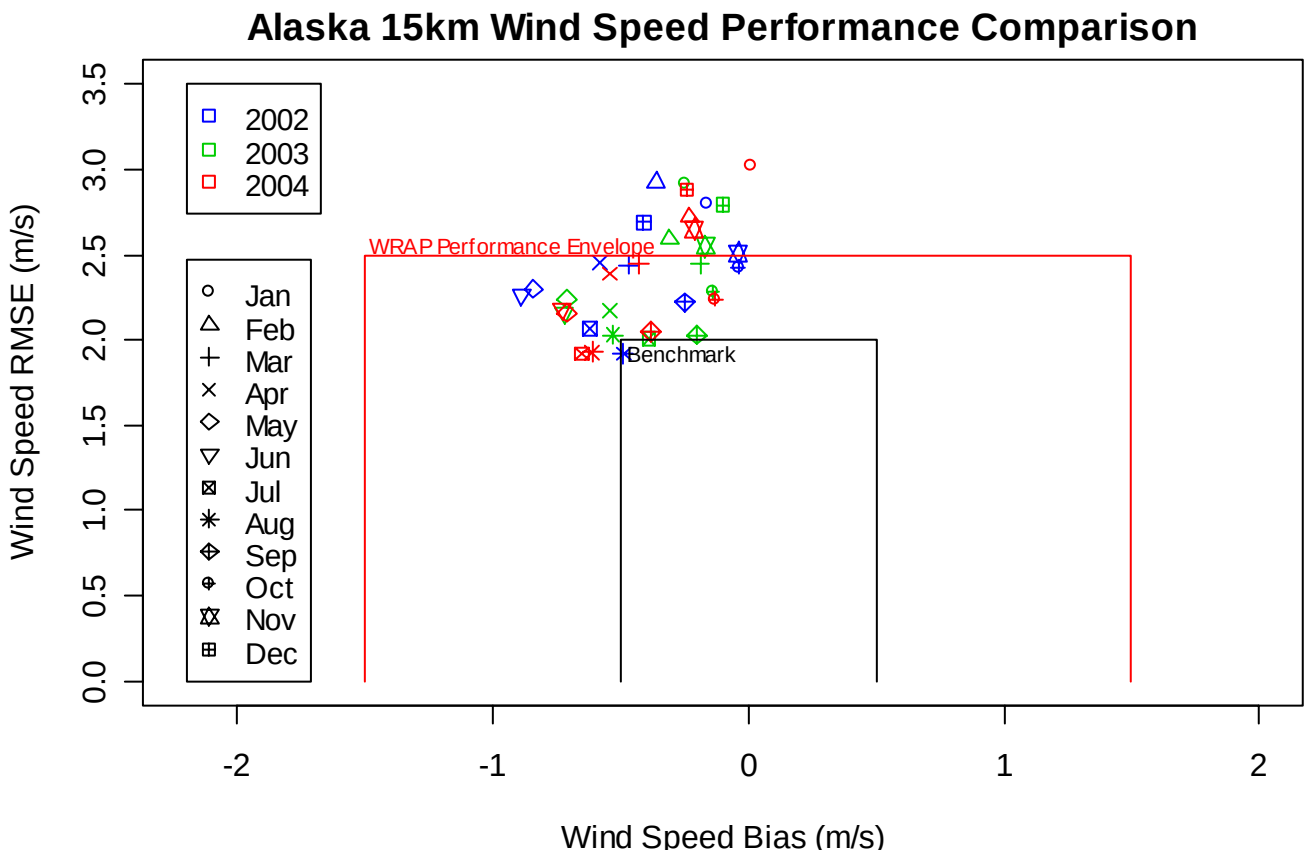


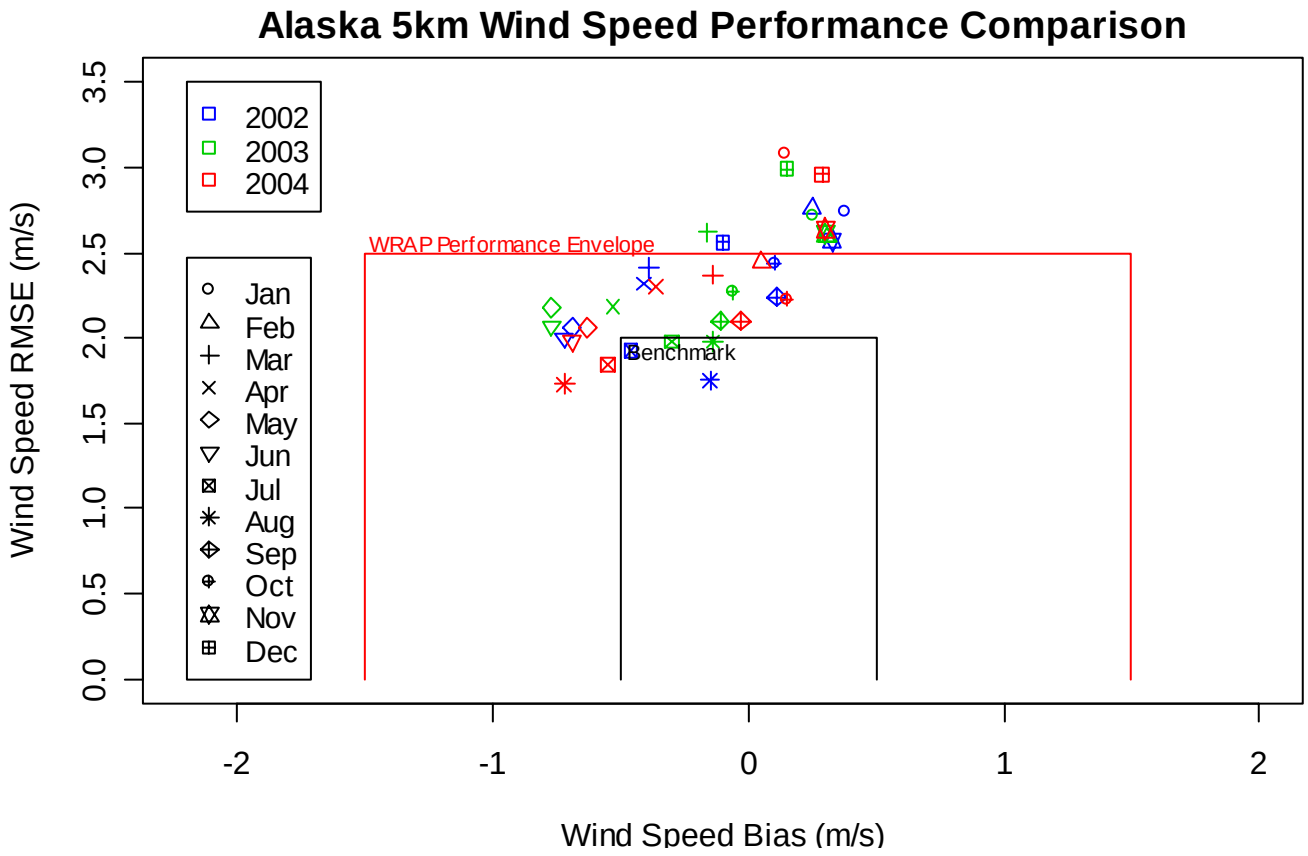






GEOMATRIX	15 KM DOMAIN AVERAGE HUMIDITY STATISTICS FOR MAY 2002, USING REVISED SWITCH-OVER DATE OF APRIL 28, 2002 Alaska MM5 Modeling for BART, Alaska	Project No. 13474.000 Figure **7**



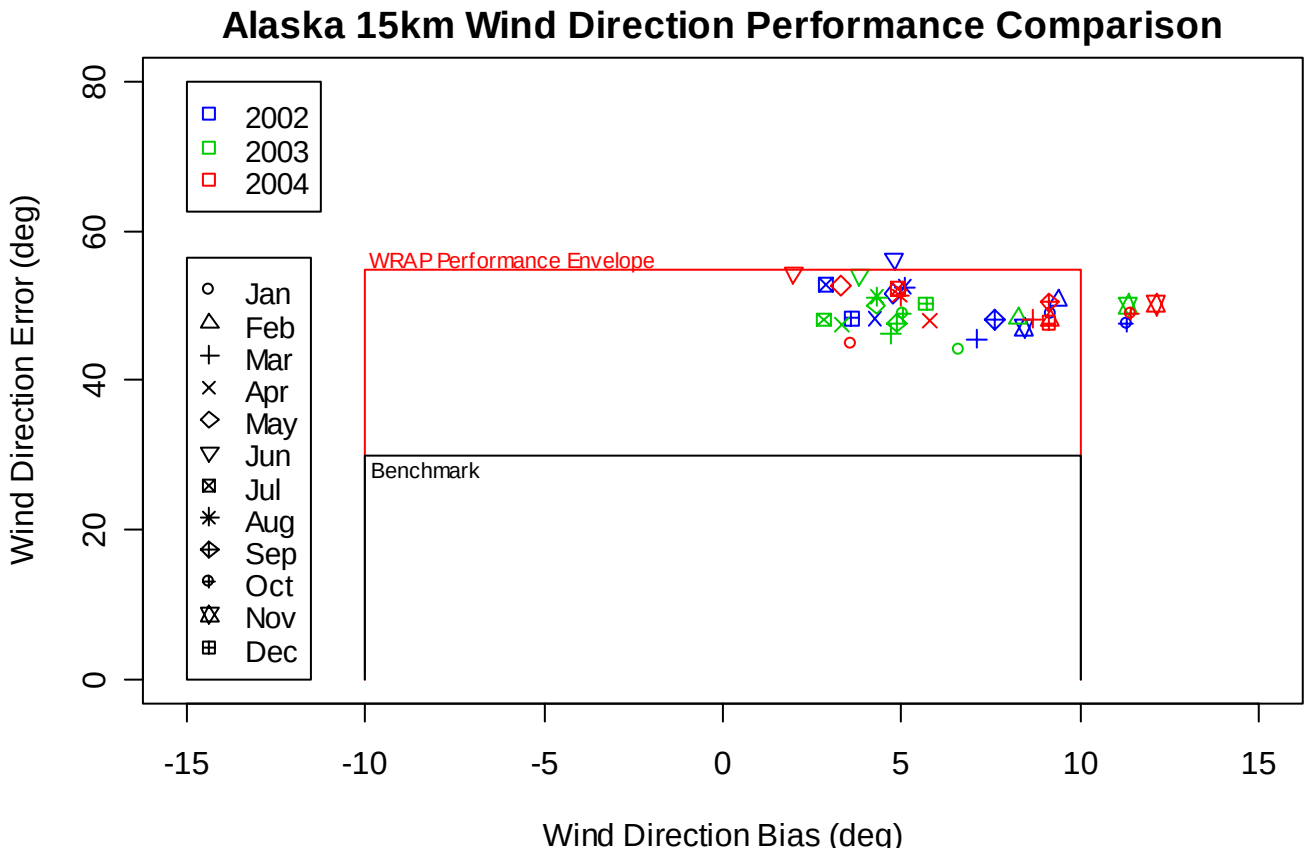


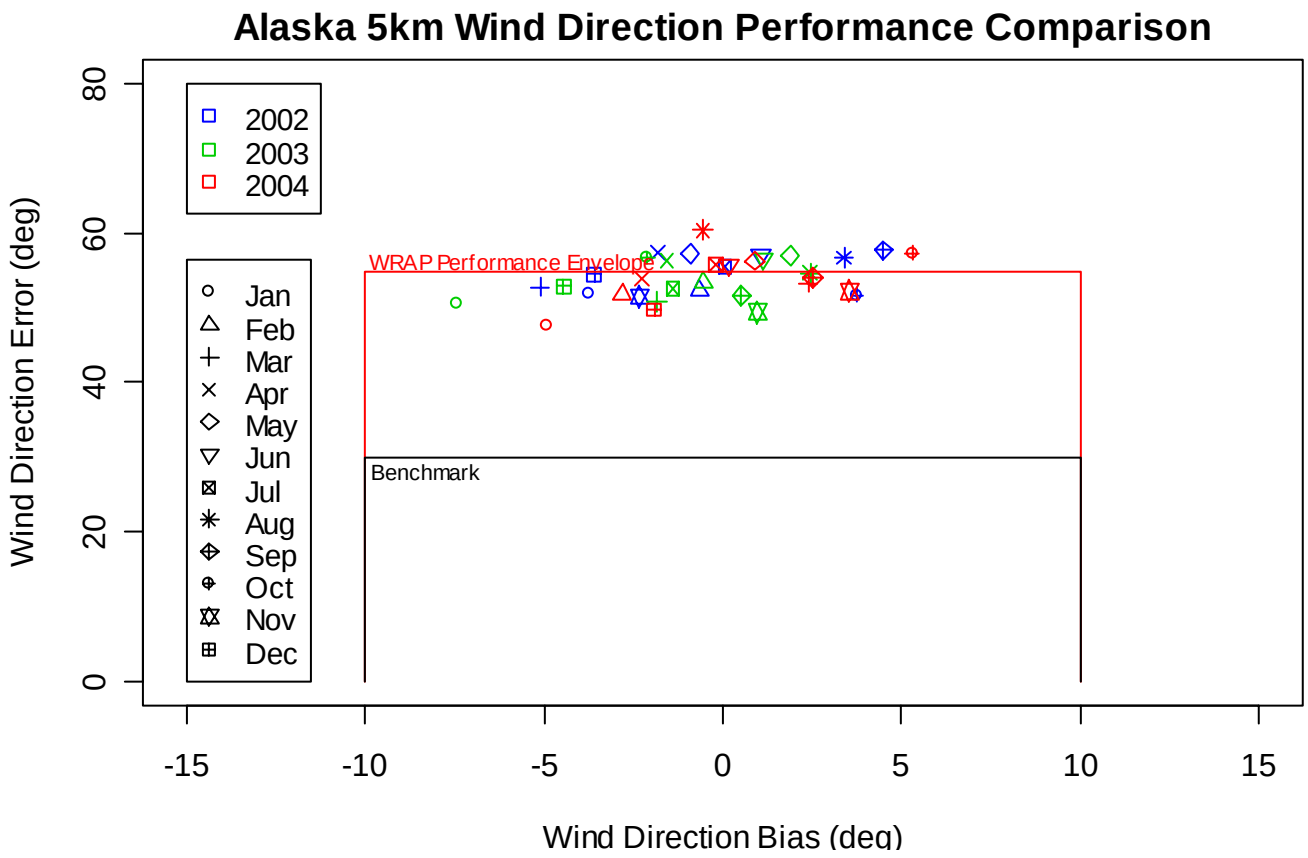
GEOMATRIX

WIND SPEED SOCCER PLOTS
Alaska MM5 Modeling for BART
Alaska

Project No.
13474.000

Figure
8



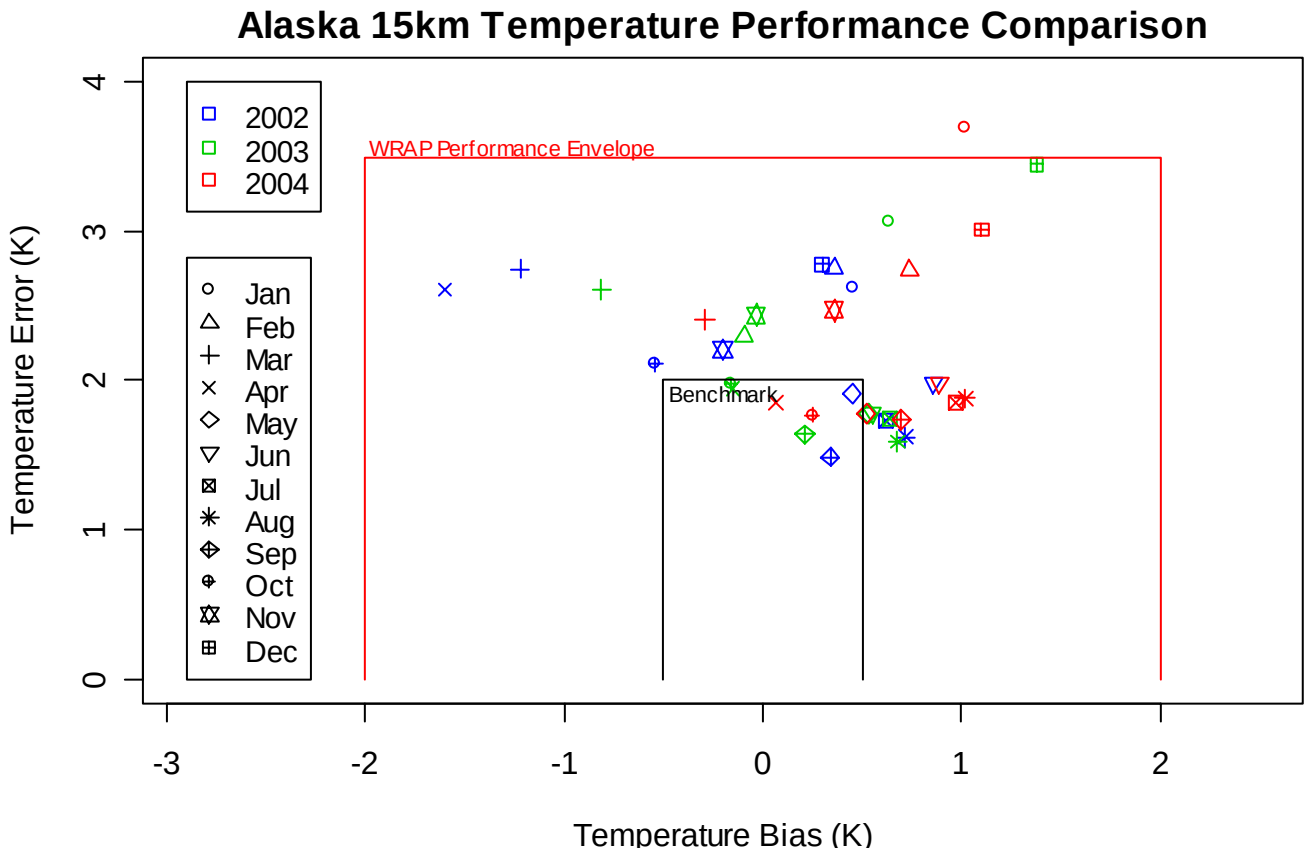


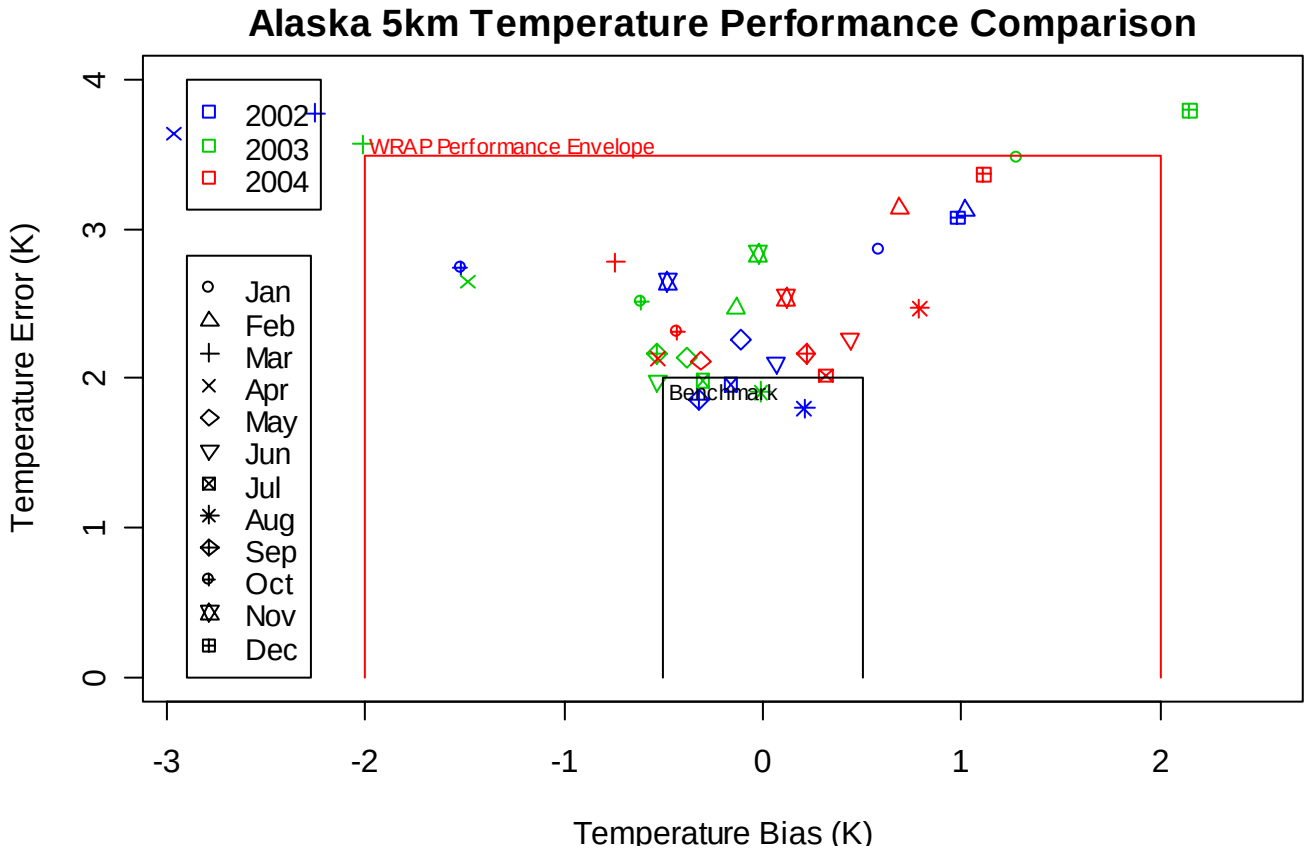
GEOMATRIX

WIND DIRECTION SOCCER PLOTS
Alaska MM5 Modeling for BART
Alaska

Project No.
13474.000

Figure
9



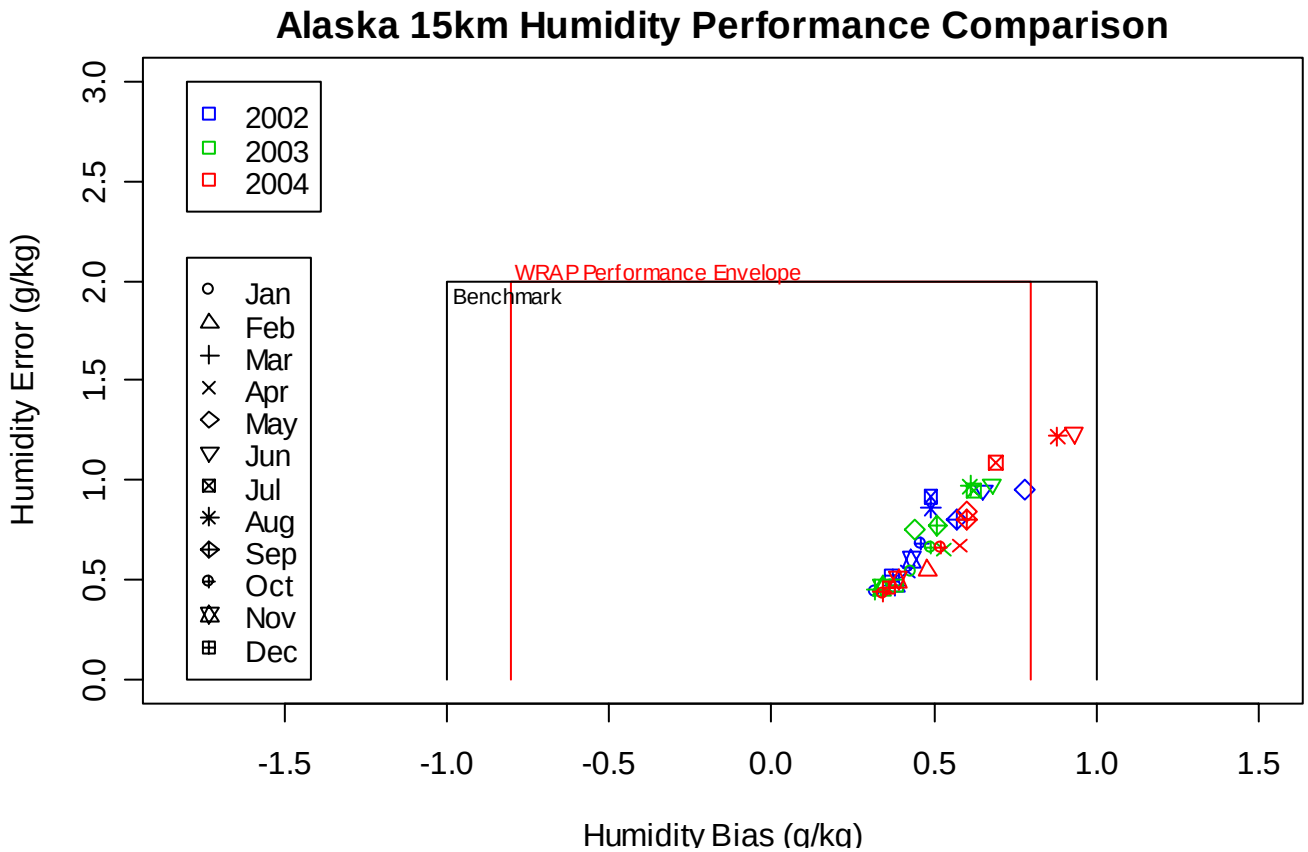


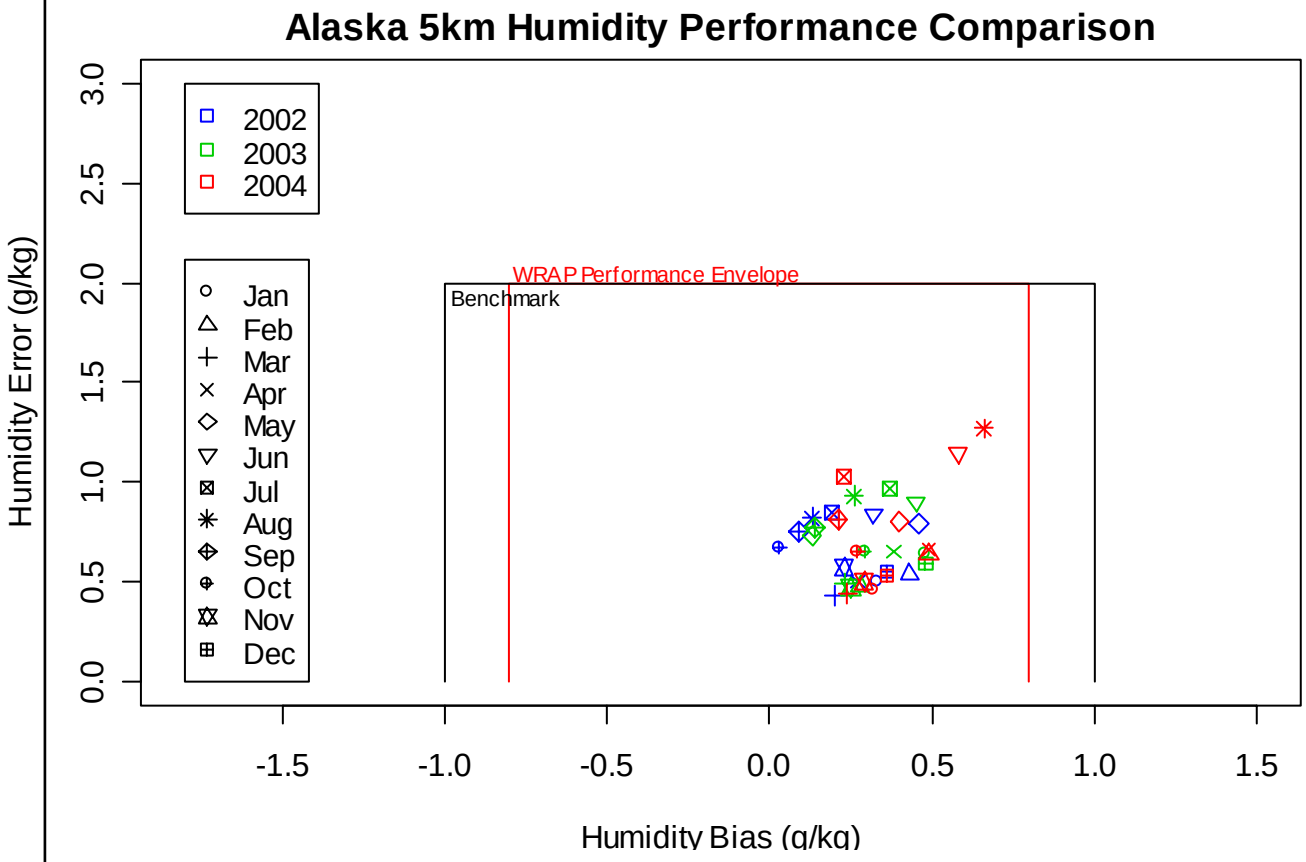
GEOMATRIX

TEMPERATURE SOCCER PLOTS
Alaska MM5 Modeling for BART
Alaska

Project No.
13474.000

Figure
10



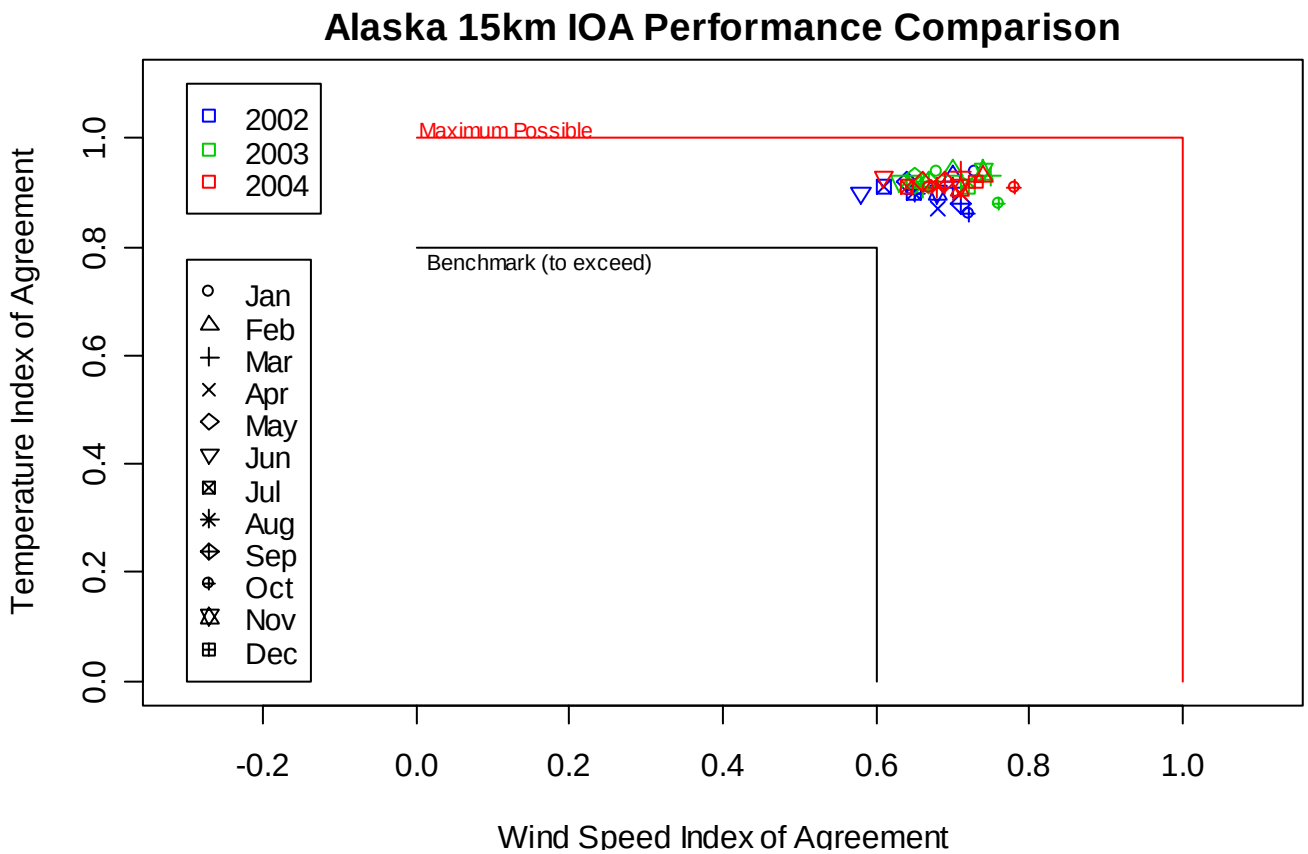


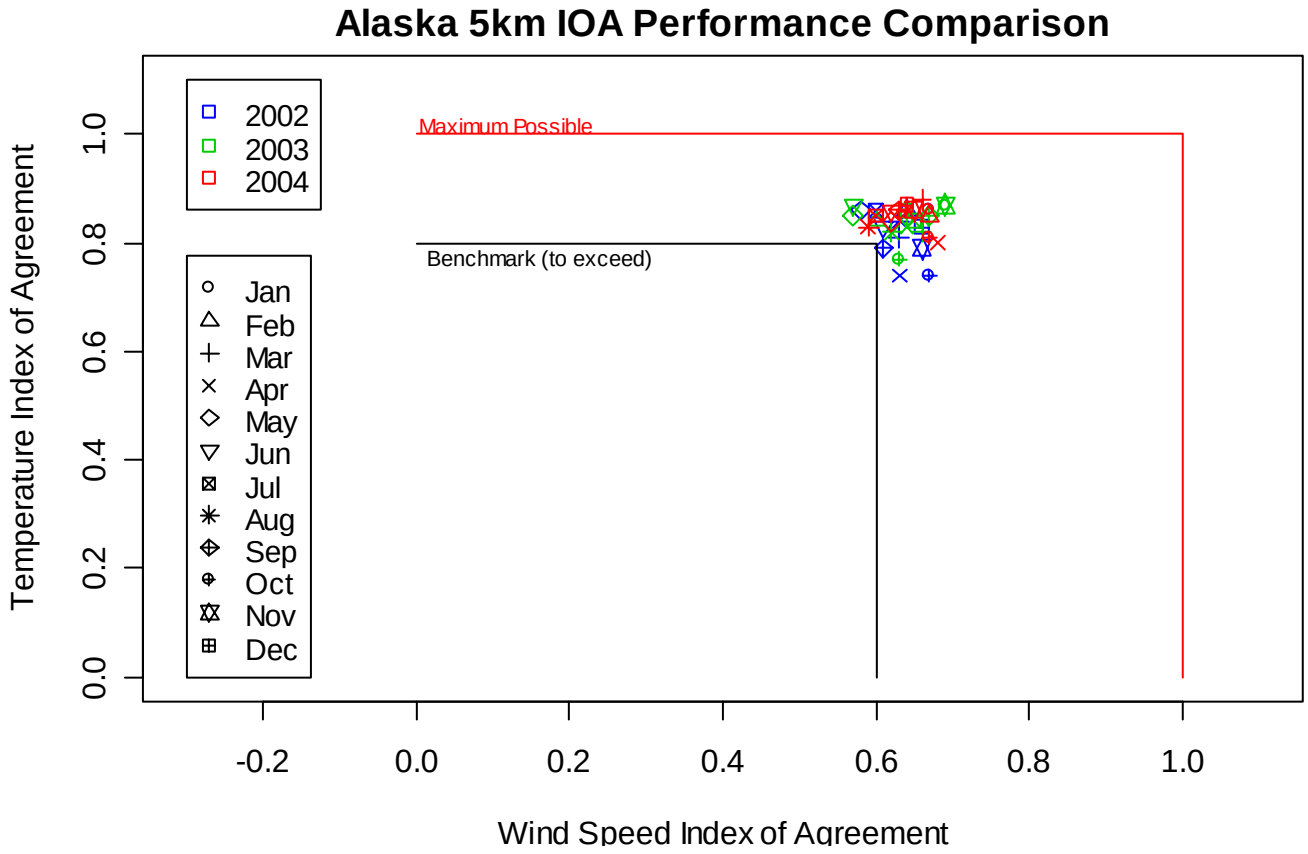
GEOMATRIX

HUMIDITY SOCCER PLOTS
Alaska MM5 Modeling for BART
Alaska

Project No.
13474.000

Figure
11





GEOMATRIX

INDEX OF AGREEMENT SOCCER PLOTS
Alaska MM5 Modeling for BART
Alaska

Project No.
13474.000

Figure
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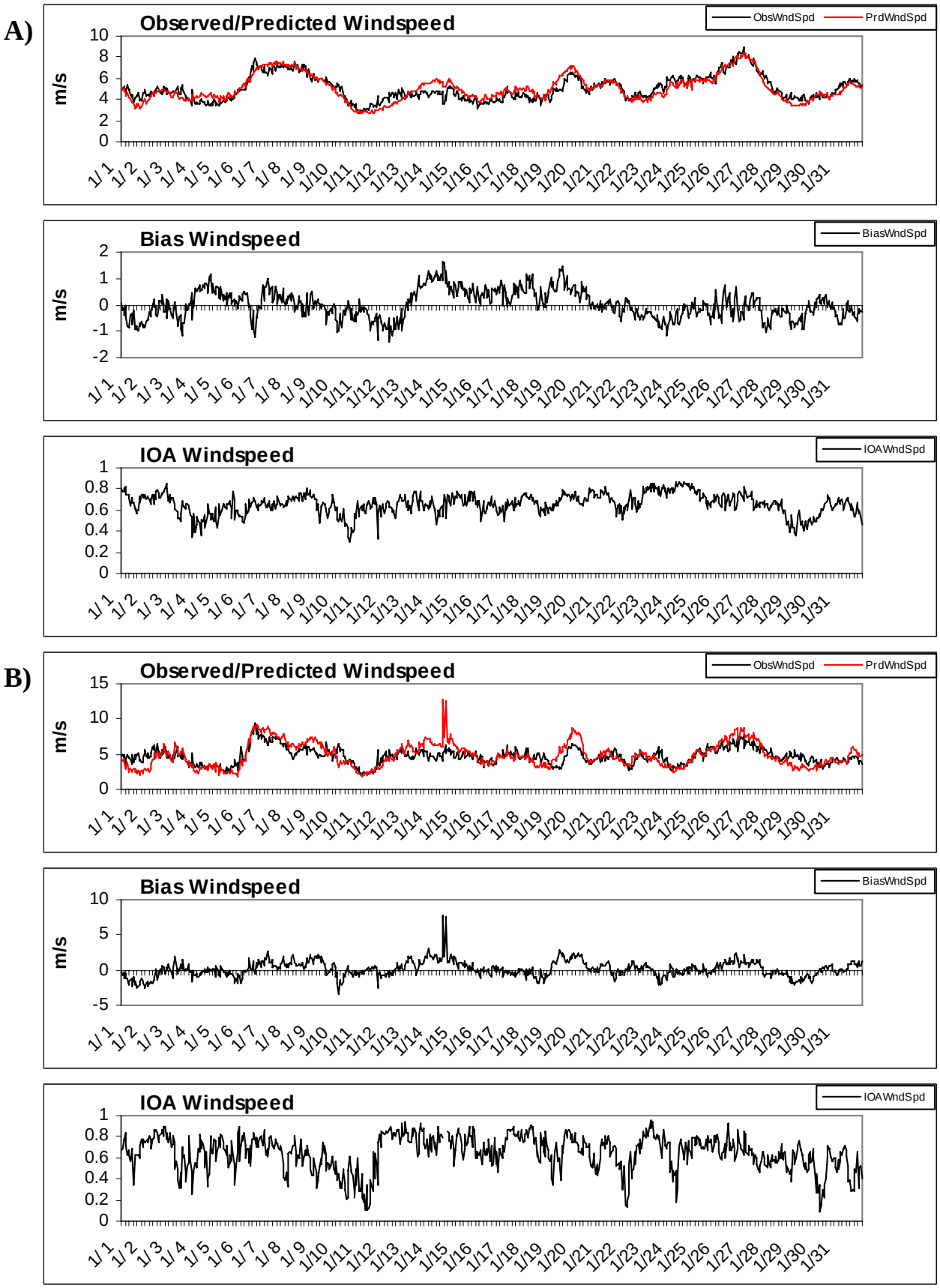

GEOMATRIX

WIND SPEED STATISTICS FOR THE 15 KM (A) AND 5 KM (B) DOMAINS
JANUARY 2004
Alaska MM5 Modeling for BART, Alaska

Project No.
13474.000

Figure
13

Appendix A

ALASKA MM5 MODELING PROTOCOL

Alaska MM5 Modeling for BART
Southern Alaska

1.0 INTRODUCTION

In 1999, the U.S. Environmental Protection Agency (EPA) announced a major effort to improve air quality in national parks and wilderness areas. The Regional Haze Rule (RHR) calls for federal agencies and States to work together to improve visibility in certain identified national parks and wilderness areas – also known as "Class I" areas. The objective of the RHR is to achieve natural visibility conditions in these federally protected lands by the year 2064. The rule requires the States to develop and implement air quality protection plans to reduce the pollution that causes visibility impairment. The Alaska Department of Environmental Conservation (ADEC) is developing a plan to protect visibility and comply with the intent of the Regional Haze Rule. A component of this plan is the implementation of the federal Best Available Retrofit Technology (BART) rules in Alaska.

The Western Regional Air Partnership (WRAP) is a consortium of federal, state, and tribal agencies charged with implementing regional planning processes to improve visibility in all western Class I areas. The WRAP has formed the Regional Modeling Center (RMC), consisting of the University of California at Riverside (UCR), ENVIRON International Corporation, and the University of North Carolina (UNC).

Starting in 2004, the RMC undertook an effort to perform the meteorological modeling necessary for the development of Section 309 SIPs/TIPs, and begin the analysis for the Section 308 SIPs/TIPs. This effort produced a one-year meteorological simulation of Alaska using the Fifth Generation Mesoscale Model (MM5), developed and maintained by the Pennsylvania State University (PSU) and the National Center for Atmospheric Research (NCAR). The modeling was documented in a Draft Modeling Protocol[1] and a Draft Report[2]. The RMC used MM5 to simulate the calendar year 2002, using two computational domains with 45 and 15 km grid spacing, respectively.

[1] Draft Modeling Protocol, PRELIMINARY WRAP ALASKA VISIBILITY MODELING, October 15th, 2004. Available at http://pah.cert.ucr.edu/aqm/308/docs/alaska.
[2] Draft Report, ALASKA MM5 MODELING FOR THE 2002 ANNUAL PERIOD TO SUPPORT VISIBILITY MODELING, September 2005. Available at http://pah.cert.ucr.edu/aqm/308/docs/alaska.

On behalf of ADEC, the RMC conducted CALPUFF simulations of Alaska BART Eligible sources. The simulations were performed to evaluate whether these eligible sources are subject to a BART Determination based on predicted impacts to visibility within Alaska Class I areas. BART Eligible sources are exempt from performing a BART determination if their impacts are below screening criteria set by ADEC, EPA, and the Federal Land Managers (FLMs). Non-exempt sources must perform a technology review and propose BART for each emission unit that comprises the BART Eligible source.

The RMC used the CALPUFF modeling system to assess the impacts from BART Eligible sources in Alaska based on the 15 km MM5 output data for 2002. The CALPUFF model grid spacing was 2 km, significantly different than the MM5 grid spacing of 15 km. In addition, because only one year was simulated, BART exemption simulations performed by WRAP used the highest modeled visibility impact, not the 98th percentile impact as is allowed under EPA rules.[3]

Several members of the ad-hoc Alaska BART Coalition (a collection of corporations with BART-eligible sources) contracted with Geomatrix Consultants (Geomatrix) to perform a refined MM5 simulation of Alaska, as well as post-process the MM5 data and prepare CALMET files in support of future CALPUFF modeling. Geomatrix in turn sub-contracted the MM5 portion of the project to 3TIER, Inc. This protocol describes the MM5 modeling 3TIER will perform.

Geomatrix will provide the Coalition with a 3-year MM5 dataset (with grid spacings of 45, 15 and 5 km) as well as a modeling report that will include a METSTAT analysis. A three year MM5 dataset with an inner 5-km mesh size domain will be a major step towards allowing ADEC and/or the BART Eligible sources in Alaska to refine the previous RMC modeling analyses and employ the more robust 98th percentile change to extinction as the BART exemption criterion. This MM5 dataset (and the use of the 98th percentile change to extinction) may also be used during the technology review phase of the BART process given that the federal rules allow for an evaluation of the degree of visibility improvement associated with each technology scenario being considered as possibly BART. A separate Air Quality Modeling Protocol will be developed and submitted to ADEC that will cover aspects pertaining to CALMM5, CALMET, and CALPUFF.

[3] "Thus, we agree with commenters that a State should not necessarily rely on the maximum modeled impact in determining whether a source may reasonably be anticipated to cause of contribute to visibility impairment in a Class I area." 70 Fed.Reg. 39121 (July 6, 2005)

This protocol draws very heavily from the RMC Draft Modeling Protocol of 2004. The modeling to be performed by 3TIER will closely follow that of the RMC, with few deviations from their model application other than the addition of a third nested grid, and extending the simulation period from one to three years.

For an overview of the Meteorology of Alaska, or a more detailed description of the MM5 modeling system, refer to the RMC Draft Modeling Protocol and Draft Modeling Report.

2.0 MM5 MODELING

The PSU/NCAR Mesoscale Model (known as MM5) is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation. The model is supported by several pre- and post-processing programs, which are referred to collectively as the MM5 modeling system. The MM5 modeling system software is mostly written in FORTRAN, and has been developed at PSU and NCAR as a community mesoscale model with contributions from users worldwide.

The latest version of the MM5 modeling system (version 3-7-4, released October 16, 2006) will be used for this project.

2.1 DATA SOURCES

Global topographic data at 10-minute (latitude/longitude) intervals will be used to find the terrain elevations for the 45 km grid, and 30-second mesh size data will be used for the 15 and 5 km mesh size grids. Land use will be defined using the 24-category USGS vegetation data (10-minute mesh size).

The NCAR dataset ds090.0[4], "NCEP/NCAR Global Reanalysis Products" (NNRP) will be used to supply boundary conditions to the model, as well as for "nudging". The NCAR datasets ds464.0[5], "NCEP ADP Global Surface Observations", and ds353.4[6], "NCEP ADP Global Upper Air Observation Subsets", will be used to re-analyze the ds090.0 data to provide "nudging" to guide the model predictions to more closely mimic the observations.

Two of the more important inputs for MM5 in the arctic are sea ice and snow cover. The RMC MM5 simulation used the NNRP dataset, which features a 2.5º by 2.5º resolution

[4] See http://dss.ucar.edu/datasets/ds090.0
[5] See http://dss.ucar.edu/datasets/ds464.0
[6] See http://dss.ucar.edu/datasets/ds353.4

(latitude/longitude, about 220 km), for both of these parameters. In an effort to increase the accuracy of the simulation, the NCAR dataset ds277.7[7] "NOAA Optimum Interpolation 1/4 Degree Daily Sea Surface Temperature Analysis" will be used to supply sea surface temperature. The sea ice concentration is diagnosed from the sea surface temperature, as discussed below. This daily dataset features 0.25º by 0.25º (latitude/longitude, about 25 km) resolution.

The National Weather Service Climate Prediction Center "Daily Snow Cover for the Northern Hemisphere" dataset[8], produced by the NOAA/NESDIS Interactive Multisensor Snow and Ice Mapping System, will be used to provide the model with higher resolution snow cover data. This dataset is given on a polar stereographic grid with a true latitude of 60ºN, with 1024 by 1024 points covering the northern hemisphere. This indicates that at 60ºN, the grid spacing is approximately 0.2º, or about 20 km.

2.2 MM5 CONFIGURATION

The MM5 modeling system configuration for this project is based on the RMC configuration, which in turn is based on the work of the Mesoscale Modeling Applications Group at the University of Alaska Fairbanks (UAF). The UAF group has extensive experience with MM5 at high latitudes.

2.2.1 Modeling Domain

MM5 will be configured to run one coarse and two nested grids, using the polar stereographic projection. The central latitude for the projection will be 59ºN; the central longitude will be 151ºW. The coarse and middle grids correspond to the inner and outer grid of the RMC modeling. The domains are shown in Figure 1.

The coarse grid (D01) will cover all of Alaska, plus significant portions of Canada, the Pacific Ocean, the Arctic Ocean, and northeast Russia. It will feature 109 (east-west) by 90 (north-south) grid cells, using 45 km grid spacing. The middle grid (D02) will cover the populated areas of Alaska, including the Class I areas. It will be comprised of 106 (east-west) by 88 (north-south) grid cells, and use 15 km grid spacing. The inner grid (D03) will cover the domain used in the WRAP CALPUFF simulations used to assess BART Eligible sources. It will be 106 points (east-west) by 130 points (north-south) and have a 5 km grid spacing.

[7] See http://dss.ucar.edu/datasets/ds277.7.
[8] See http://www.cpc.noaa.gov/data/daily_snow

All three grids will be run simultaneously, but the two nested grids will use “one-way” nesting option. In this mode, information from each coarser grid influences the finer grid, but there is no feedback of averaged information from a nested grid to its parent grid.

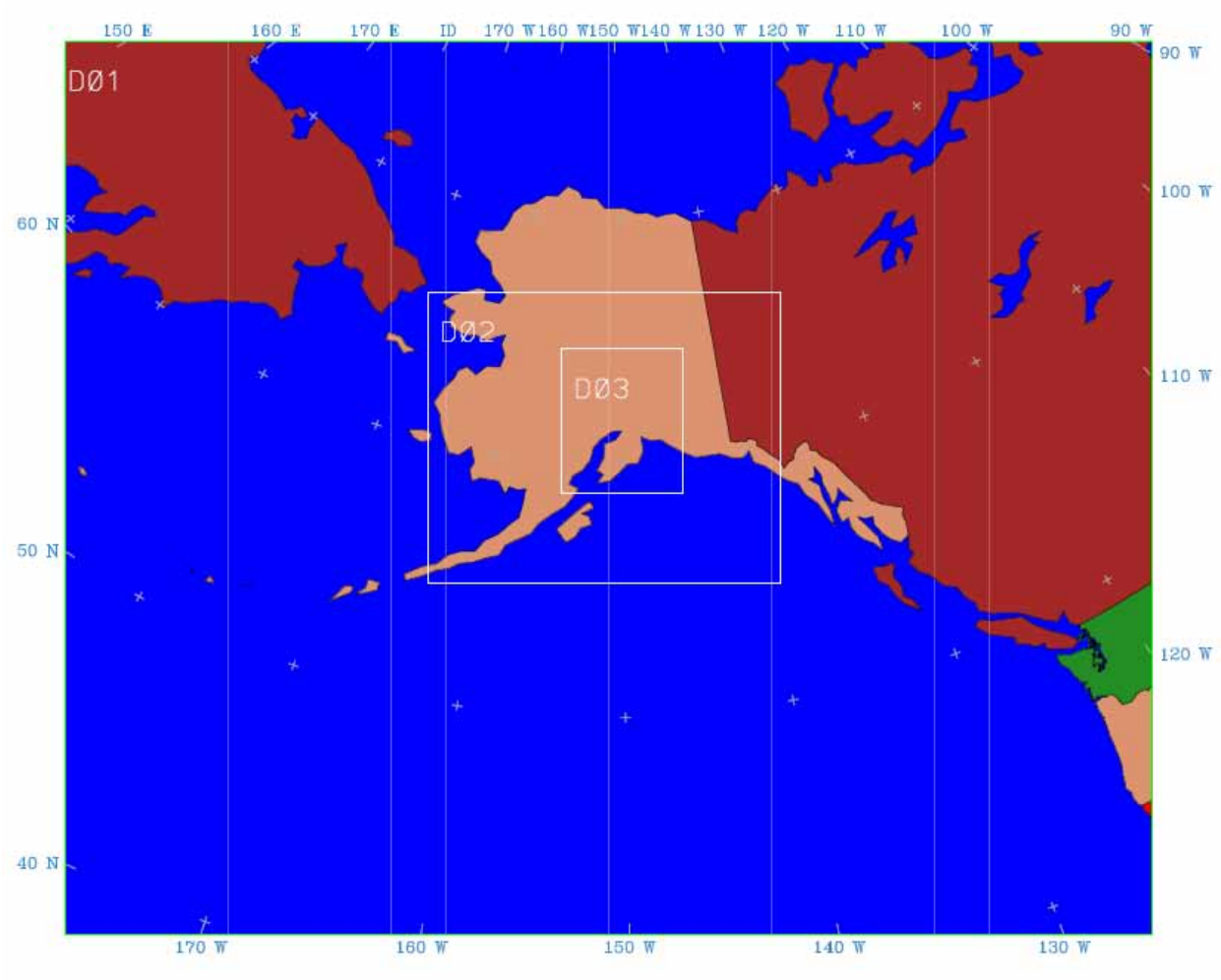

Figure 1. MM5 Coarse (D01) and Nested (D02 and D03) Domains

2.2.2 Vertical Grid Structure

The vertical extent of the domain will be from the ground up to 50 millibars (mb). The vertical layer structure will be the same as was used in the RMC modeling: 40 sigma levels from the surface to a model top. A sigma value of 0.000 corresponds with the model top, and a sigma value of 1.000 corresponds with the ground. The levels and sigma values are shown in Table 1.

Table 1. MM5 Vertical Layers (Sigma Levels)

Level	Sigma	Level (cont).	Sigma (cont.)
40	0.018	20	0.590
39	0.040	19	0.623
38	0.060	18	0.654
37	0.085	17	0.687
36	0.107	16	0.718
35	0.134	15	0.749
34	0.134	14	0.778
33	0.187	13	0.806
32	0.213	12	0.832
31	0.244	11	0.855
30	0.272	10	0.878
29	0.304	9	0.897
28	0.334	8	0.917
27	0.367	7	0.932
26	0.398	6	0.949
25	0.431	5	0.961
24	0.462	4	0.975
23	0.495	3	0.983
22	0.526	2	0.992
21	0.559	1	0.995

2.2.3 Physics Options

The rationale behind the choices for physics options and four-dimensional data assimilation (FDDA) choices were discussed in the RMC Draft Modeling Protocol. The annual cycle of sea ice is one of the more important aspects of modeling near-polar meteorology. MM5 can diagnose the sea ice coverage from the sea surface temperature (SST), but only when using the 5-layer land surface model (LSM). MM5 will be run in two modes, “summer” and “winter” mode, each with a different choice of LSM. The switch over for 2002 from summer to winter configuration will be the same as in the RMC configuration: May 30 and October 13. For 2003 and 2004, sea ice cover maps[9] from the National Snow and Ice Data Center will be consulted to determine the switch over date from “winter” to “summer.”

[9] For example, the Daily Total Sea Ice Extent product available at http://nsidc.org/data/smmr_ssmi_ancillary/area_extent.html

The choice of physics options is covered in detail in the RMC Draft Modeling Report. Only a synopsis of the choices is presented here, with no justification or explanation. The selected physics options are given for winter in Table 2, and for summer in Table 3.

Table 2. Physics Options for Winter

Physics Option	Parameterization
Cloud Microphysics	Reisner II
Cumulus Parameterization	Grell
Planetary Boundary Layer	ETA
Land Surface Model	5-Layer Model
Radiation	RRTM
Shallow Convection	None
Varying SST with time?	Yes
Sea Ice	Yes
Snow Cover	Simple Snow Model

Table 3. Physics Options for Summer

Physics Option	Parameterization
Cloud Microphysics	Reisner II
Cumulus Parameterization	Grell
Planetary Boundary Layer	ETA
Land Surface Model	OSU
Radiation	RRTM
Shallow Convection	None
Varying SST with time?	Yes
Sea Ice	No
Snow Cover	No

The polar physics option will be selected (IPOLAR = 1) for all three domains. Solar slope and topography shadowing effects will be included, but only in the 5km domain (LEVSLP = 3, OROSHAW = 3).

Data from the NNRP reanalysis dataset will be used to supply boundary conditions. SST will be taken from the ds277.7 data, and will be allowed to vary in time. Snow cover will be taken from the Climate Prediction Center's Daily 1024x1024 Northern Hemisphere snow cover dataset.

2.2.4 Nudging

MM5 can be configured to use four-dimensional data assimilation (FDDA), commonly called "nudging". Nudging can be used to guide the model to more closely mimic observations. Observations of wind speed/direction, temperature, and humidity taken from automated surface weather stations can be ingested. It is used to guide, but not force, MM5 toward a particular solution.

MM5 can be configured to use two kinds of analysis nudging, so-called "3D" and "SFC" nudging, where three-dimensional and two-dimensional (respectively) fields of gridded data are supplied to the model. Additionally, MM5 can use observational nudging, called "OBS" nudging, where measurements of winds, temperature and water vapor at specific points are supplied to the model.

Generally, the input grids used for 3D and SFC nudging are much coarser than the MM5 grid. For example, the NNRP data is gridded on 2.5º by 2.5º latitude/longitude grid (about 100 by 200 km). To increase the accuracy of these nudging grids, the initial coarse data is often re-processed by an objective analysis package, such as the MM5 program "little_r". It takes the coarse data and deforms the fields in response to the local observations.

The RMC simulation used a 3-hourly interval for both 3D and SFC nudging, using the NNRP dataset. They did not use OBS nudging, but did incorporate observations into the 15 km nudging grid by using the MM5 program "little_r". The 3-hour interval was used to avoid using hourly nudging, as this can sometimes lead to model instability.

Our simulation will also use a 3-hourly interval for the analysis nudging of the 45 km and 15 km domains. The program "little_r" will be used to objectively re-analyze the NNRP data using the ds464.0 observations and ds353.4 upper-air data. To avoid numeric instability, nudging will be applied differently inside and outside the planetary boundary layer diagnosed by MM5. Above the boundary layer, the wind, temperature and water vapor fields will be adjusted, while inside the boundary layer only temperature and water vapor will be adjusted. Analysis nudging coefficients, the same as were used in the RMC runs, are given in Table 4.

Selected meteorological observation stations in Alaska are shown in Figure 2, along with the approximate boundaries of the 5 km domain. Stations with more than 40% of the wind speed observations missing have been excluded from the plot. The center of the Lambert Conformal Conic (LCC) projection is 59ºN, 151ºW.

The simulation will use a 90-second time step for the 45 km domain, a 30-second time-step for the 15 km domain, and a 10-second time-step for the 5 km domain.

Table 4. FDDA Analysis Nudging Coefficients (s^{-1})

Variable	45 km	15 km
Wind	2.5×10^{-4}	1.0×10^{-4}
Temperature	2.5×10^{-4}	1.0×10^{-4}
Water Vapor	1.0×10^{-5}	1.0×10^{-5}

2.3 MM5 APPLICATION

The 2002-2004 simulation will be performed in sequential 5-day segments, each with extra initial 12-hour spin-up period that overlaps the preceding run. No data will be kept from the spin-up period, and all output data will be in hourly files. Each 5-day segment is independent of the preceding segment, allowing them to be run concurrently on modern Linux clusters. The simulation period will start on December 15, 2001, to allow for sufficient "spin-up" for photochemical or visibility models that may wish to use this data in the future.

3.0 MM5 STATISTICAL EVALUATION

The WRAP RMC Draft Modeling Report presented the METSTAT Analysis Package, developed by ENVIRON. It is a statistical analysis software package to calculate and graphically present statistical measures, and has become widely used to evaluate MM5 performance. Benchmarks for statistical performance have been suggested, primarily based on MM5 simulations of the lower 48 states.

Geomatrix will perform the standard METSTAT analysis for our Alaska MM5 simulations, using the same sub-domains that were presented in the RMC Draft Modeling Report, using the 15 km domain. The 5 km domain will also be analyzed, but without dividing it into sub-domains. The results will be presented in an MM5 Modeling Report.

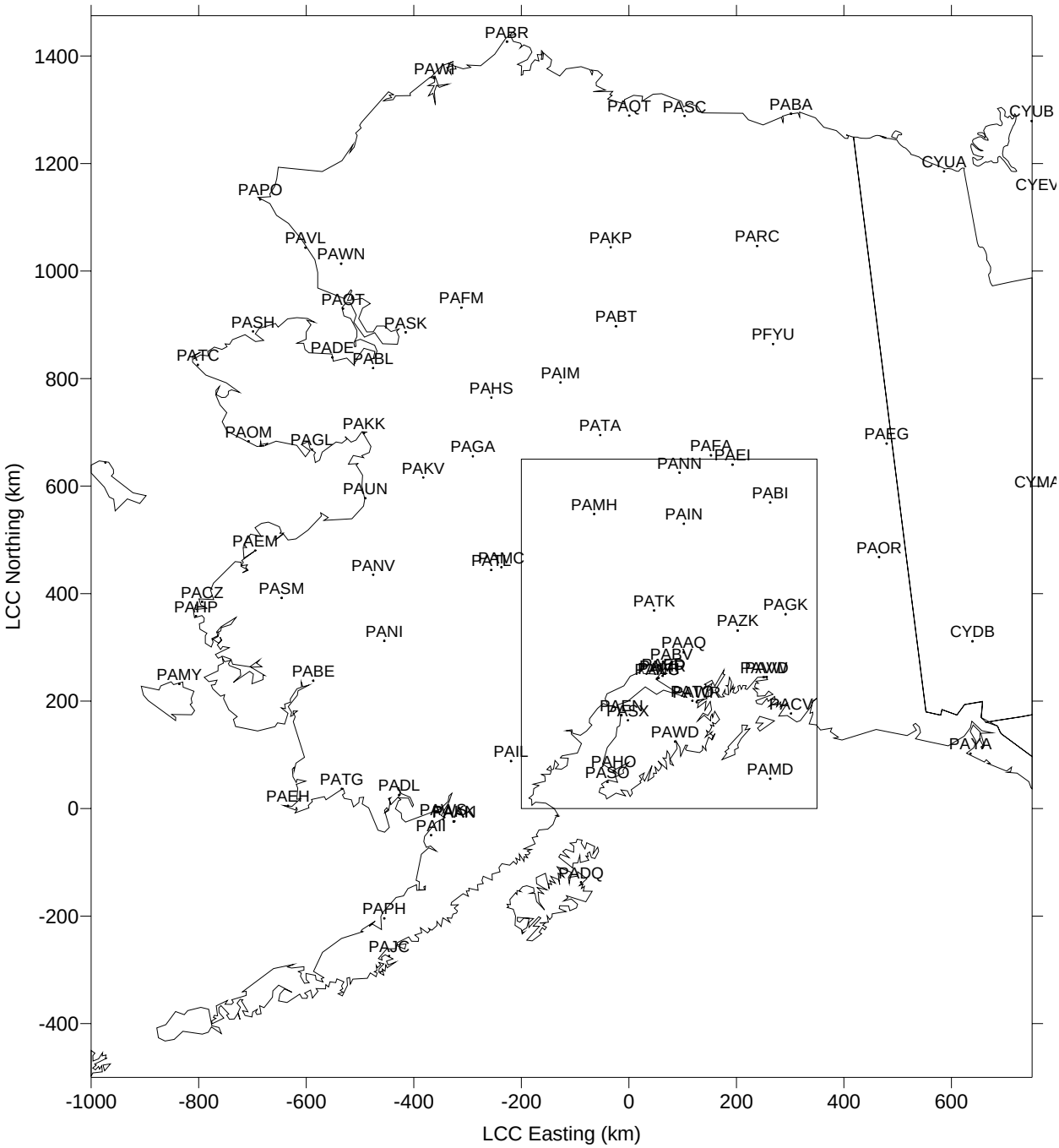

Figure 2. Selected MET Stations, and the Approximate 5km Domain Boundary.

Appendix B

Sample “mmlif” (MM5 control) file:

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    SVLAST = .FALSE.,
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    TAPFRQ = 60.0,
    BUFFRQ = 1440.0,
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 PRTFRQ = 720.,
 MASCHK = 99999,
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   TSLON = 0.0,0.0,0.0,0.0,0.0,
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 &LPARAM
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 IMVDIF    = 0,
 IVQADV    = 1,
 IVTADV    = 1,
 ITHADV    = 1,
 ITPDIF    = 1,
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 IEXSI     = 0,
 IFUPR     = 1,
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 RDBRDALB=.FALSE.
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 ICUPA  = 3,3,3,
 IMPHYS = 7,7,7
 IBLTYP = 4,4,4
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 ISOIL = 1
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 &NPARAM
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 NESTJX =  109,  106,  109,  ,   ,    ,    ,
 NESTI  =   1,  36,  28,   , , , ,
 NESTJ  =   1,  37,  41,   , , , ,
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            0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
            0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
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 IMOVEJ =   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
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            0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
            0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
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 &PPARAM
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 ZZWTR  = 0.0001,
 ALBLND = 0.15,
 THINLD = 0.04,
 XMAVA  = 0.3,
 CONF   = 1.0,
 SOILFAC= 2.0,
 &END
 &FPARAM
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 FDAEND = 8640.,8640.,0.,0.,0.,0.,0.,0.,0.,0.,
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 IWIND  = 1,1,0,0,0,0,0,0,0,0,
          0,0,0,0,0,0,0,0,0,0,
 GV     = 2.5E-4,1.0E-4,0.,0.,0.,0.,0.,0.,0.,0.,
          2.5E-4,1.0E-4,0.,0.,0.,0.,0.,0.,0.,0.,
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          1.0E-5,1.0E-5,0.,0.,0.,0.,0.,0.,0.,0.,
 IROT   = 0,0,0,0,0,0,0,0,0,0,
 GR     = 0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,
 INONBL = 1,1,0,0,0,0,0,0,0,0,
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 IMOVET =   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
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&END
&PPARAM
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ZZWTR  = 0.0001,
ALBLND = 0.15,
THINLD = 0.04,
XMAVA  = 0.3,
CONF   = 1.0,
SOILFAC= 2.0,
&END
&FPARAM
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FDAEND = 8640.,8640.,0.,0.,0.,0.,0.,0.,0.,0.,
I4D    = 1,1,0,0,0,0,0,0,0,0,
         1,1,0,0,0,0,0,0,0,0,
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GV     = 2.5E-4,1.0E-4,0.,0.,0.,0.,0.,0.,0.,0.,
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IROT   = 0,0,0,0,0,0,0,0,0,0,
GR     = 0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,
INONBL = 1,1,0,0,0,0,0,0,0,0,
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ISWIND = 0,0,0,0,0,0,0,0,0,0,
GIV    = 0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,
ISTEMP = 0,0,0,0,0,0,0,0,0,0,
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ISMOIS = 0,0,0,0,0,0,0,0,0,0,
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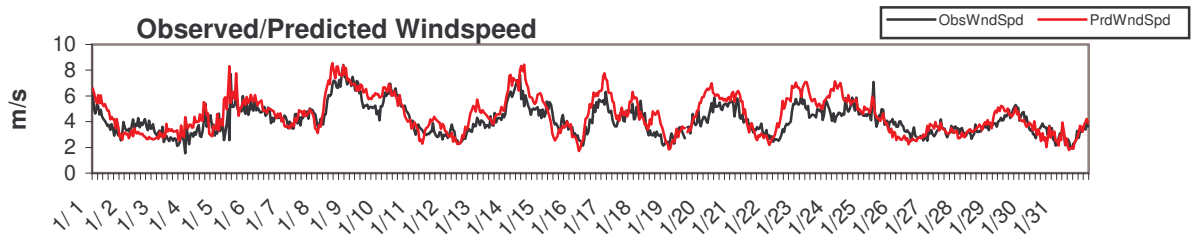
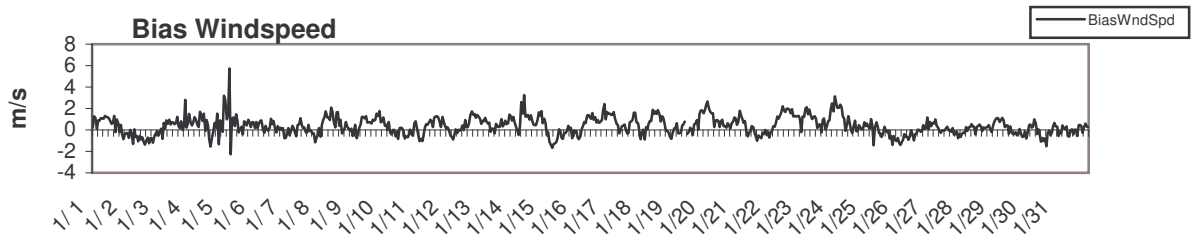
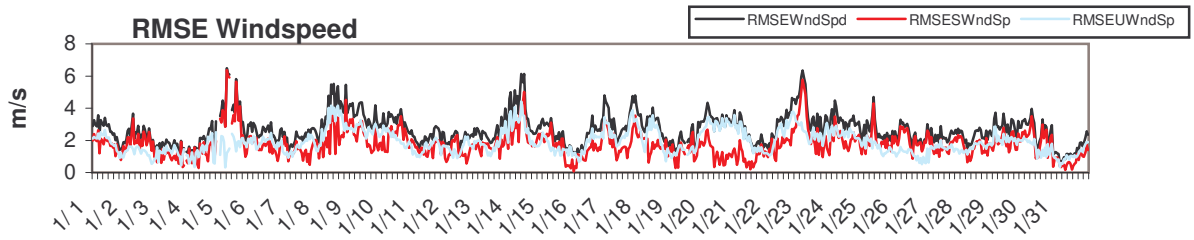
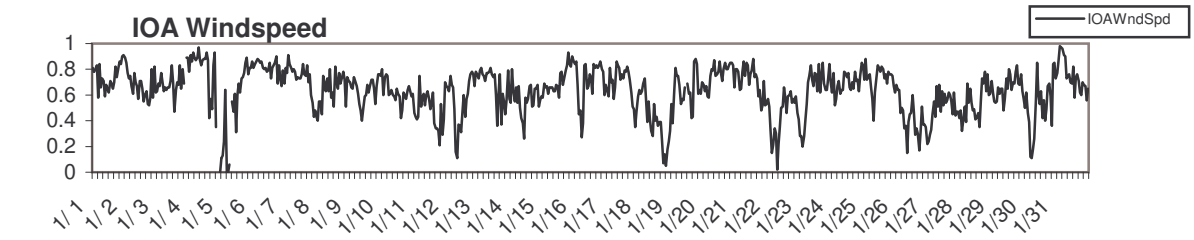
Appendix C

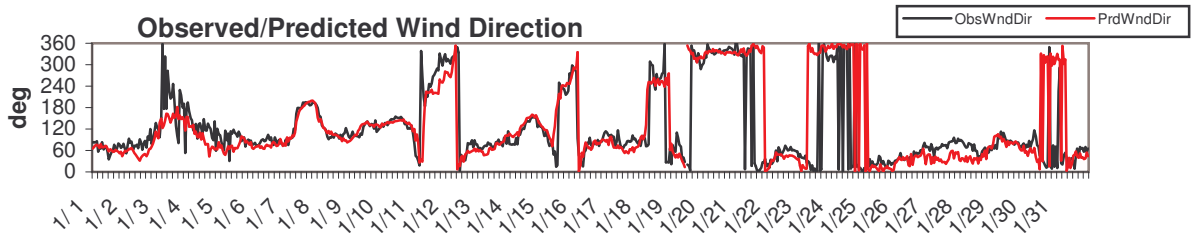
Alaska 5km 2002-01

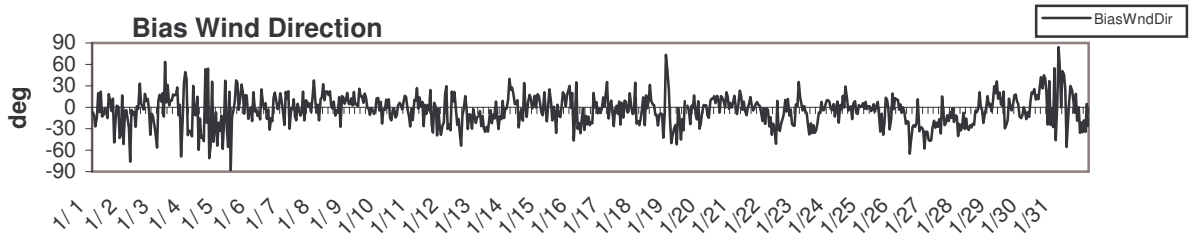




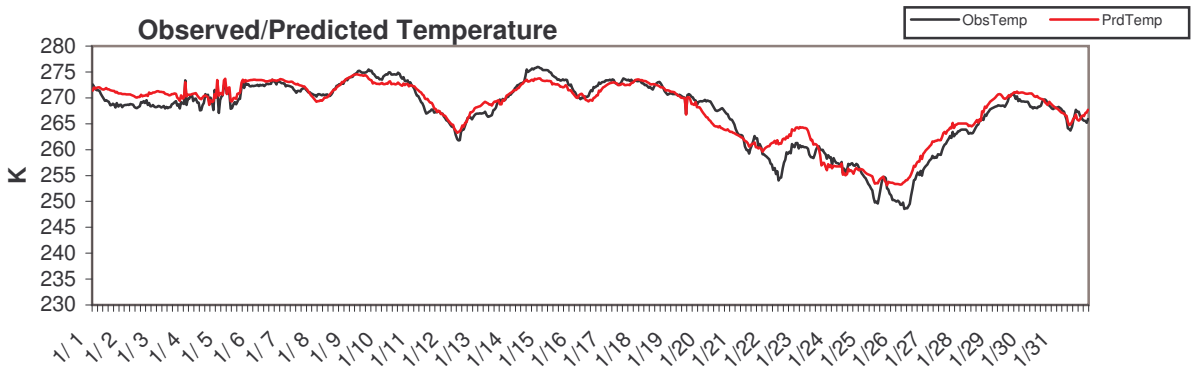


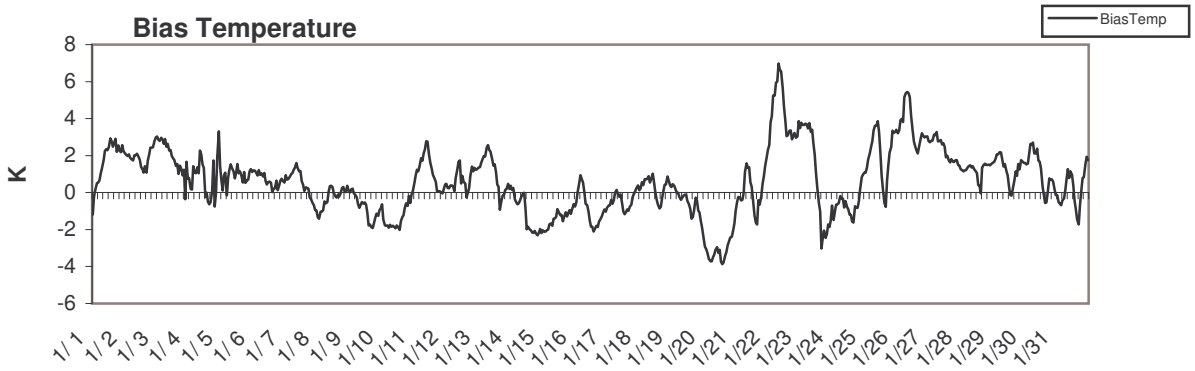


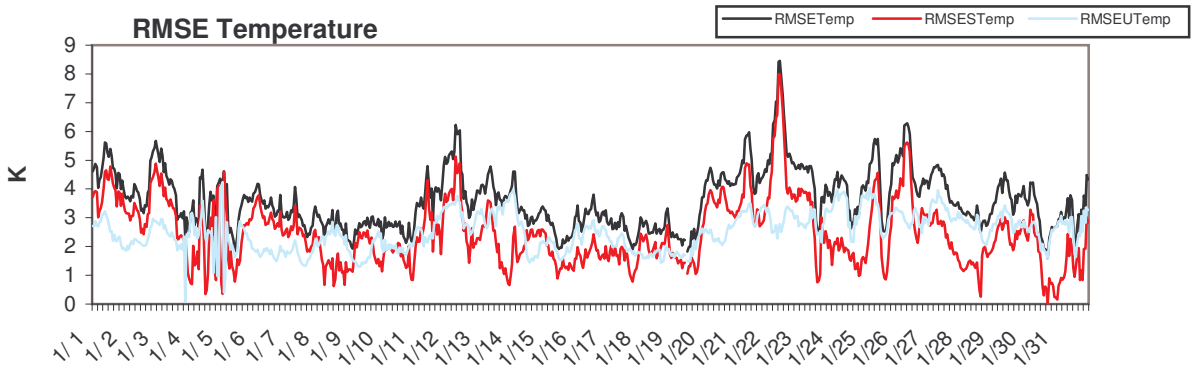


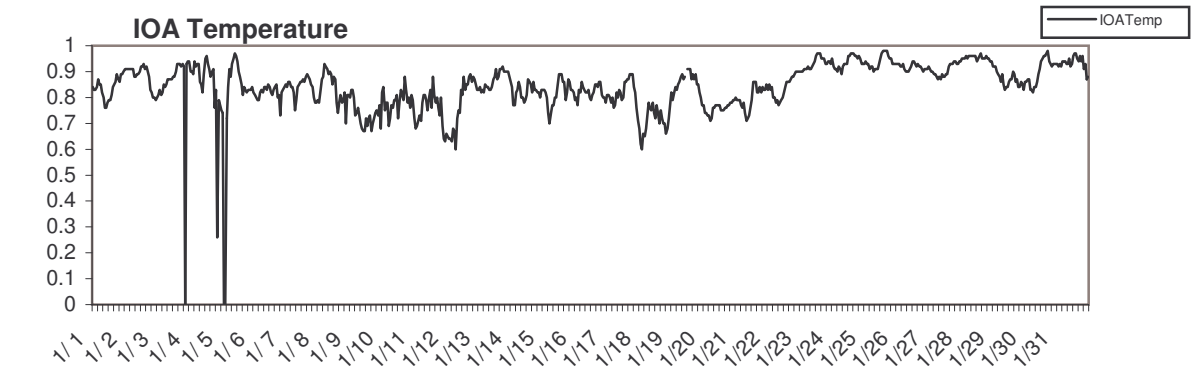


Alaska 5km 2002-01

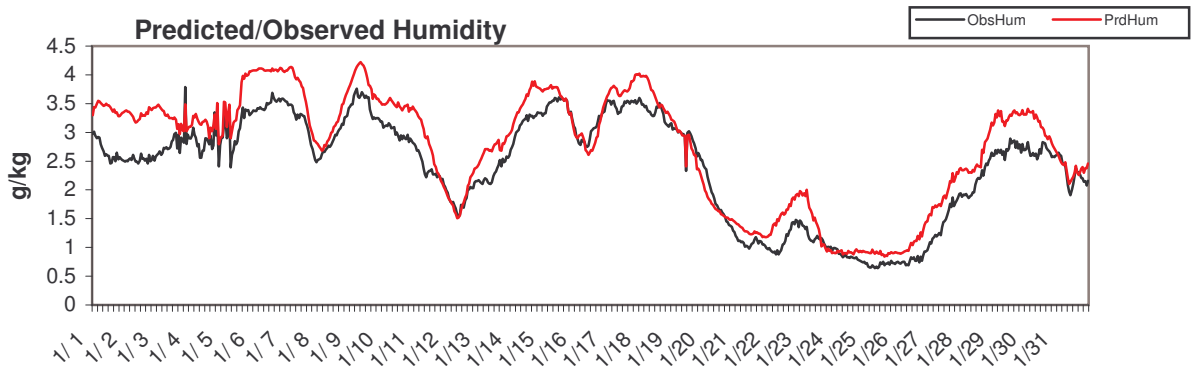


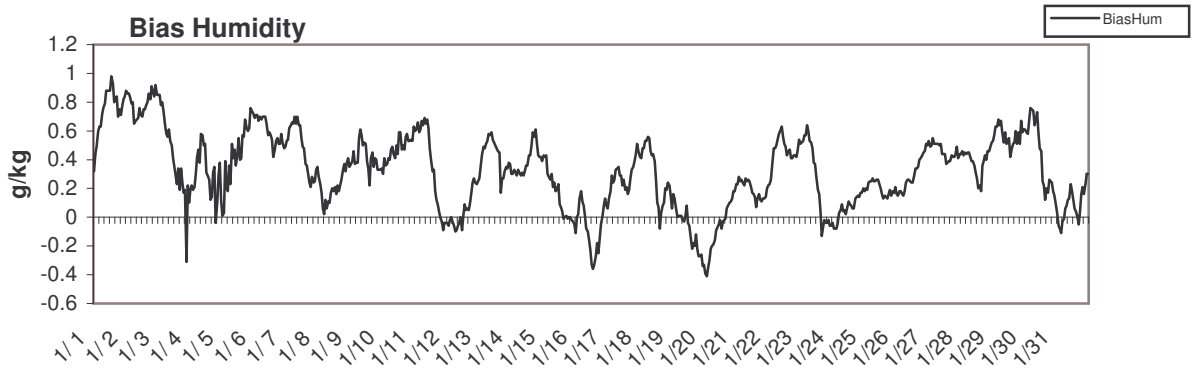


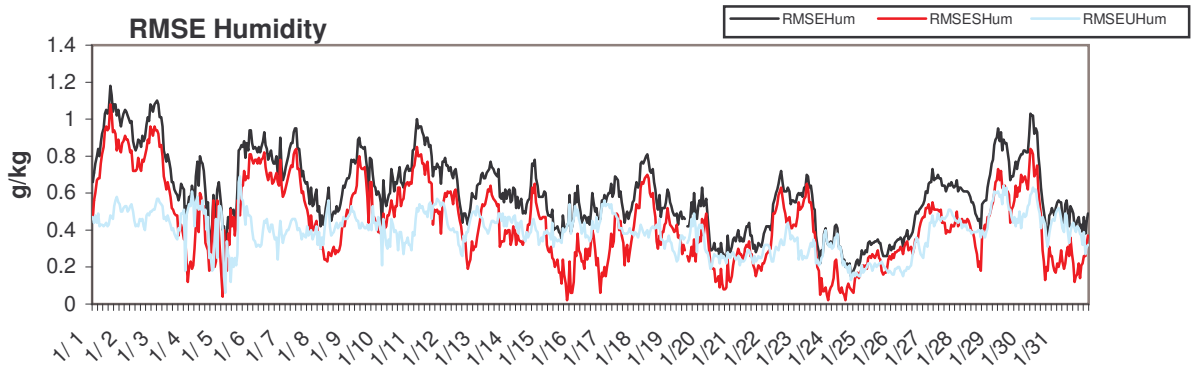


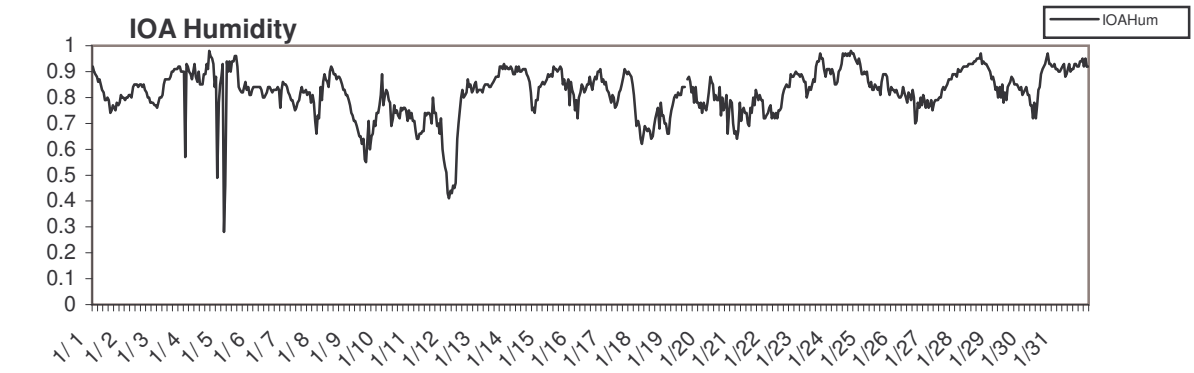


Alaska 5km 2002-01

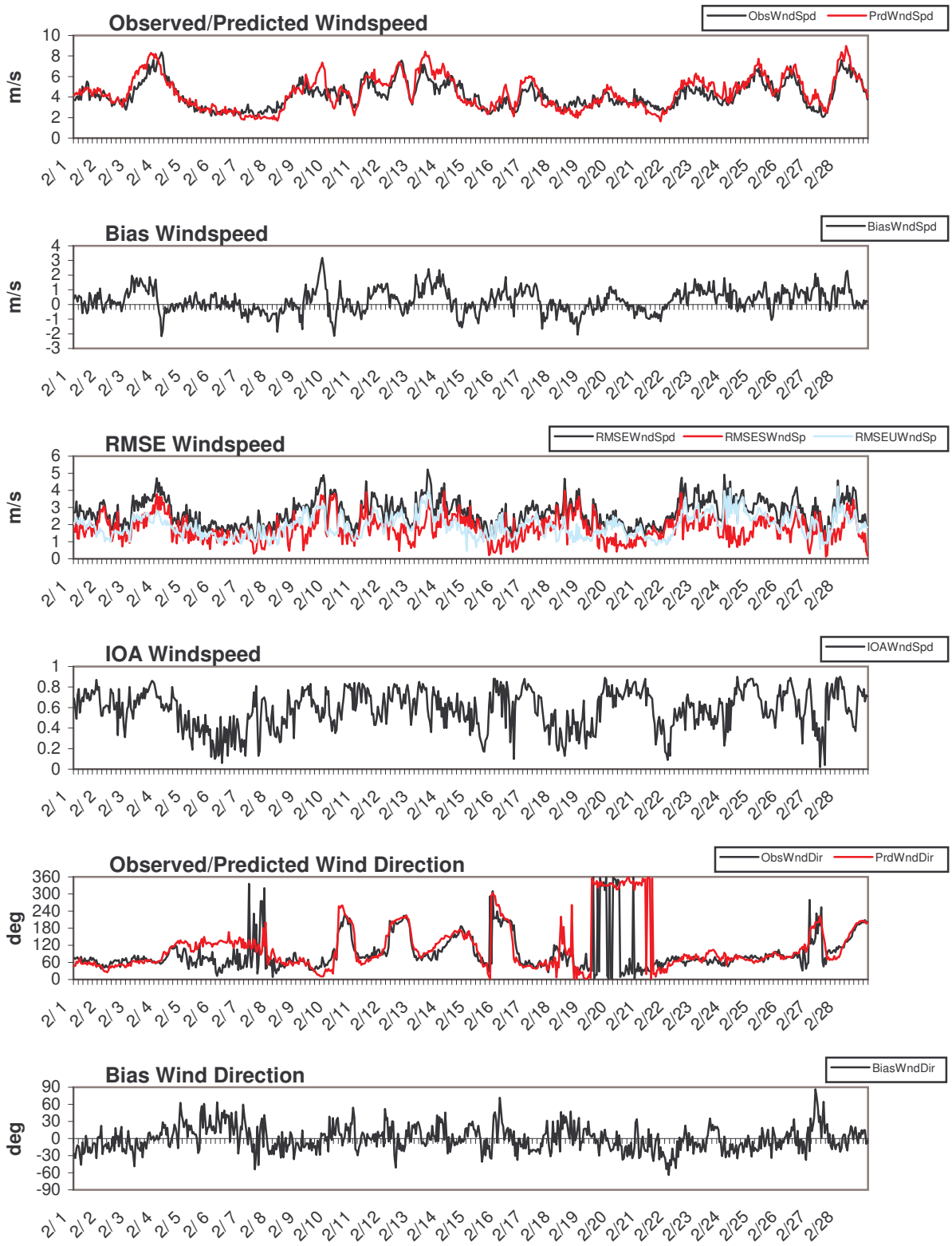




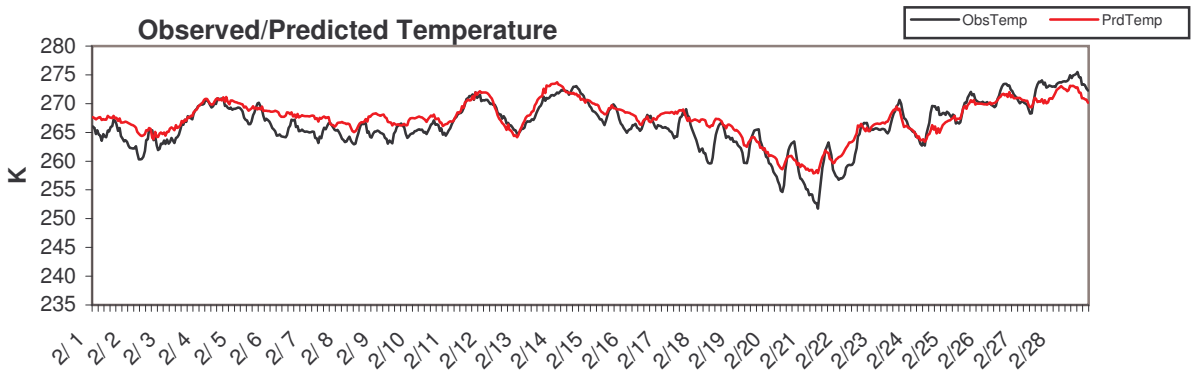


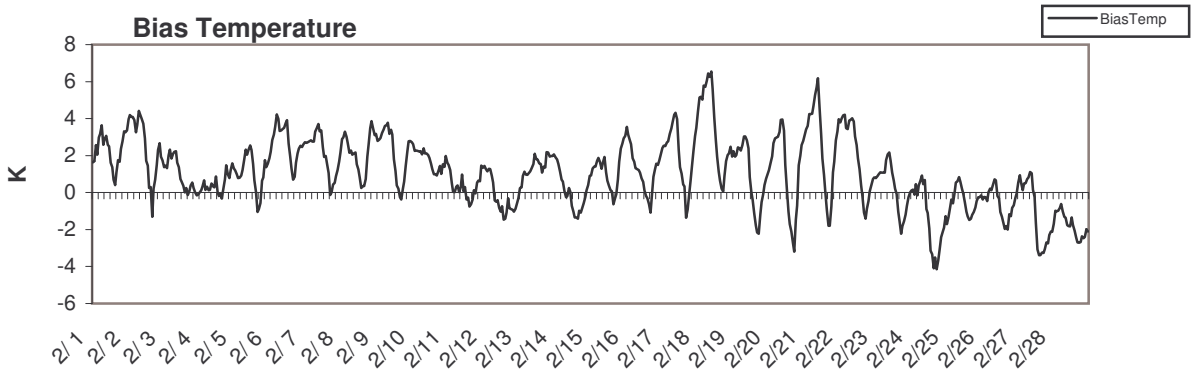


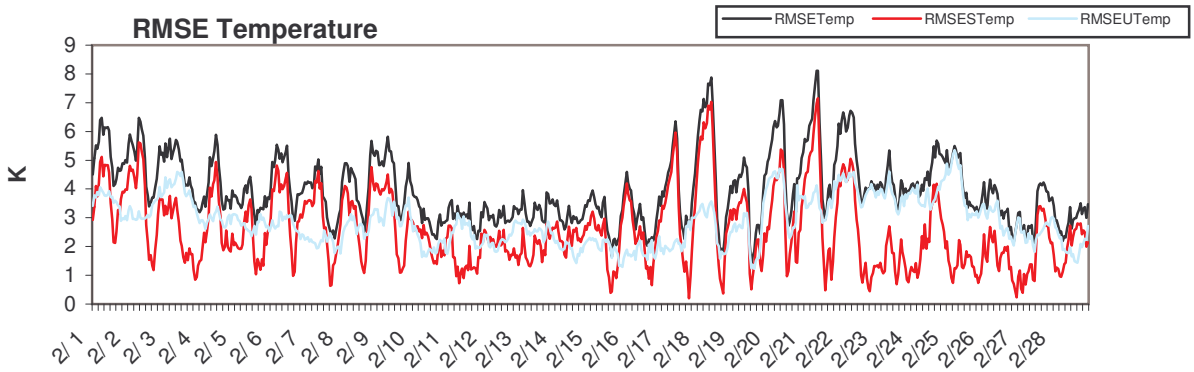
Alaska 5km 2002-02

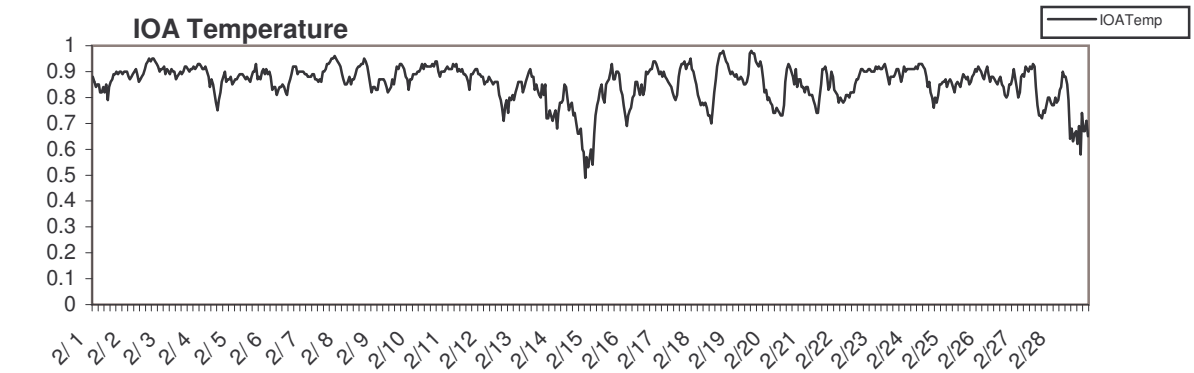


Alaska 5km 2002-02

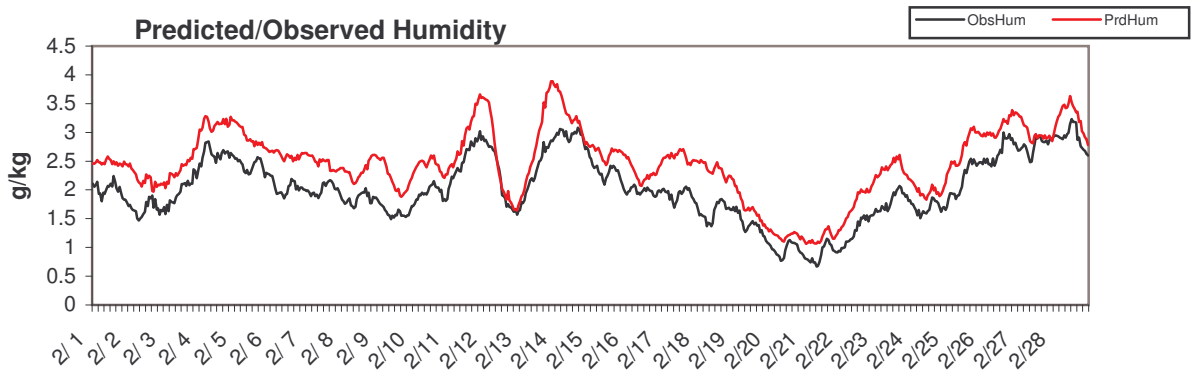


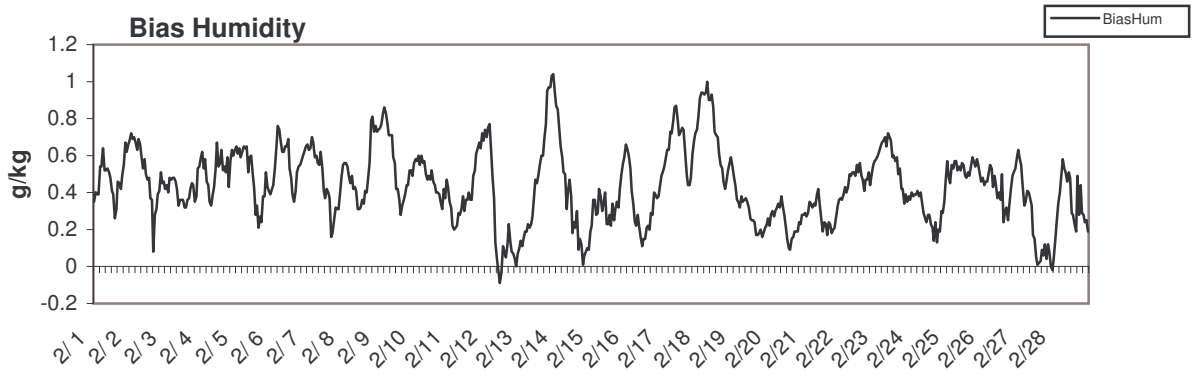


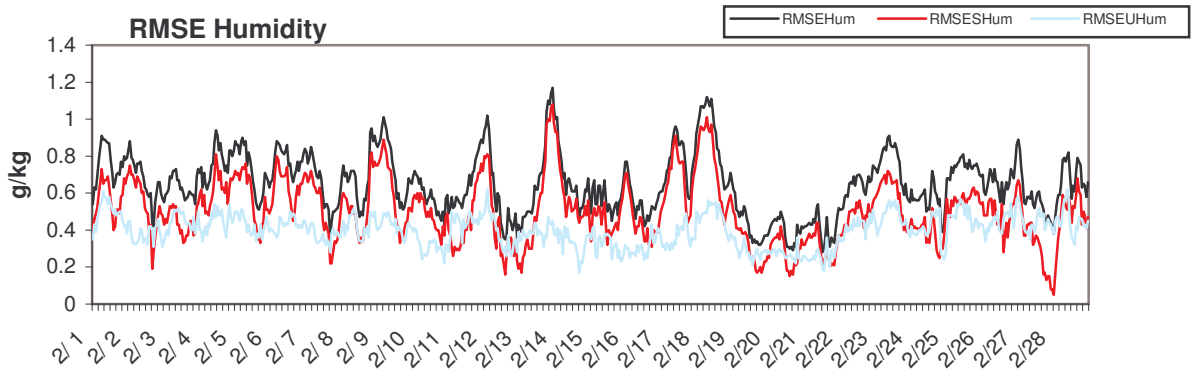


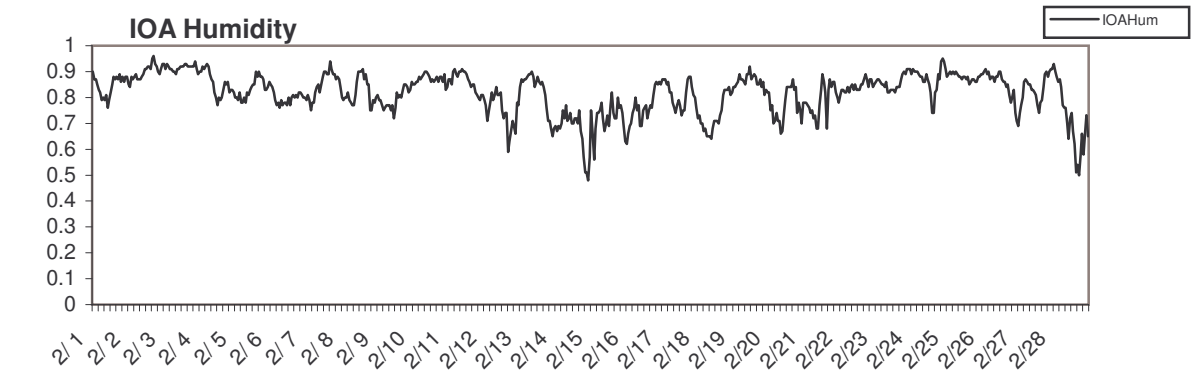


Alaska 5km 2002-02

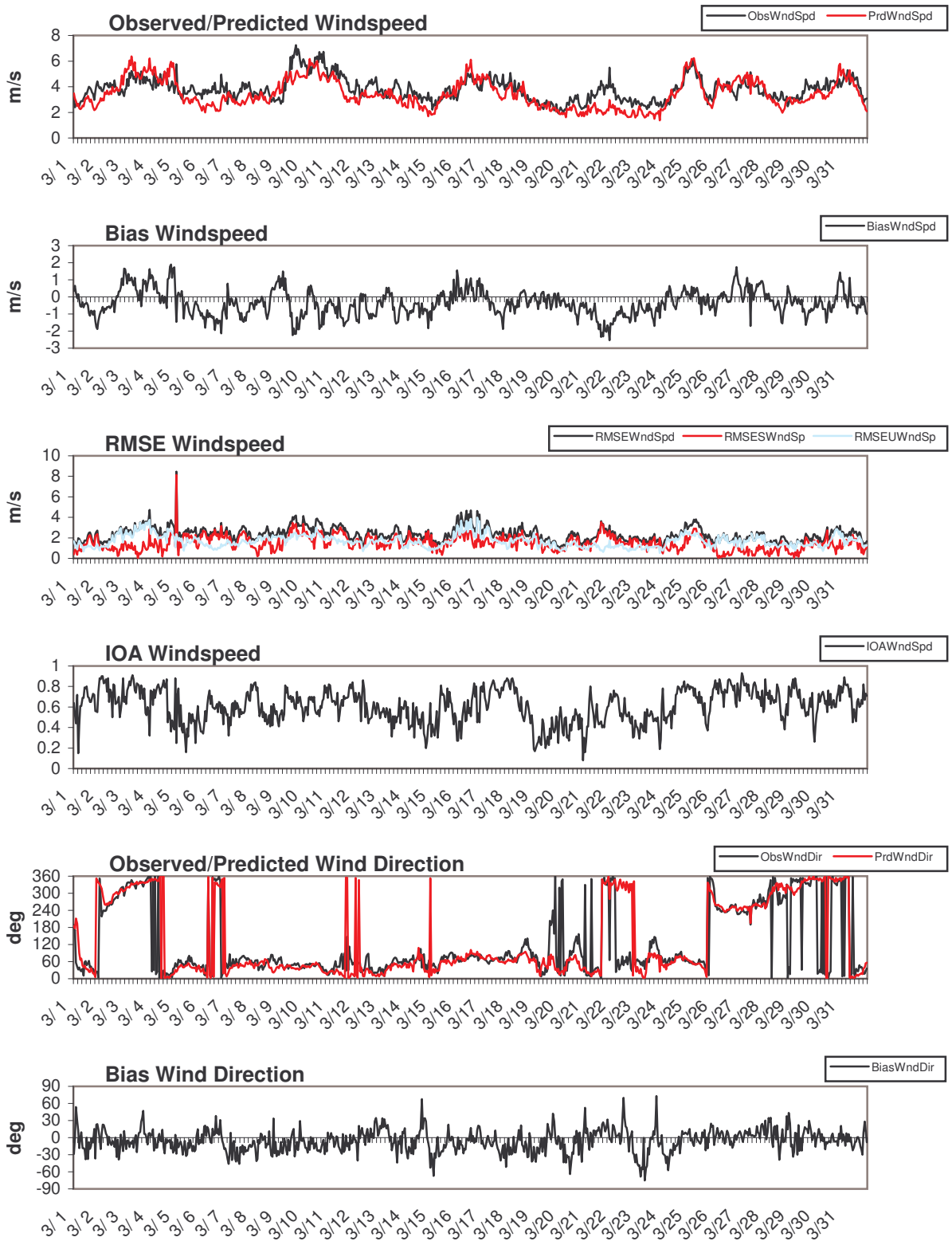




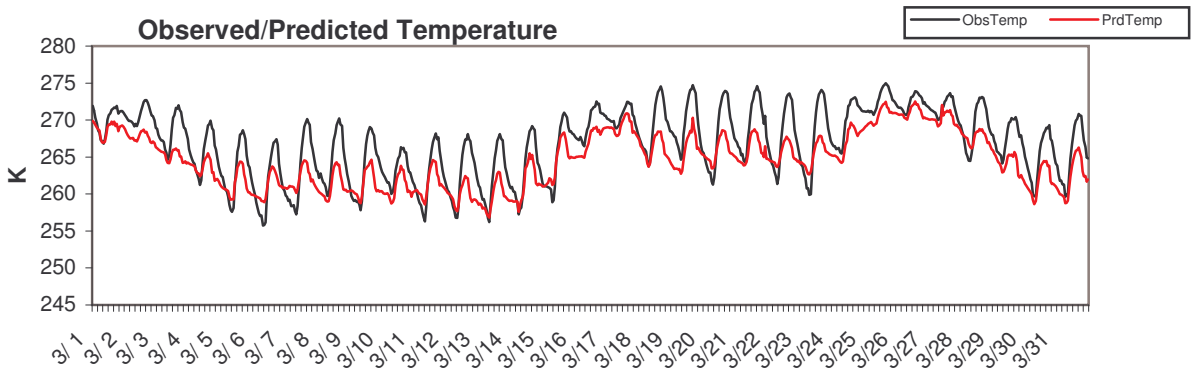


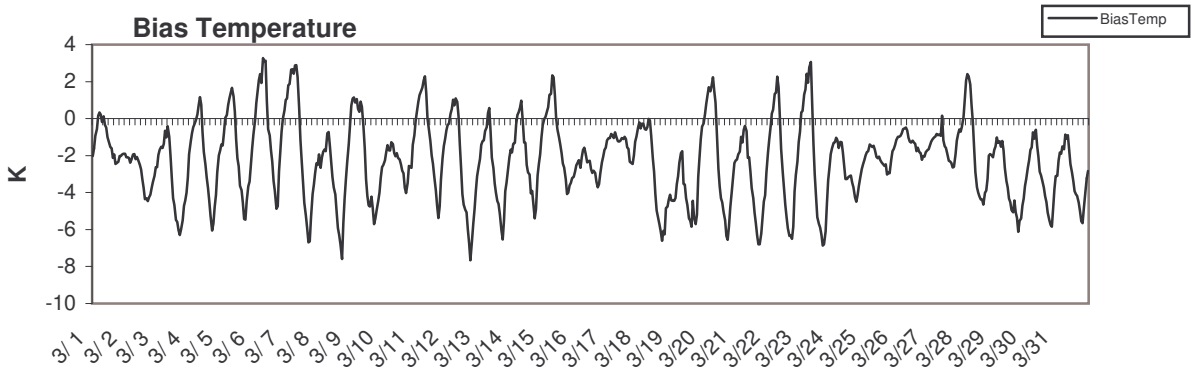


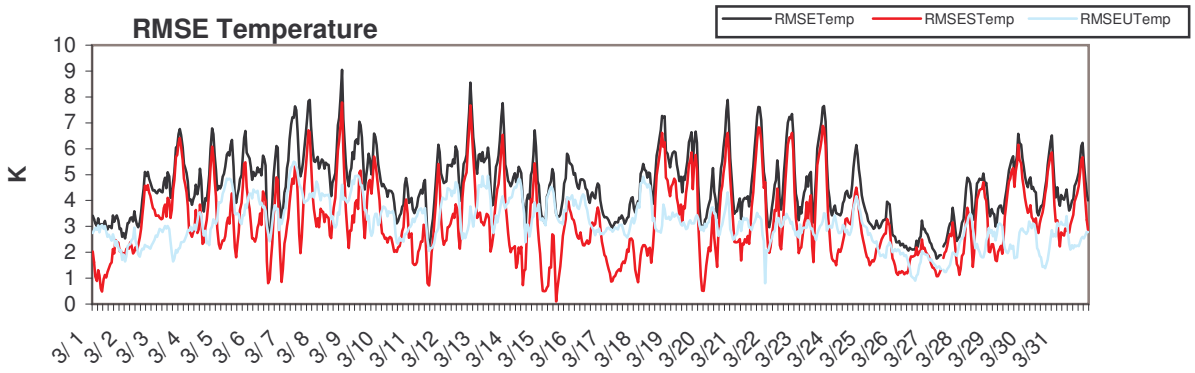
Alaska 5km 2002-03

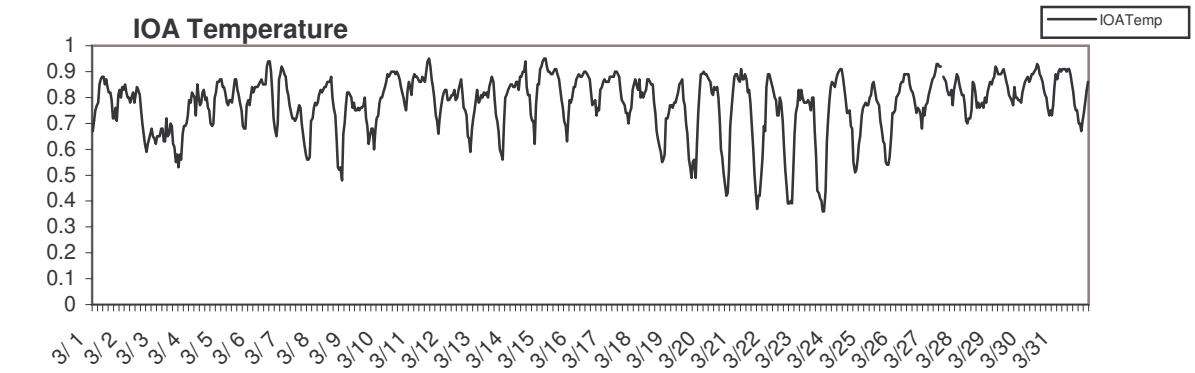


Alaska 5km 2002-03

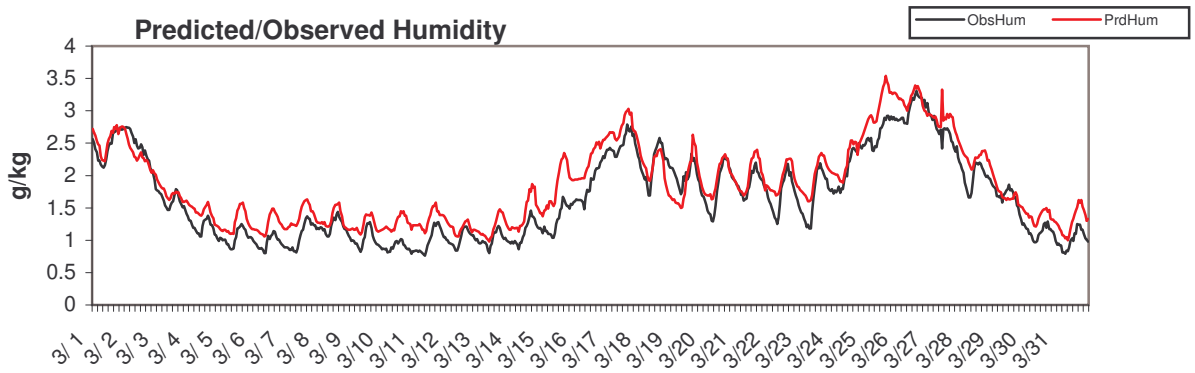


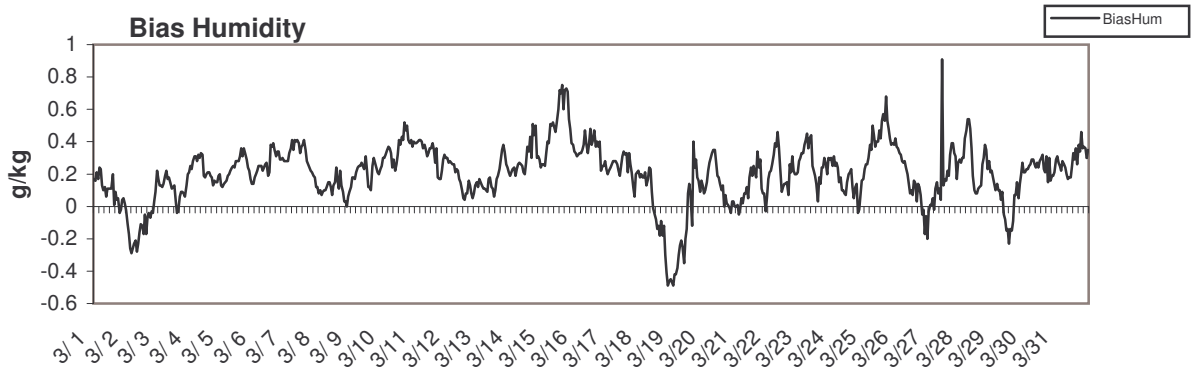


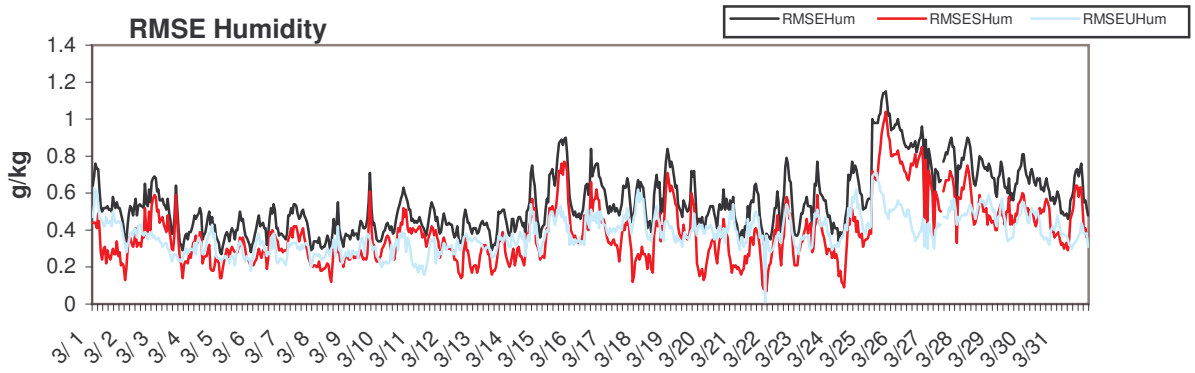


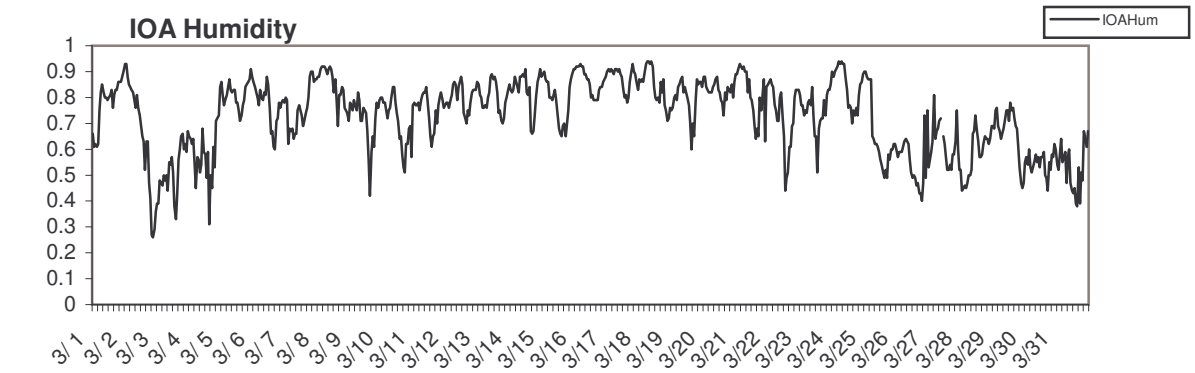


Alaska 5km 2002-03

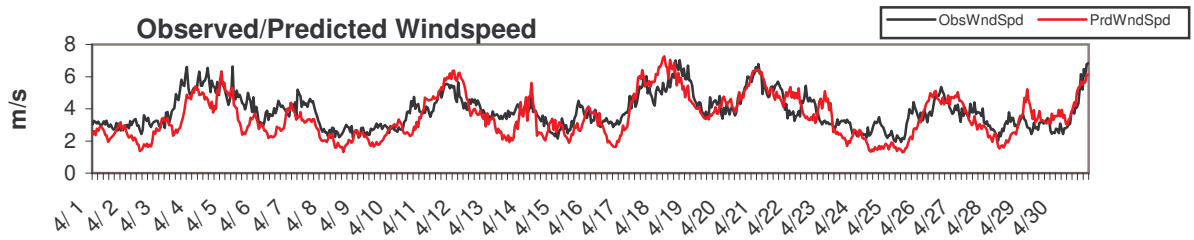


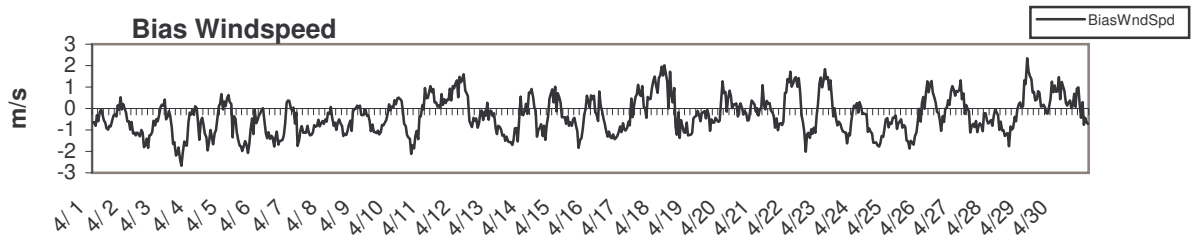


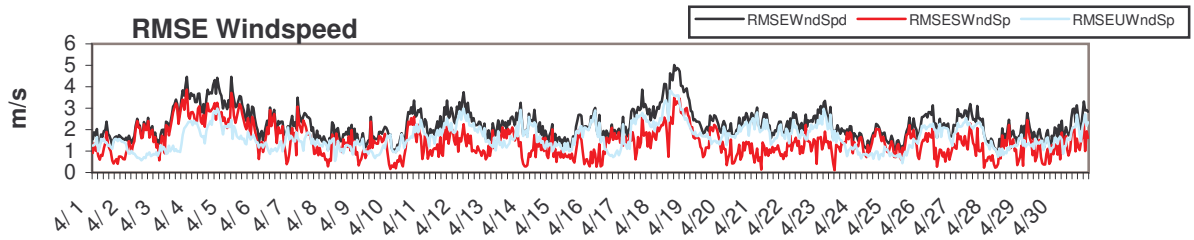


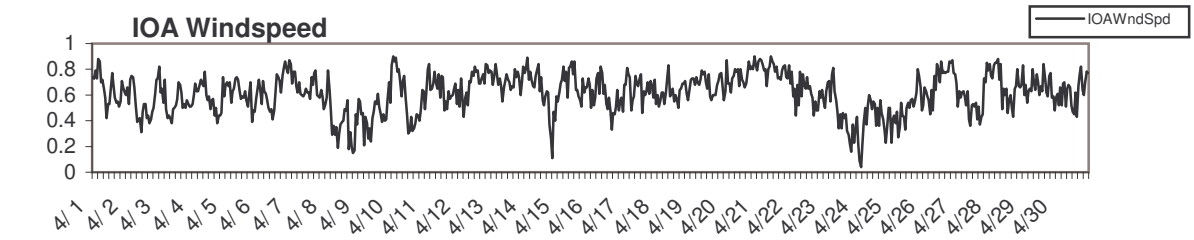


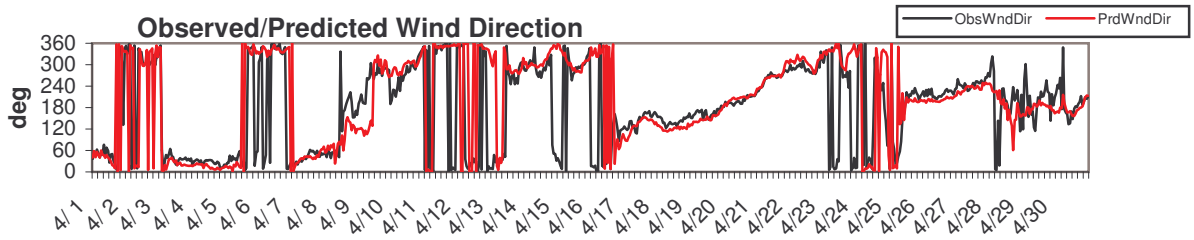
Alaska 5km 2002-04

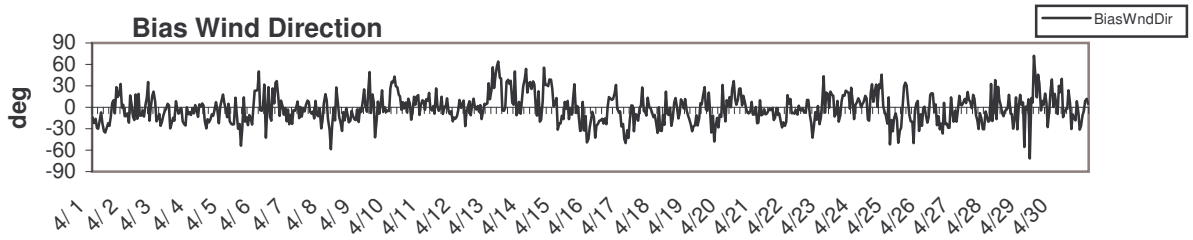




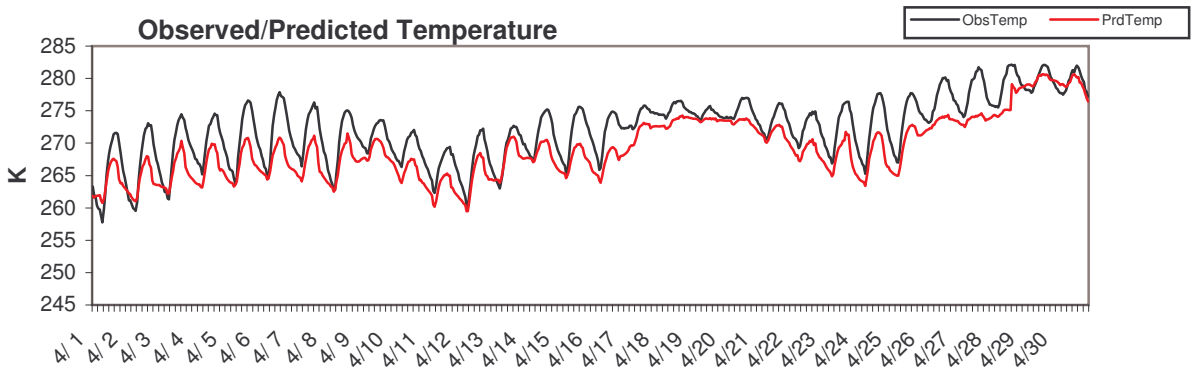


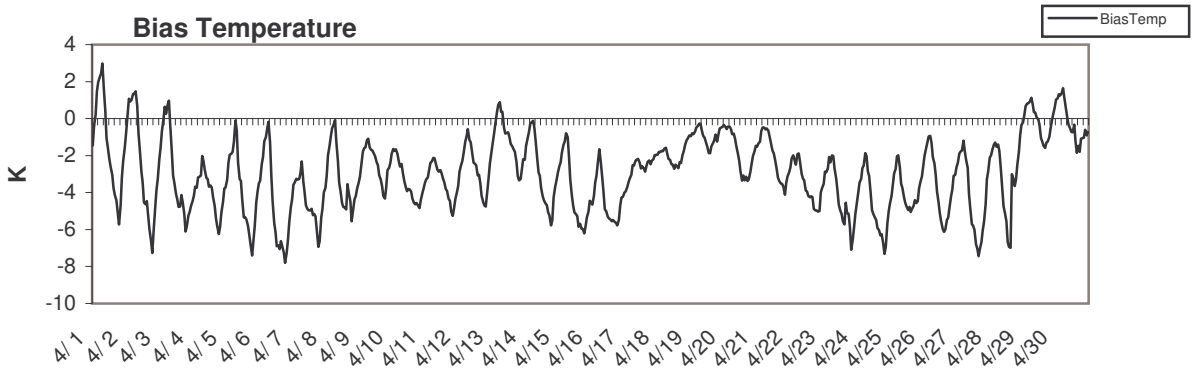


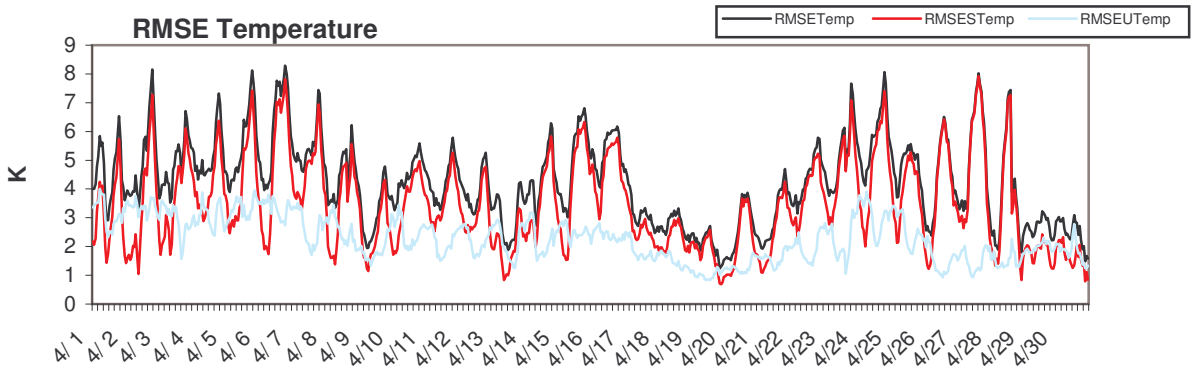


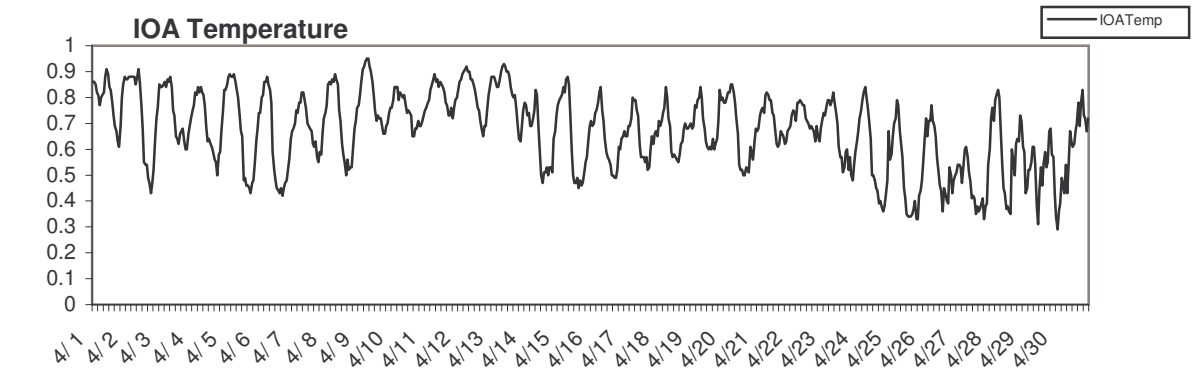


Alaska 5km 2002-04

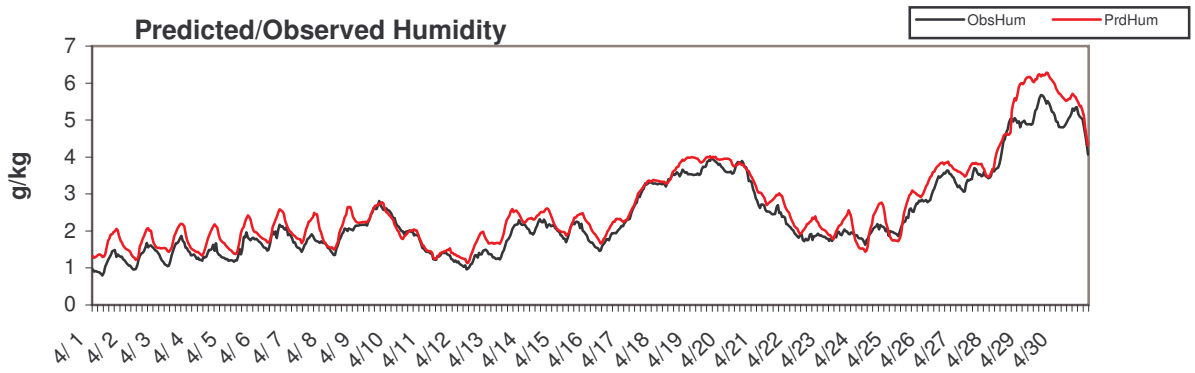


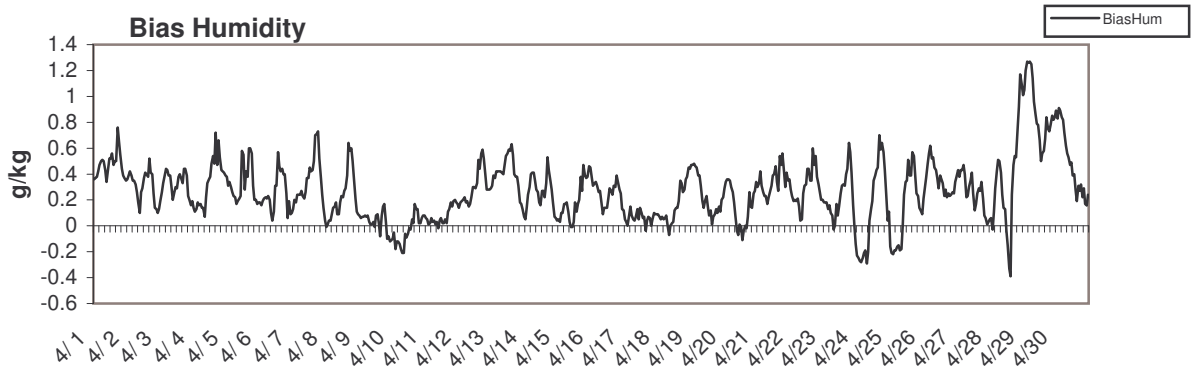


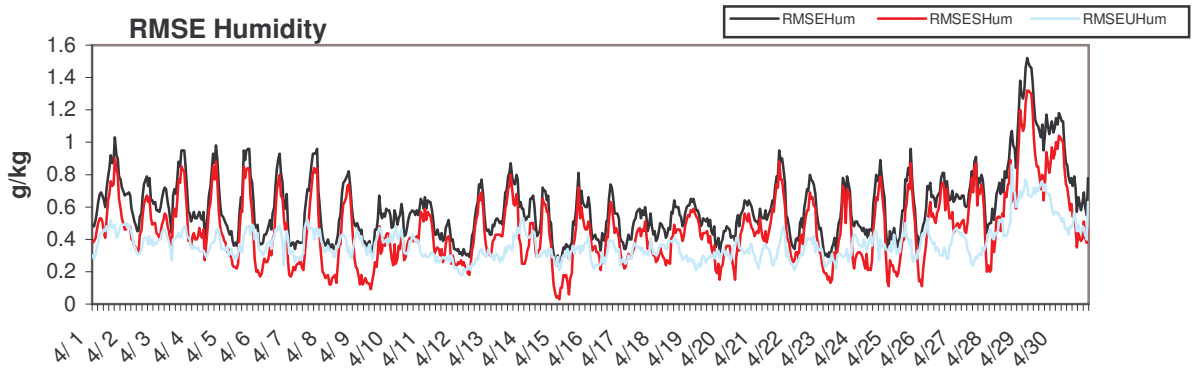


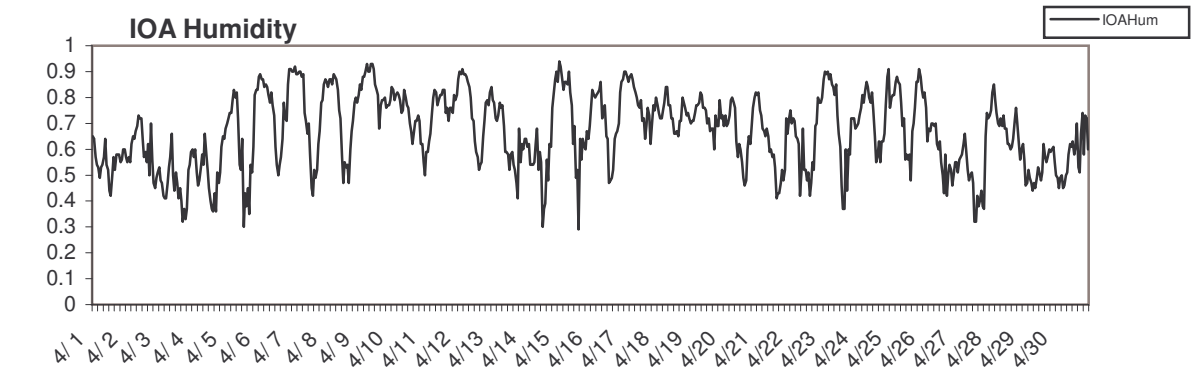


Alaska 5km 2002-04

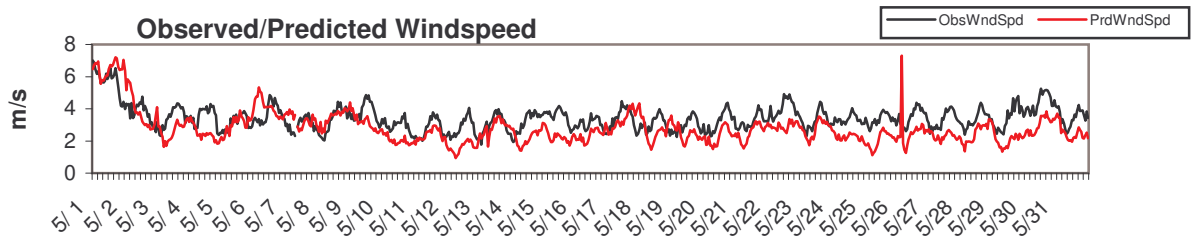


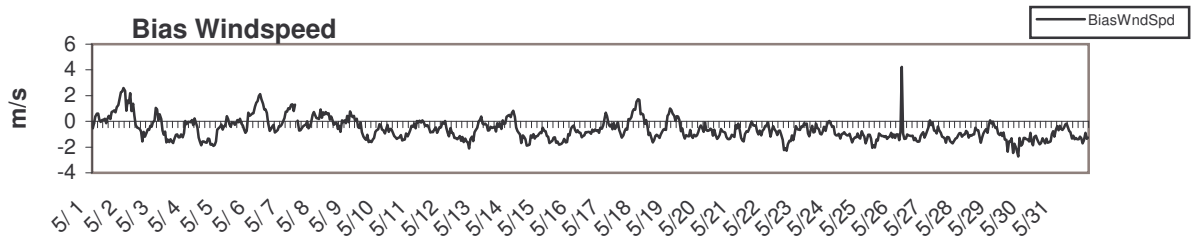


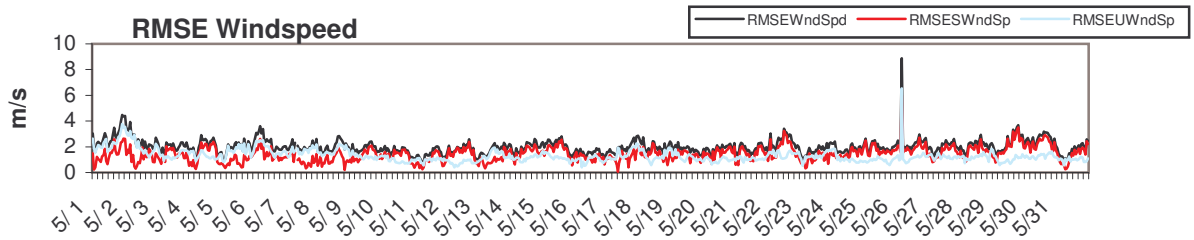


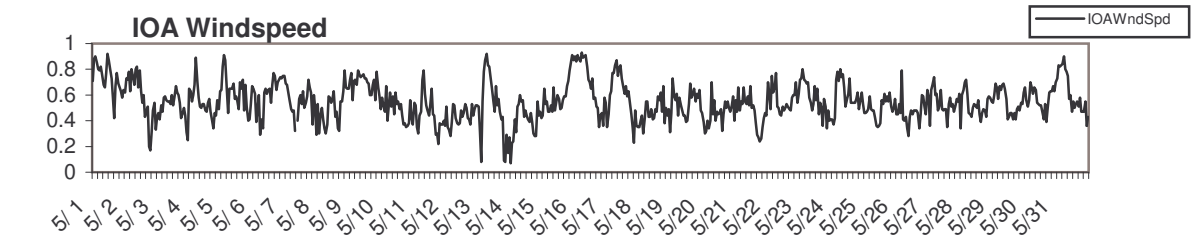


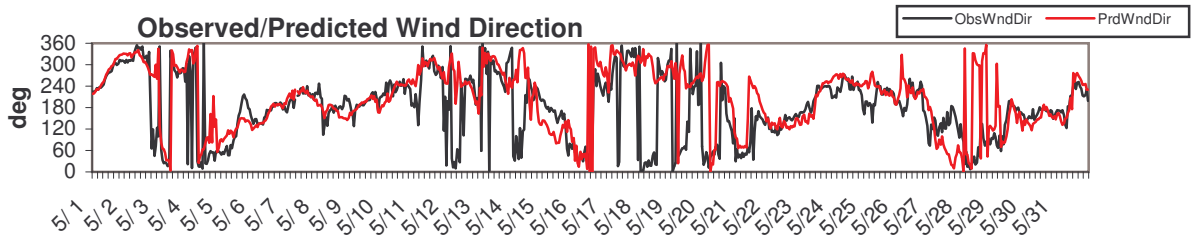
Alaska 5km 2002-05

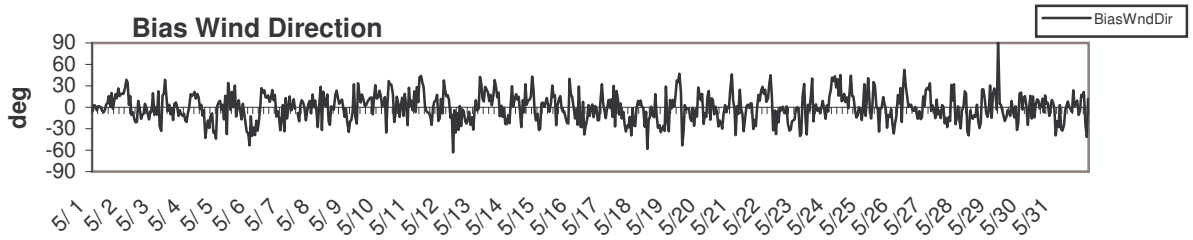




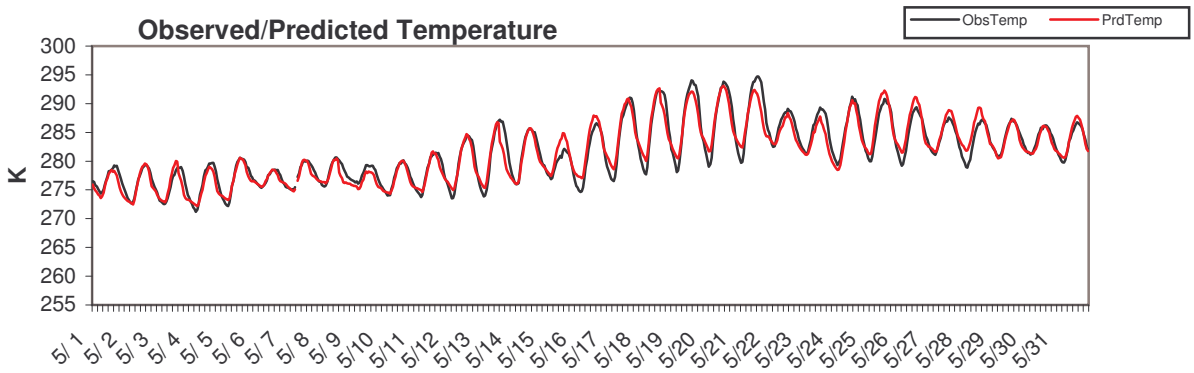


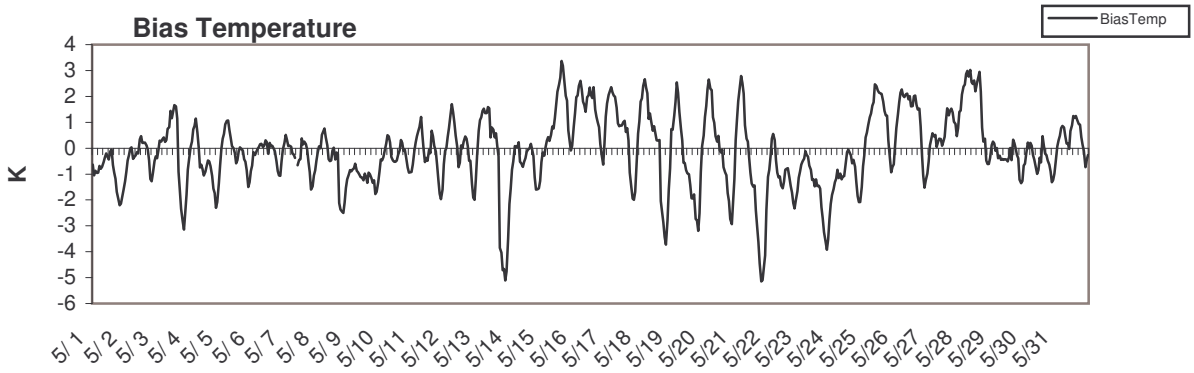


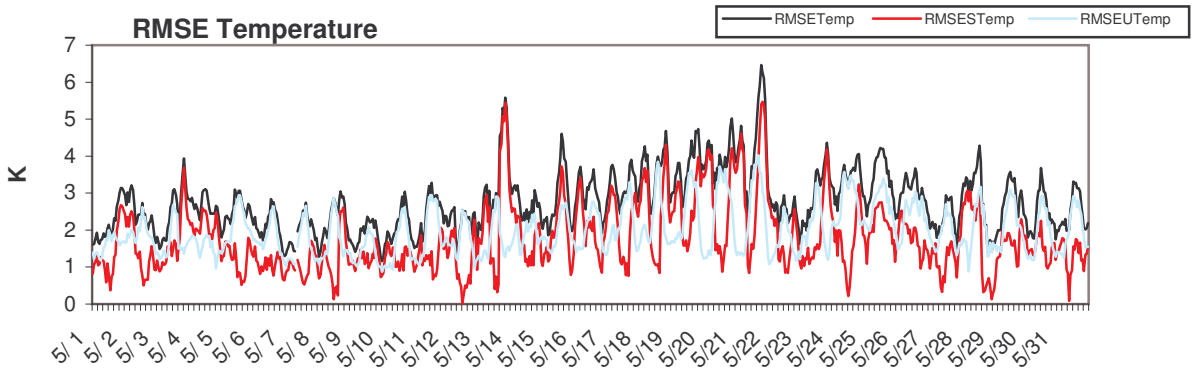


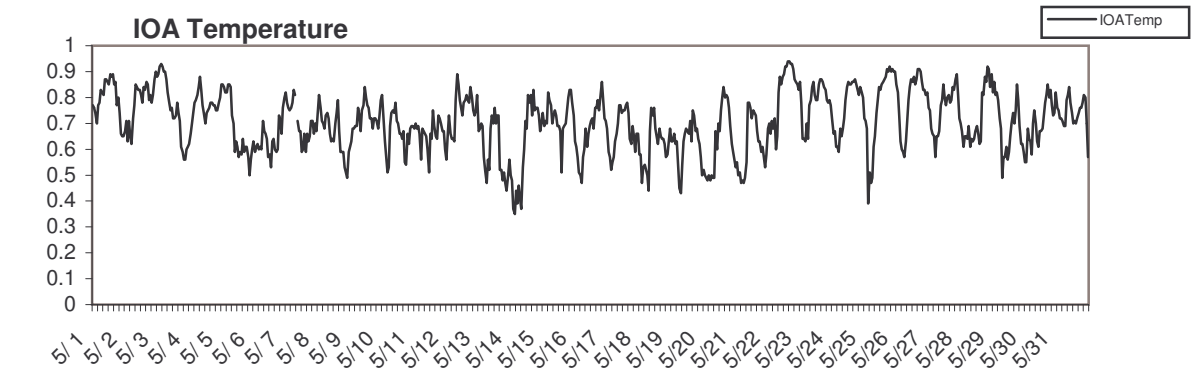


Alaska 5km 2002-05

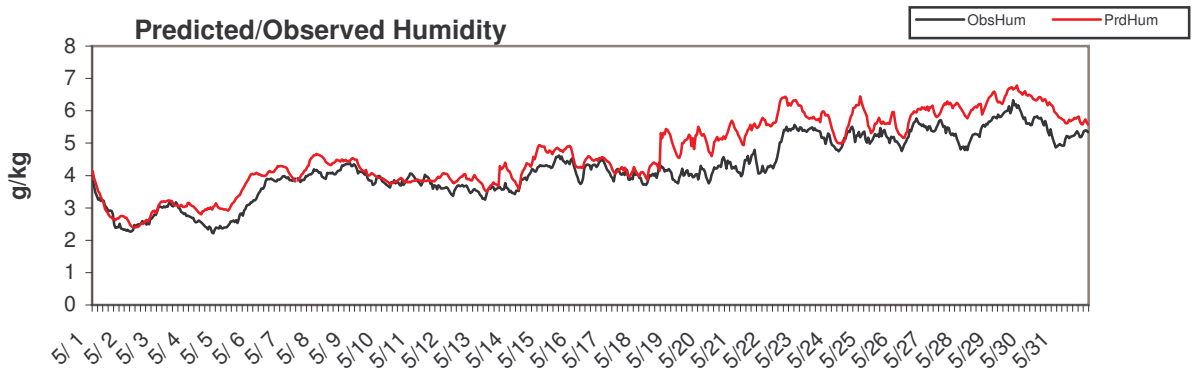


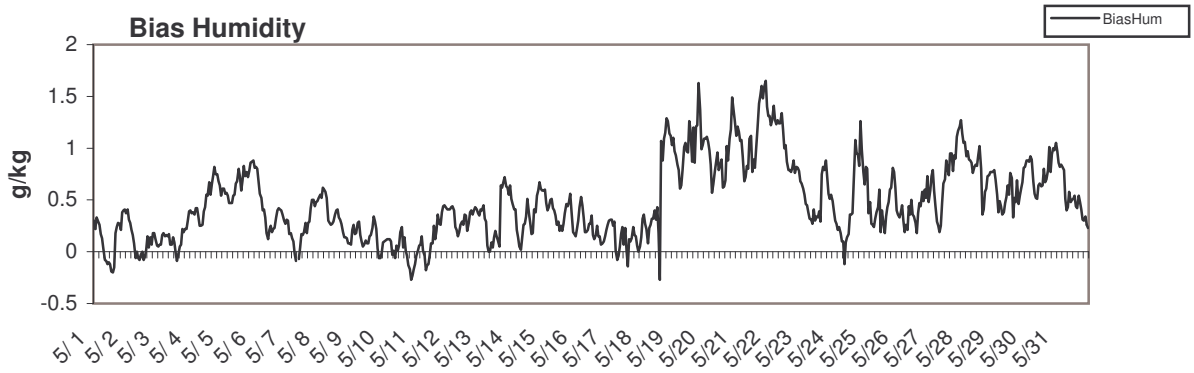


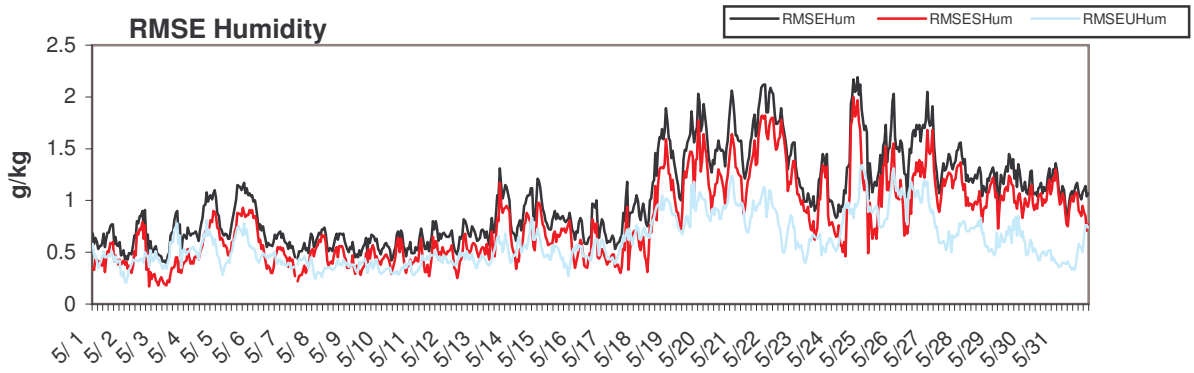


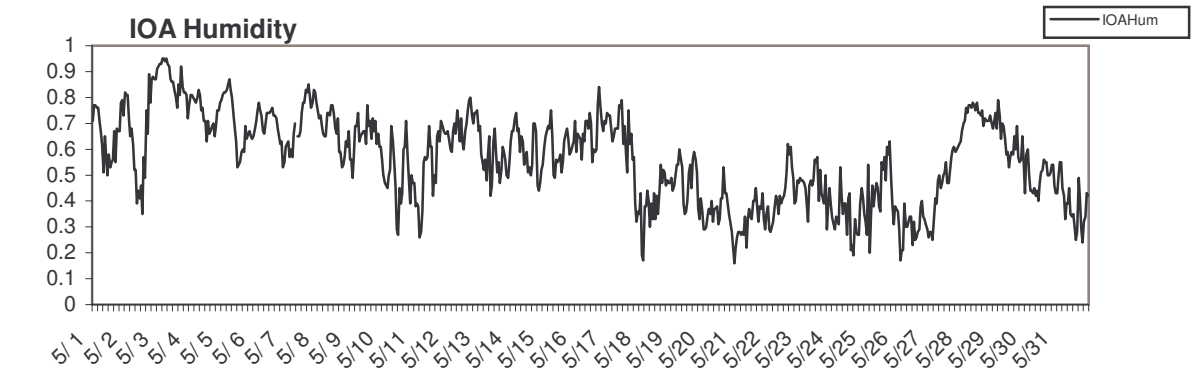


Alaska 5km 2002-05

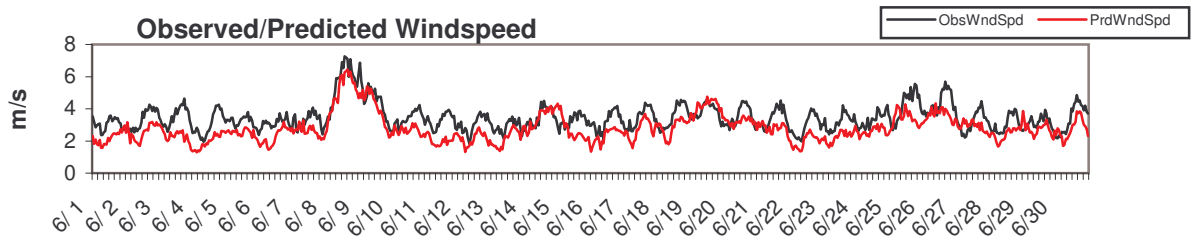


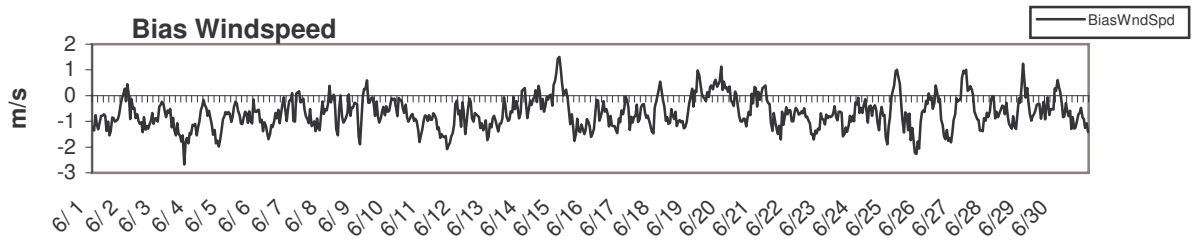


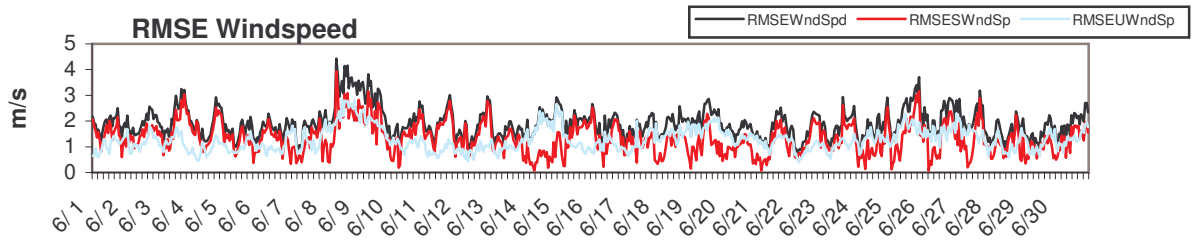


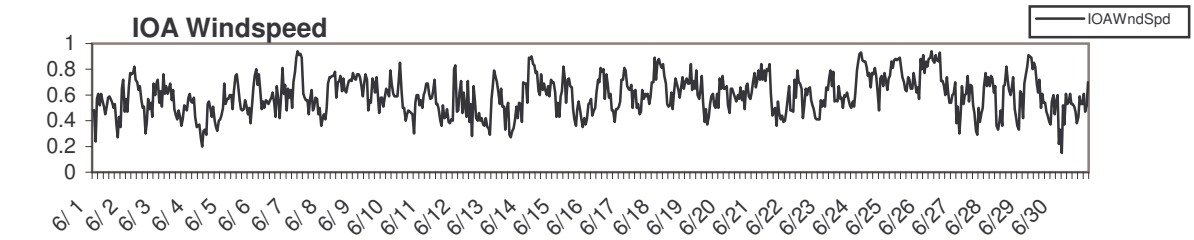


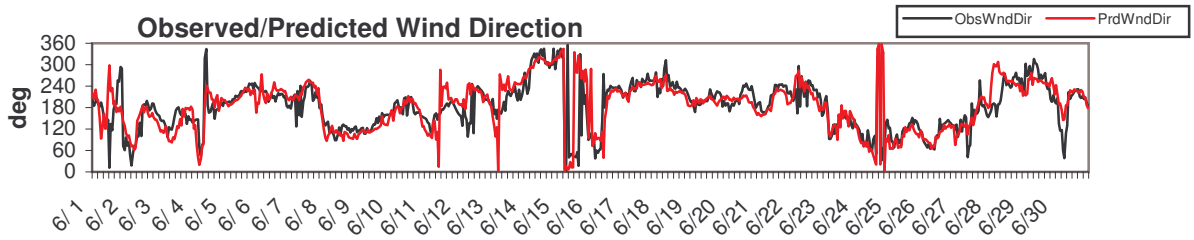
Alaska 5km 2002-06

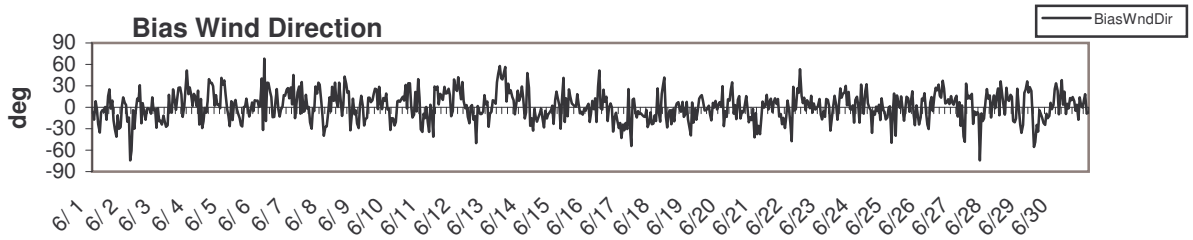




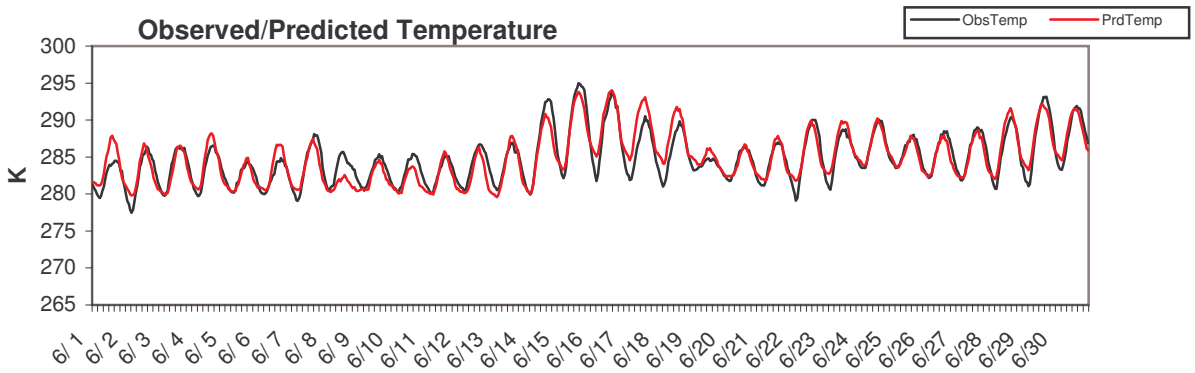


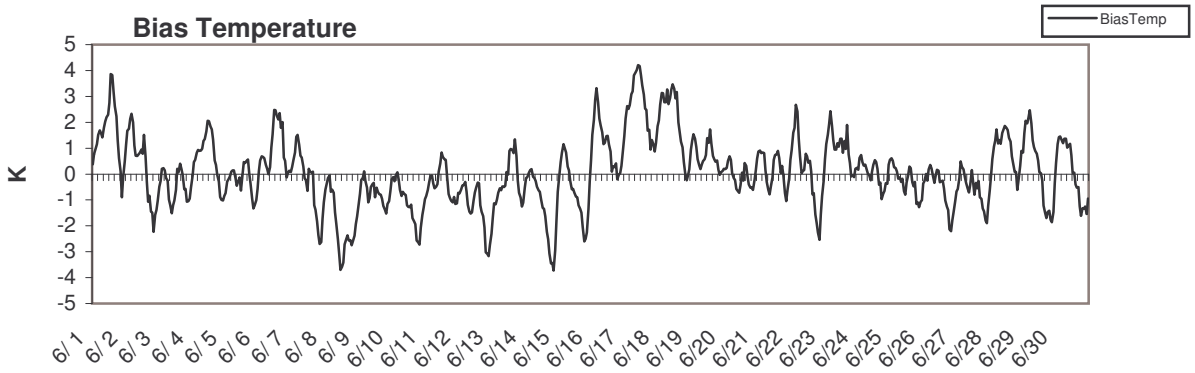


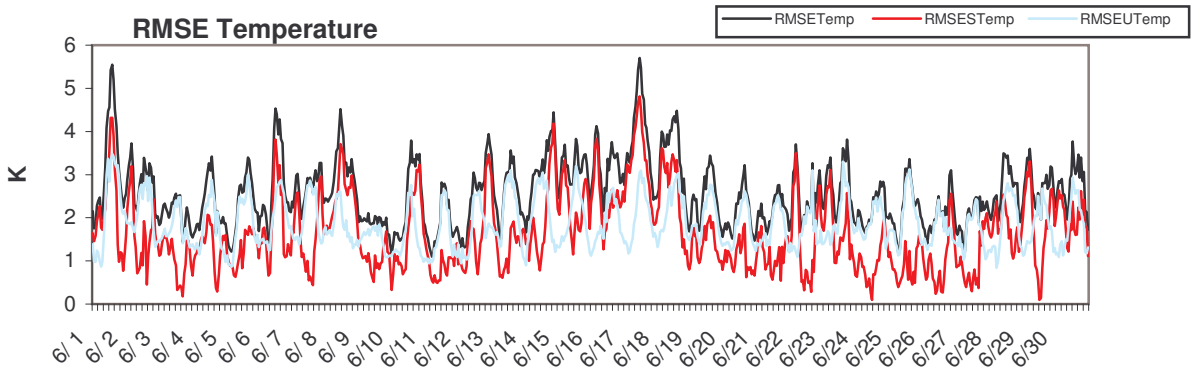


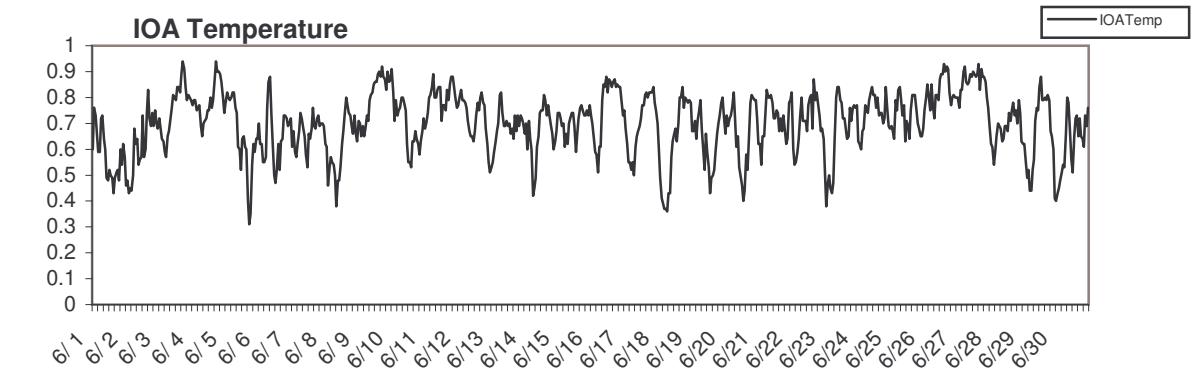


Alaska 5km 2002-06

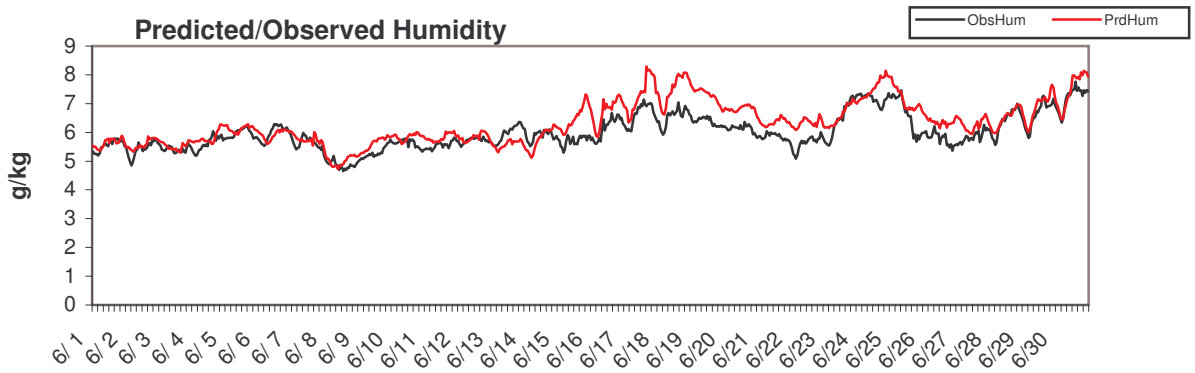


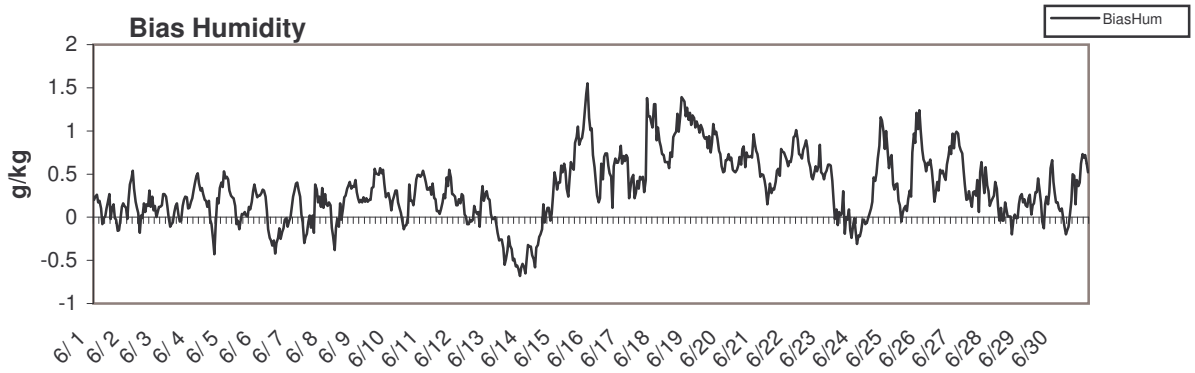


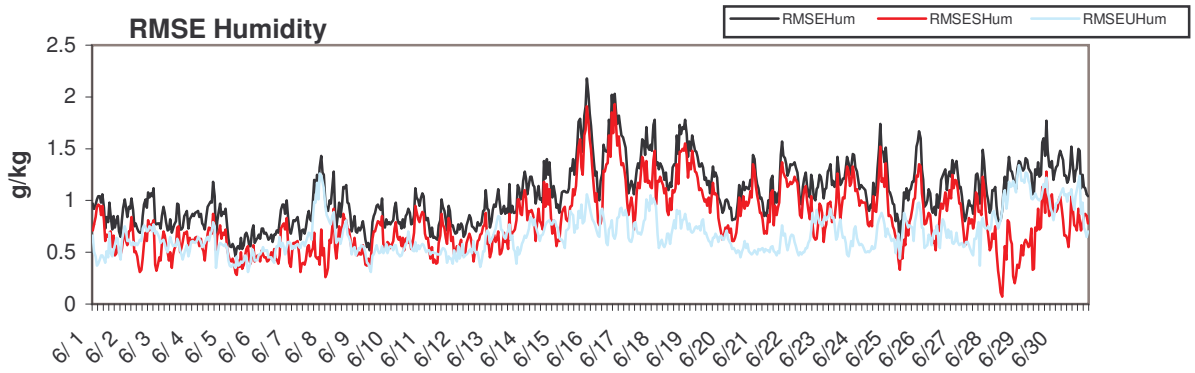


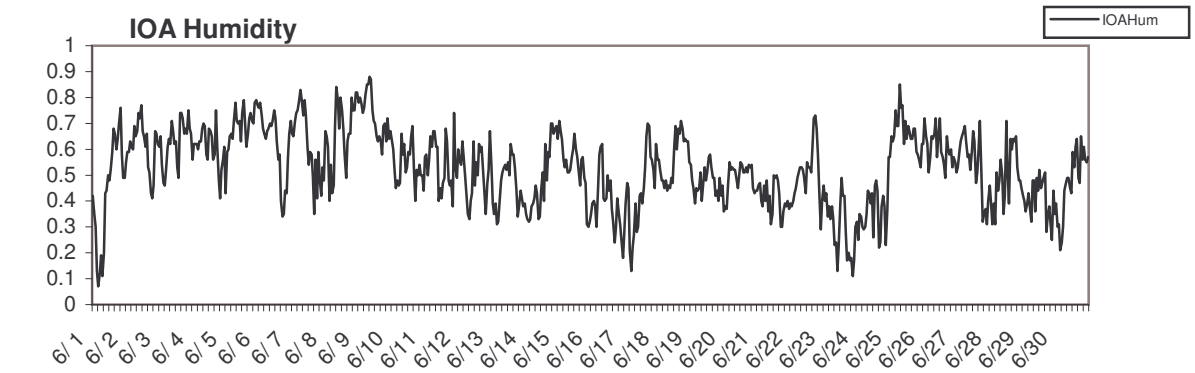


Alaska 5km 2002-06

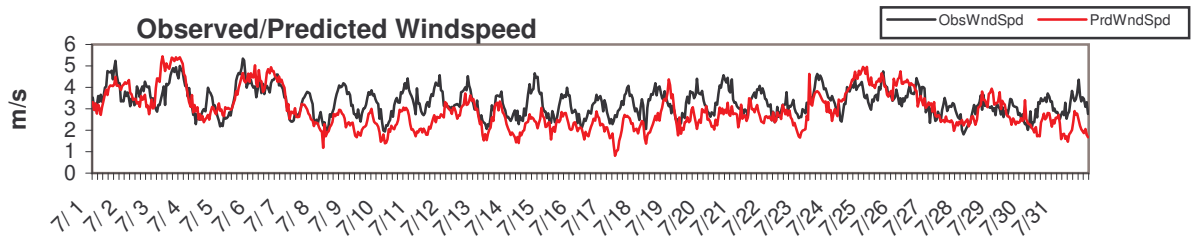


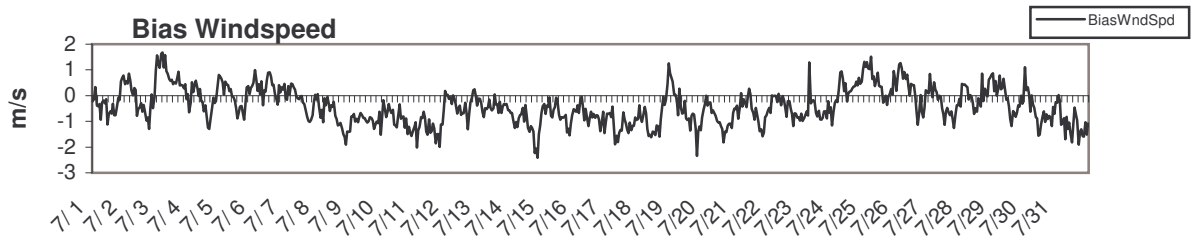


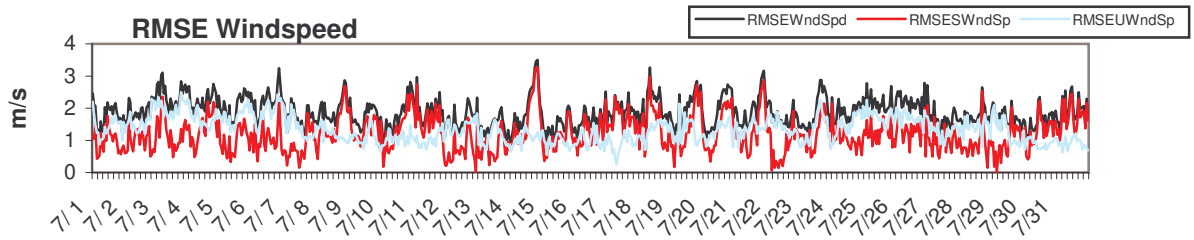


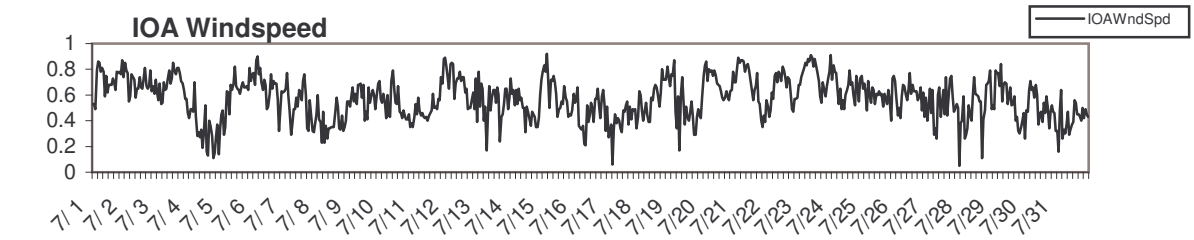


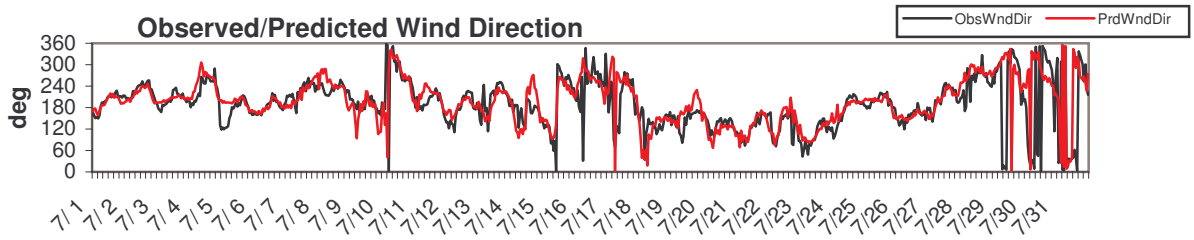
Alaska 5km 2002-07

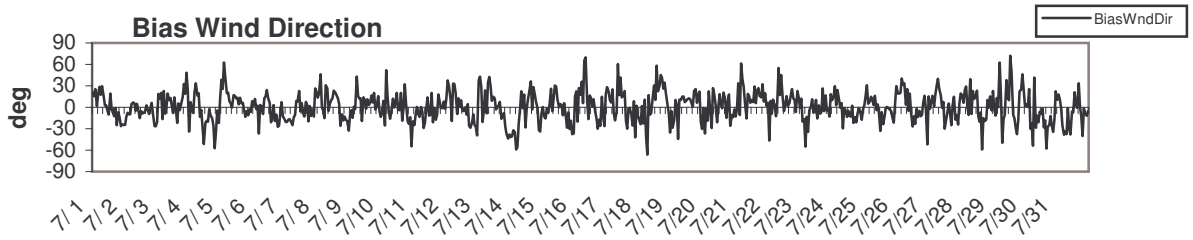




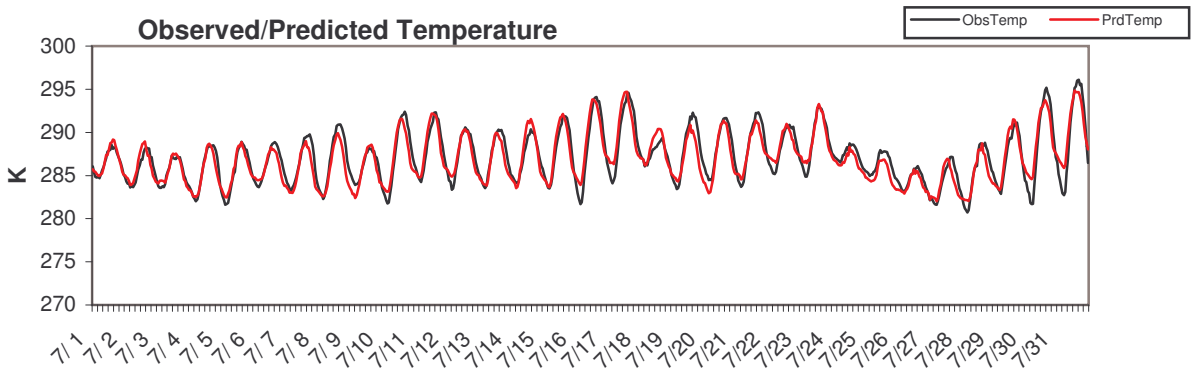


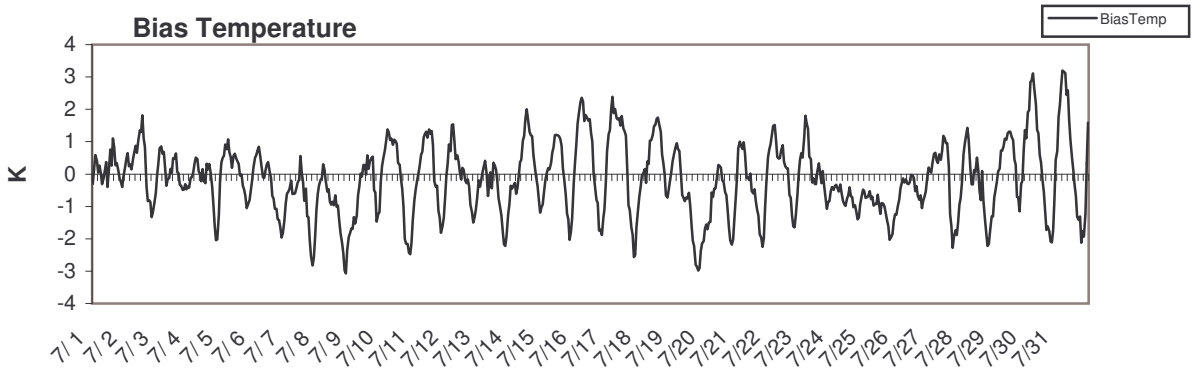


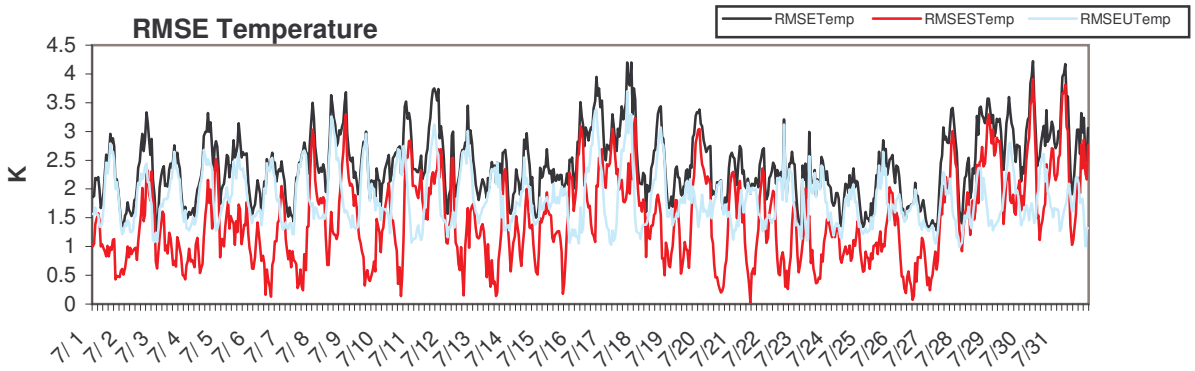


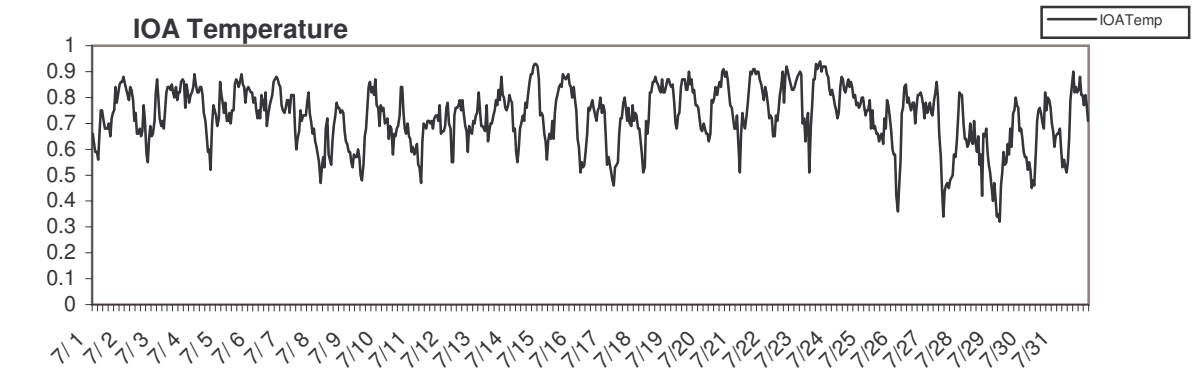


Alaska 5km 2002-07

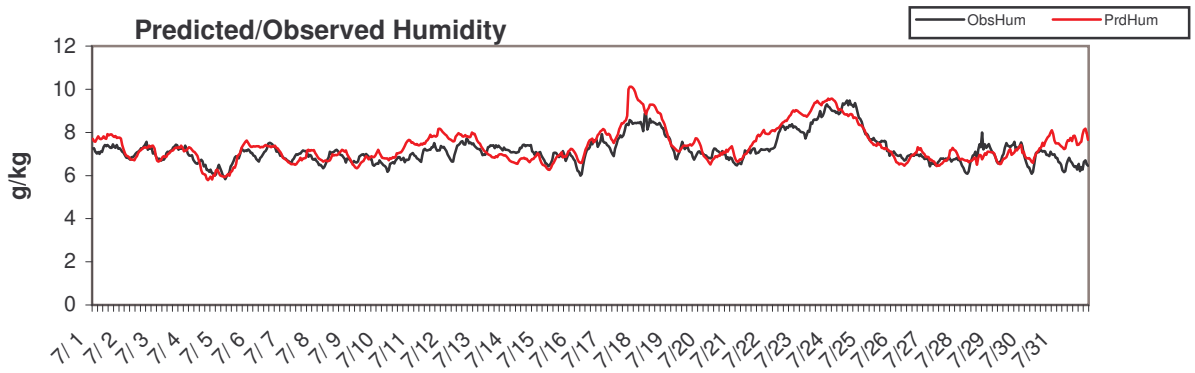


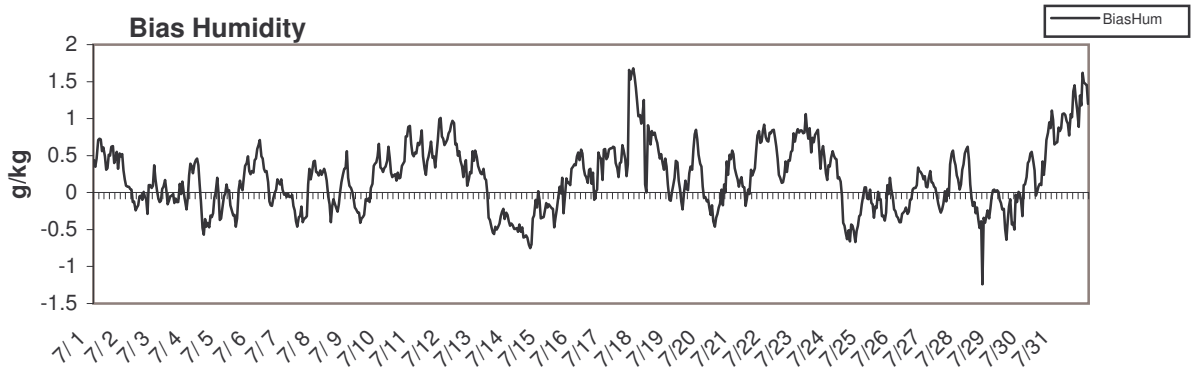


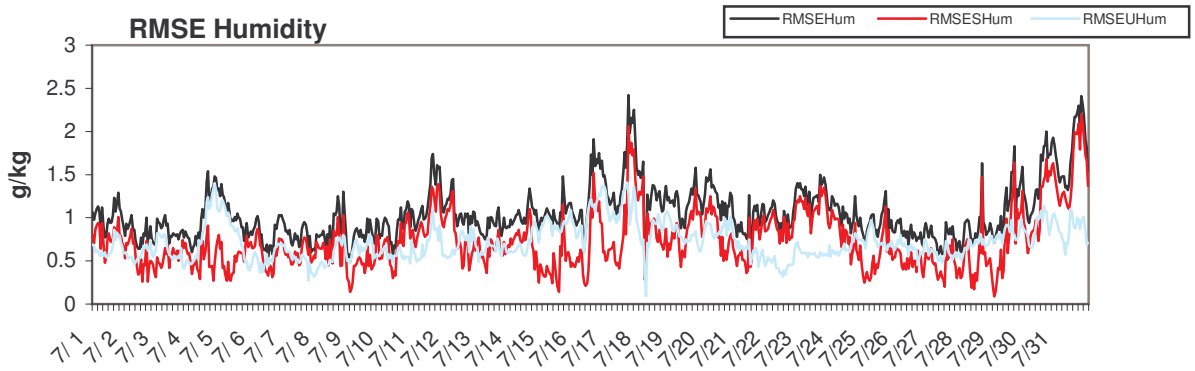


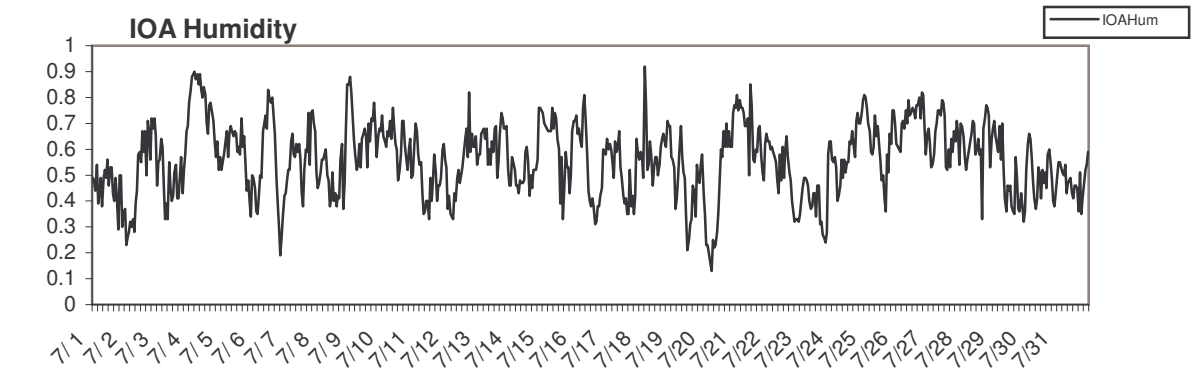


Alaska 5km 2002-07

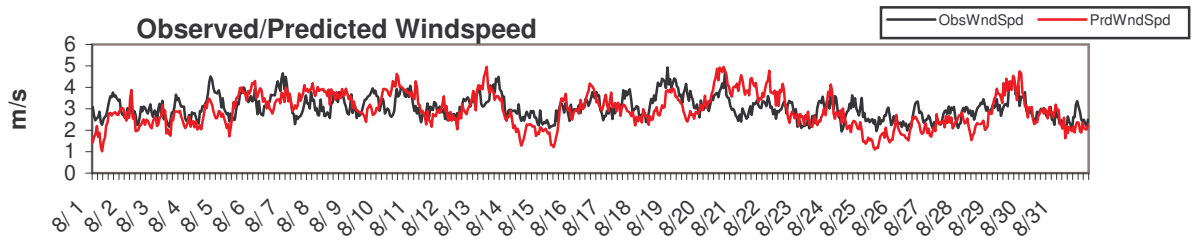


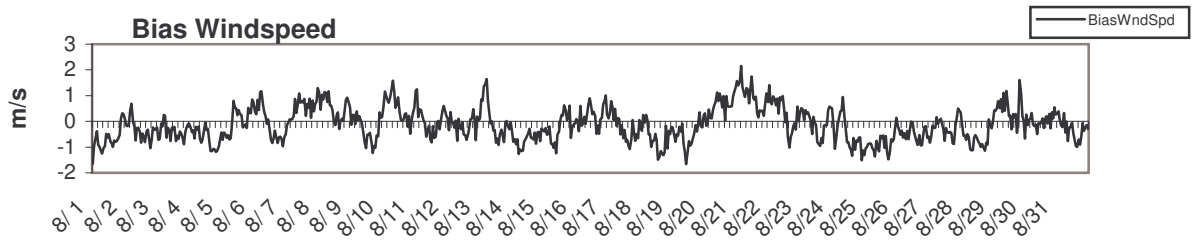


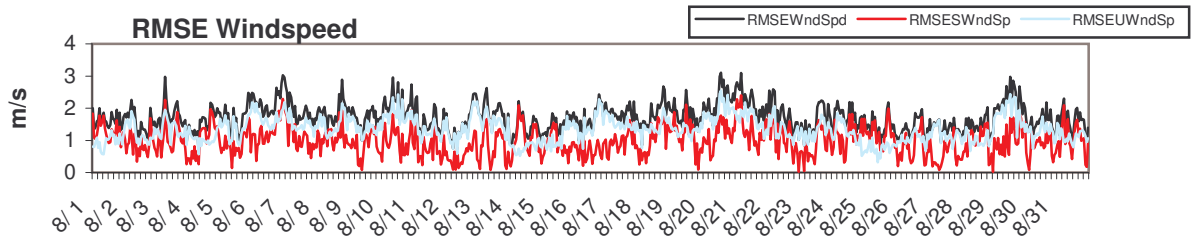


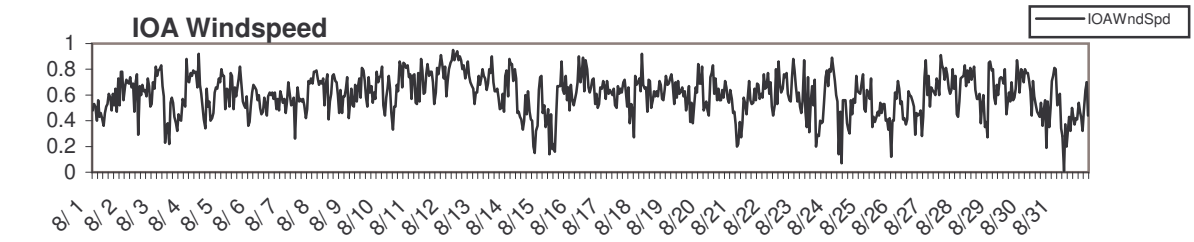


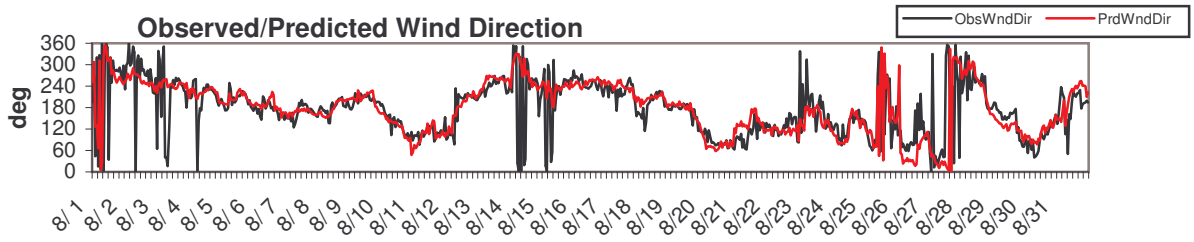
Alaska 5km 2002-08

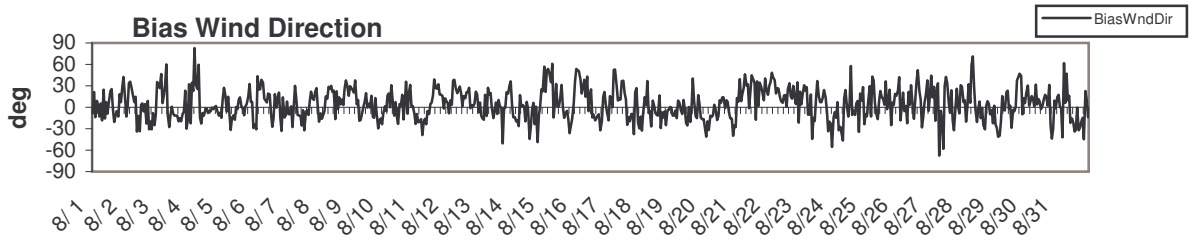




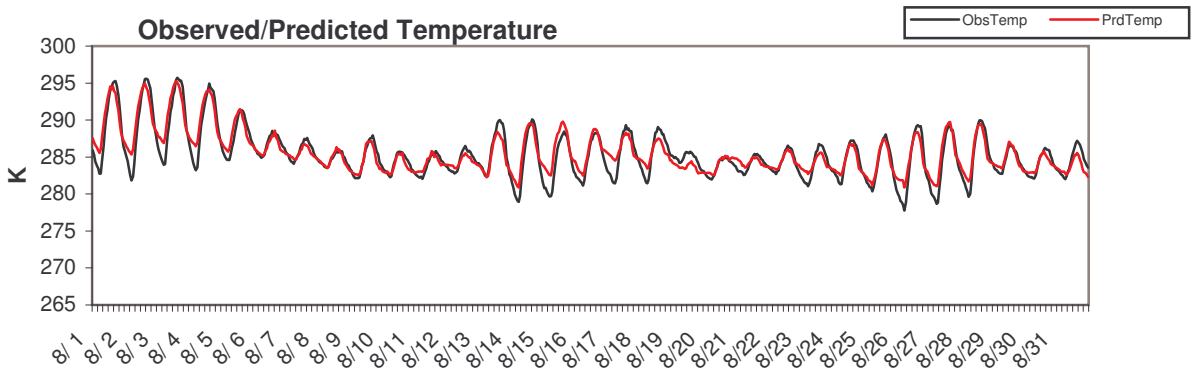


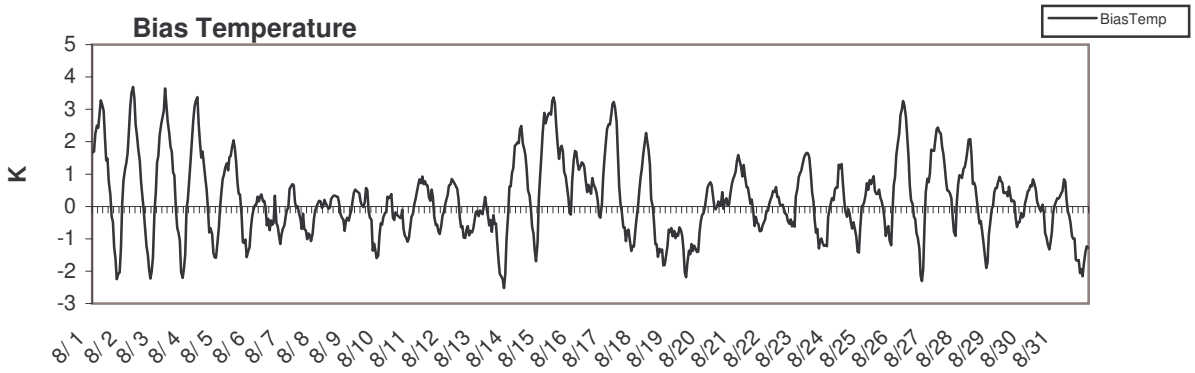


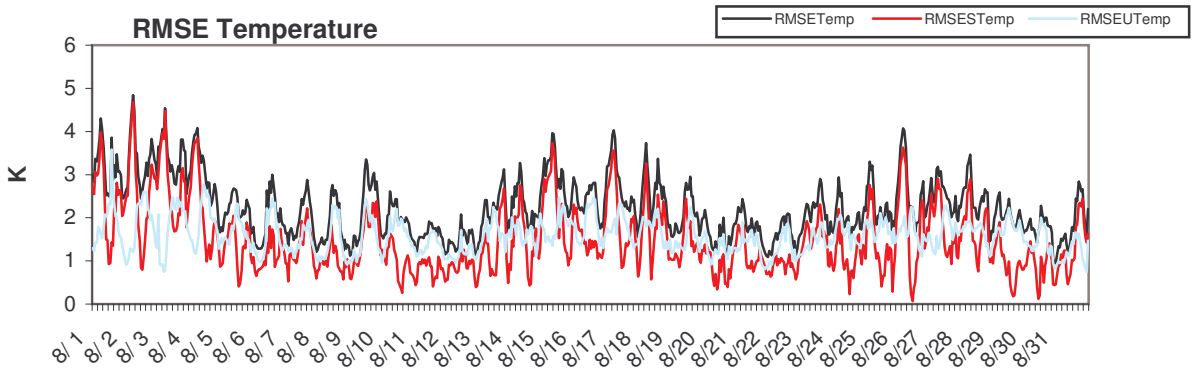


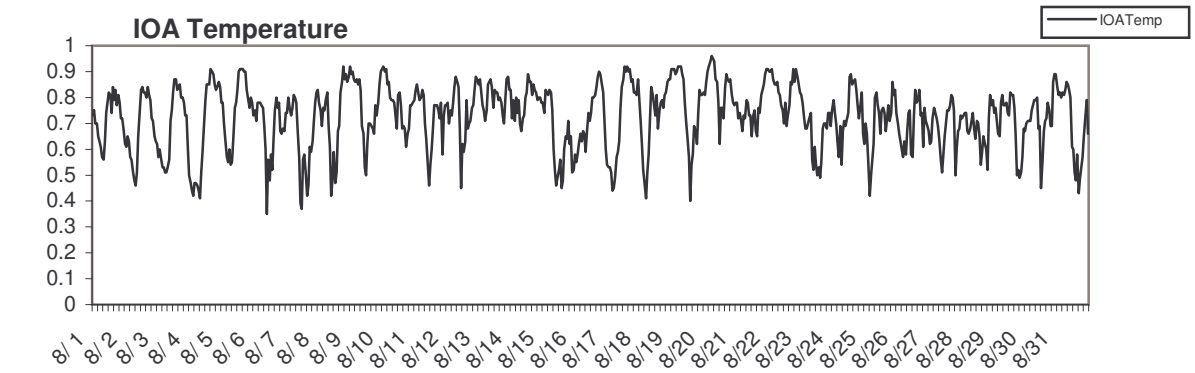


Alaska 5km 2002-08

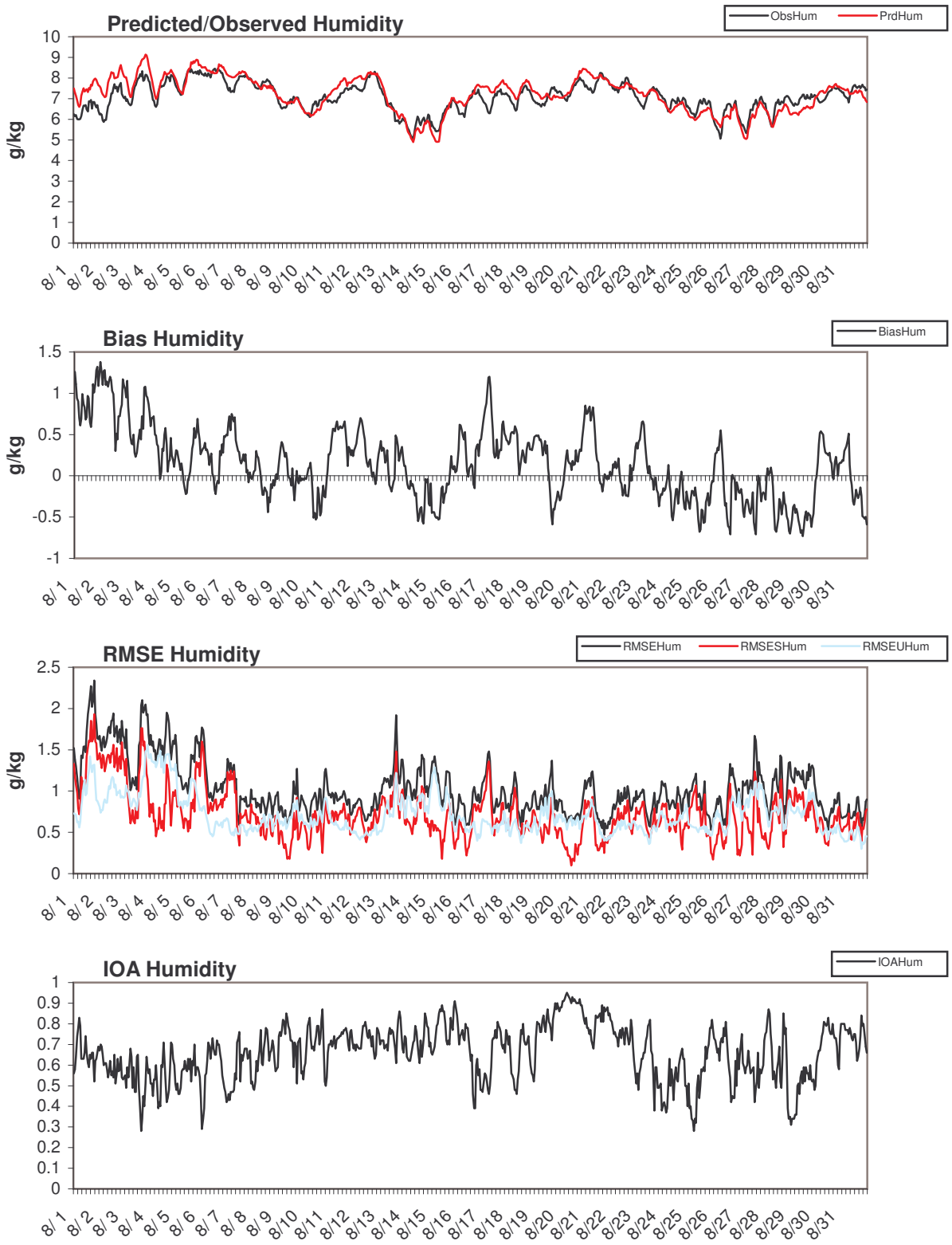




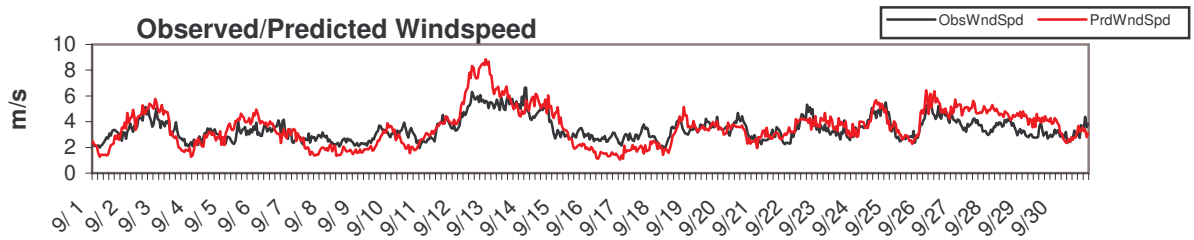


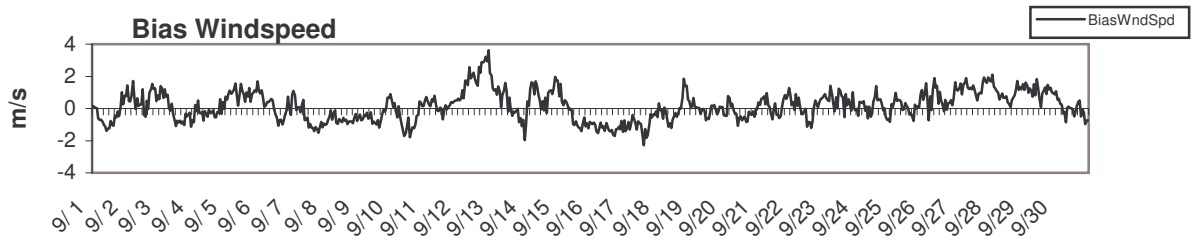


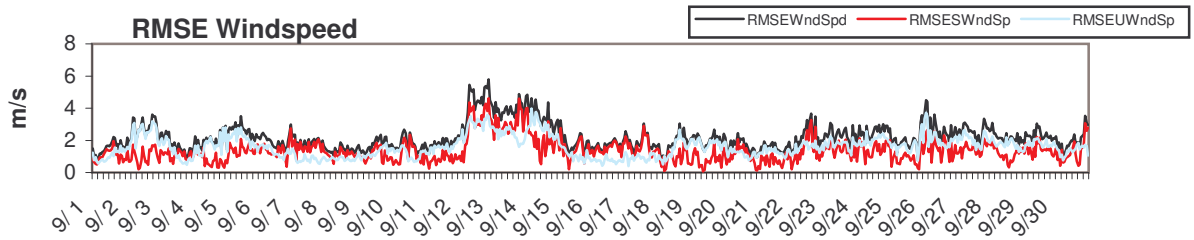
Alaska 5km 2002-08

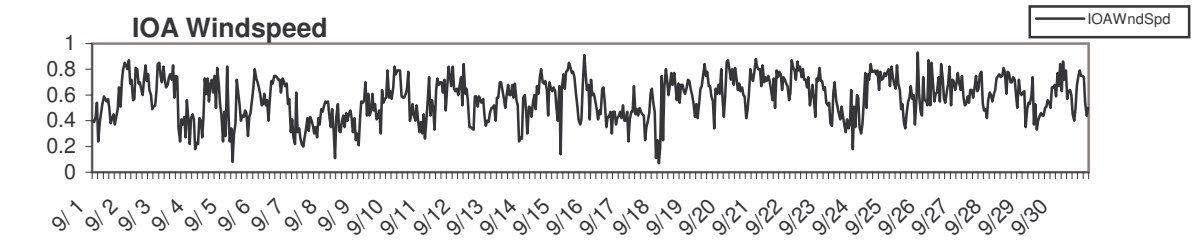


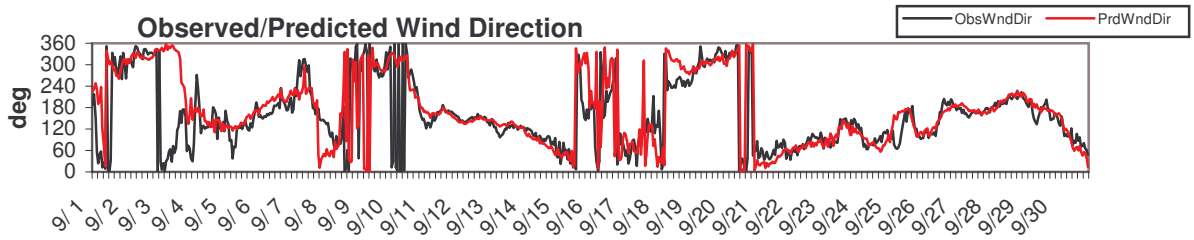
Alaska 5km 2002-09

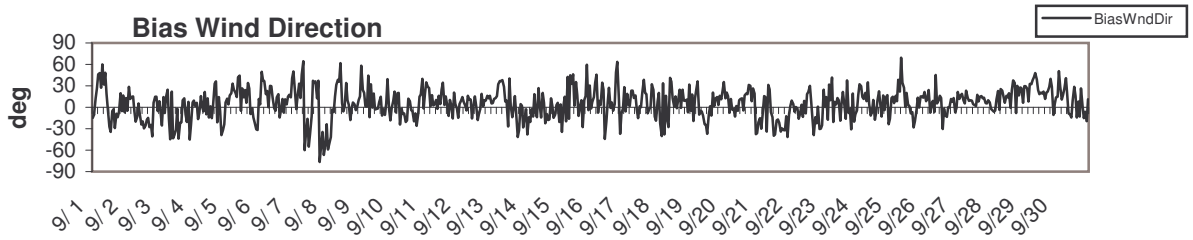




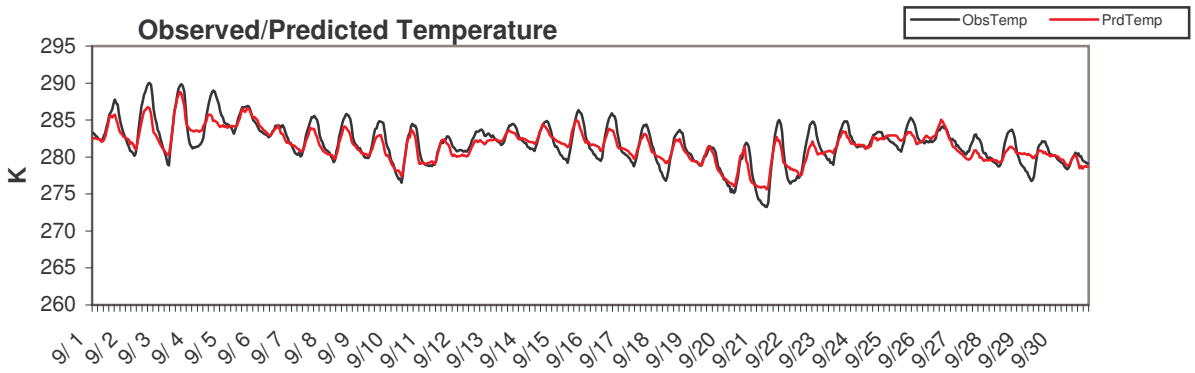


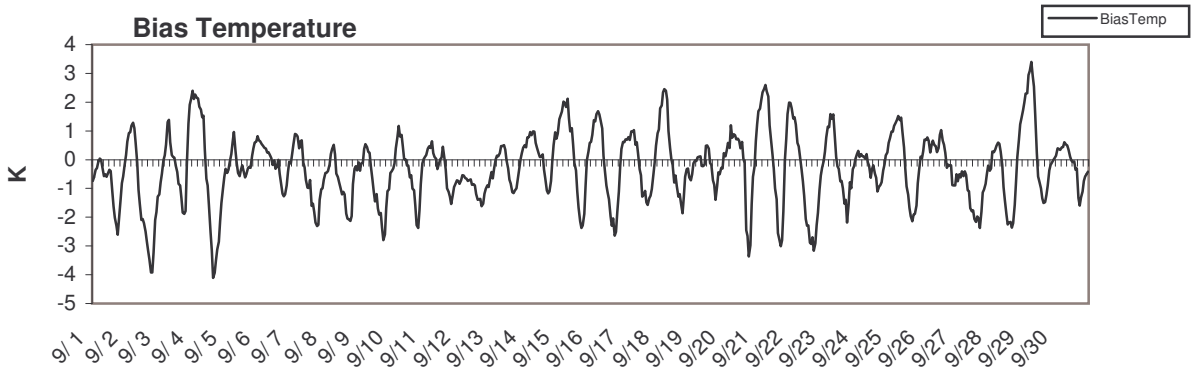


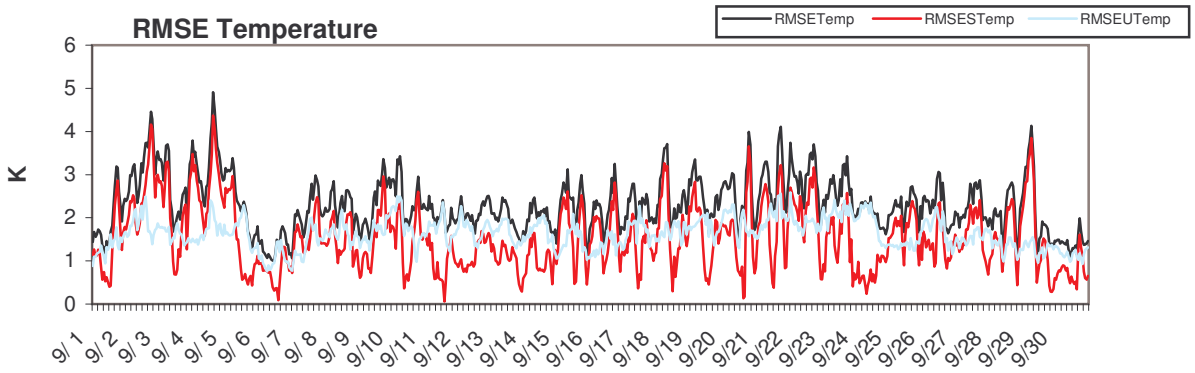


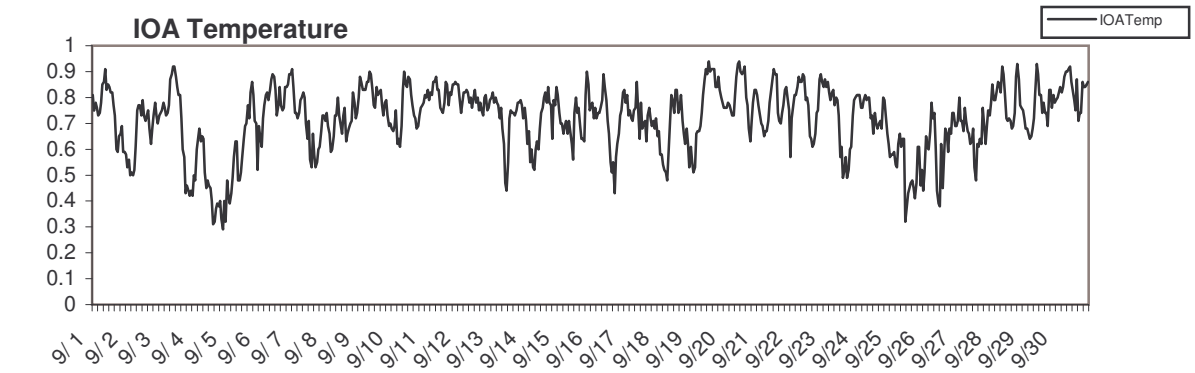


Alaska 5km 2002-09

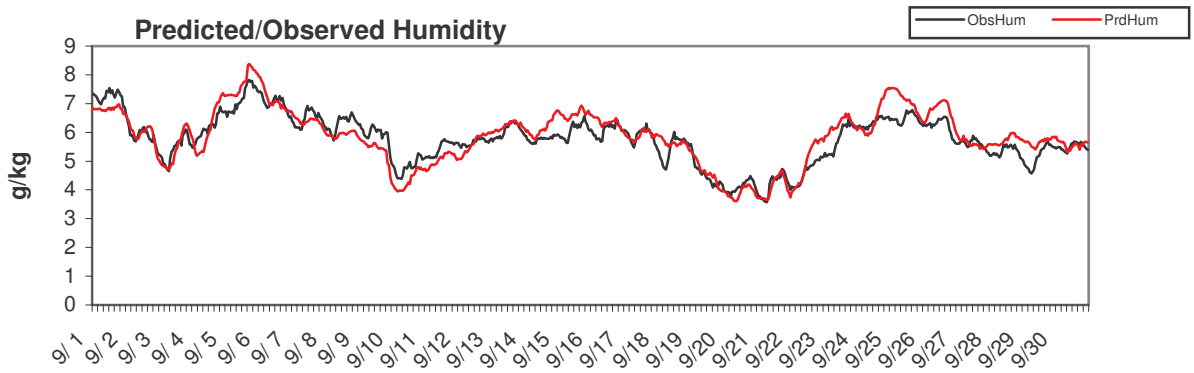


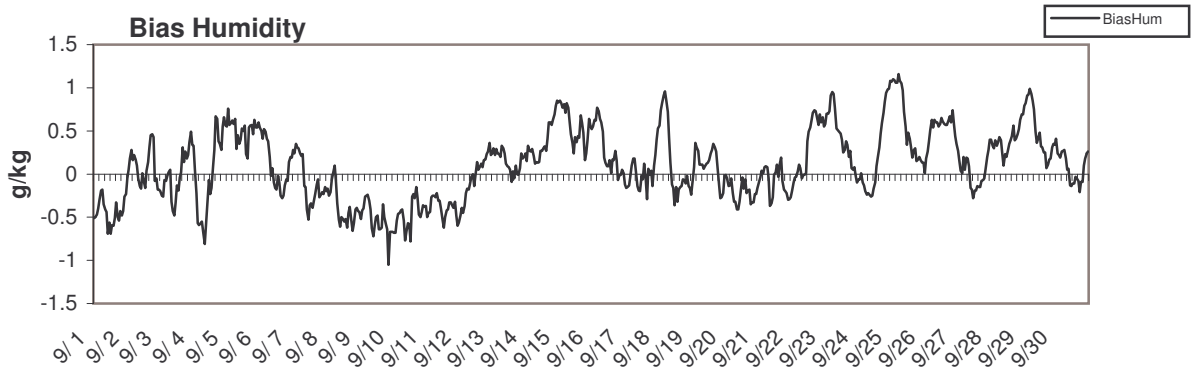


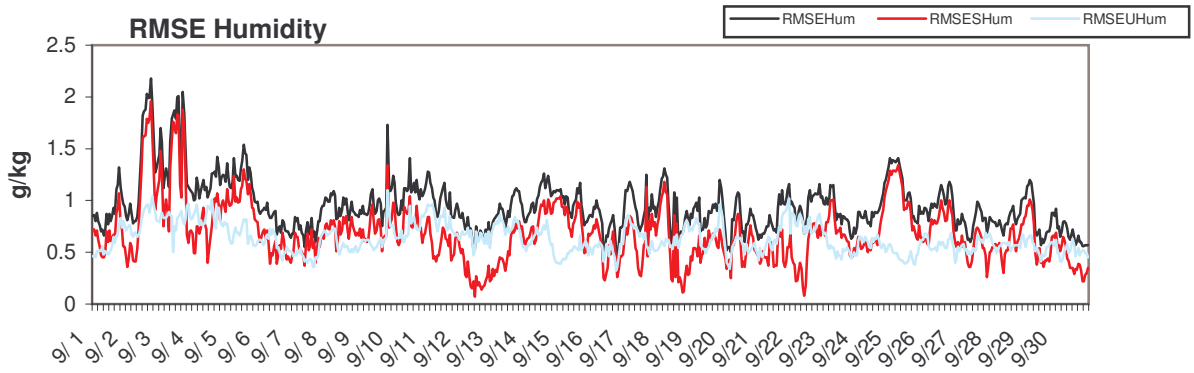


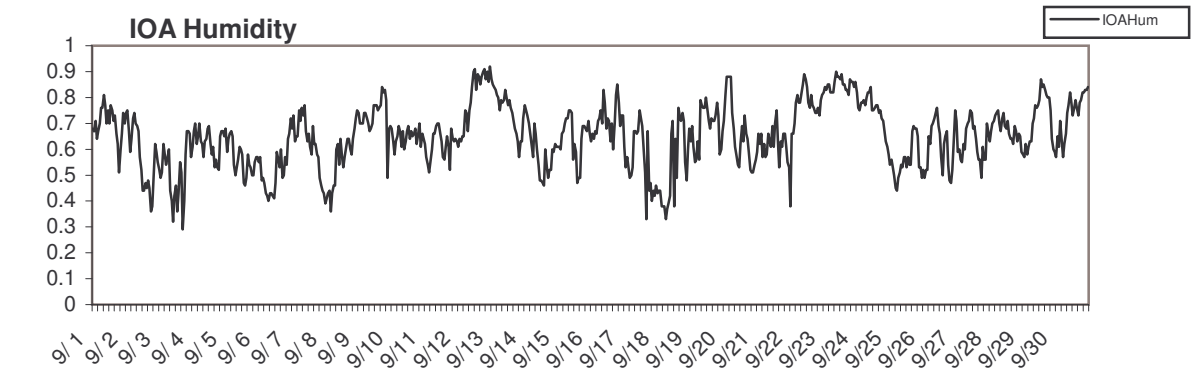


Alaska 5km 2002-09

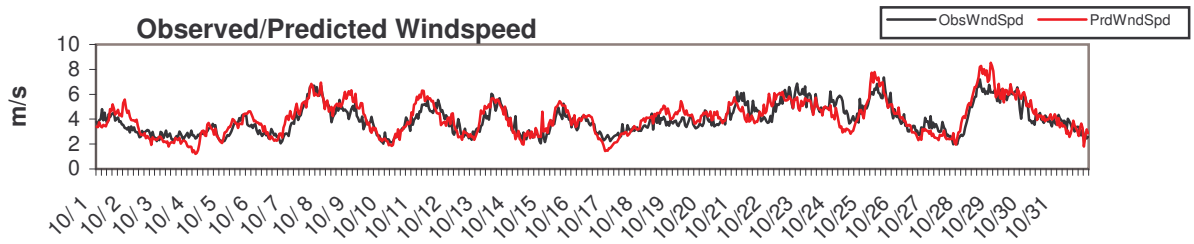


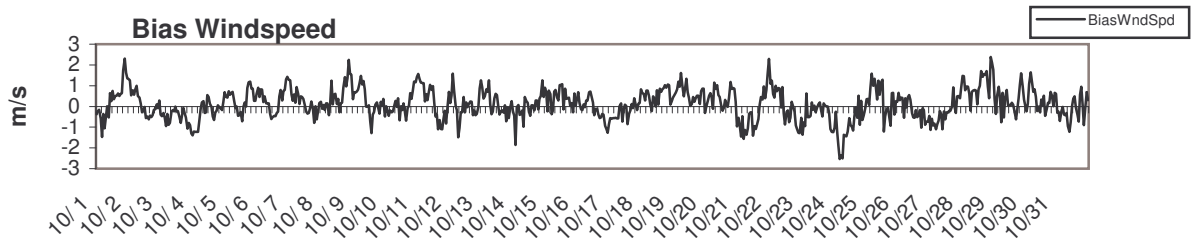


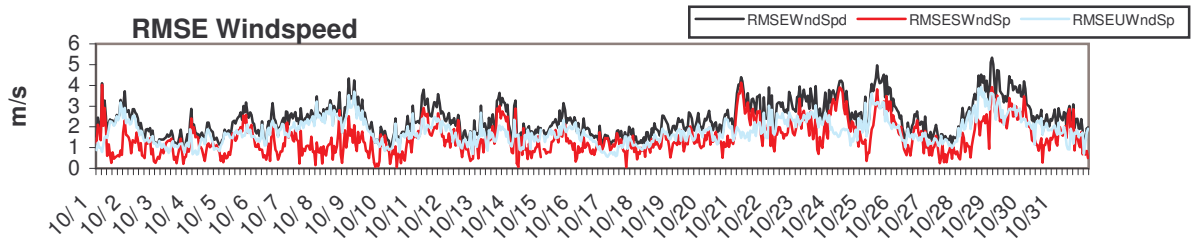


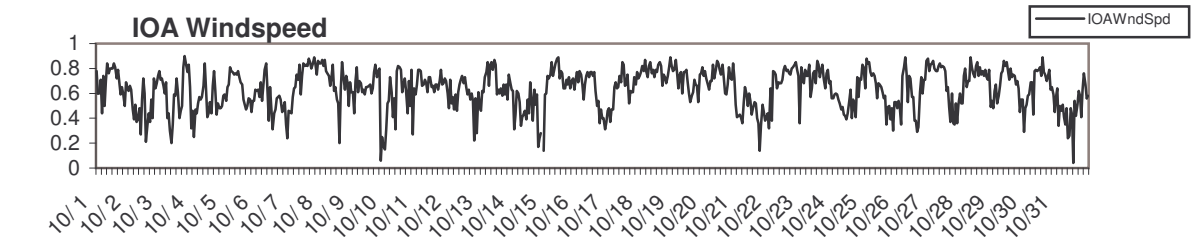


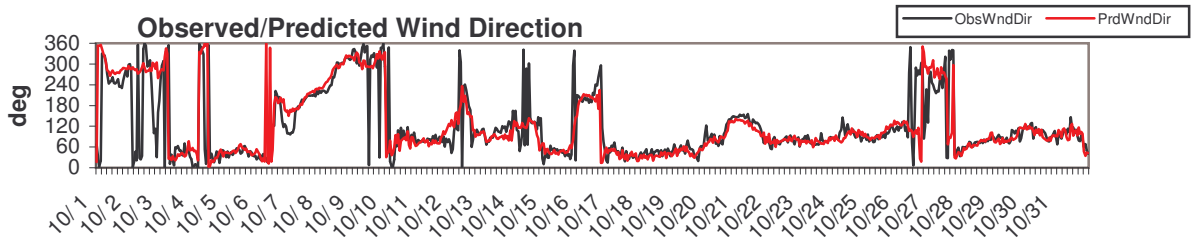
Alaska 5km 2002-10

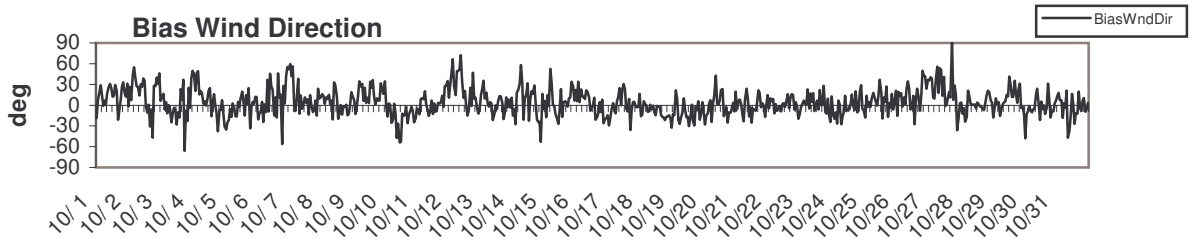




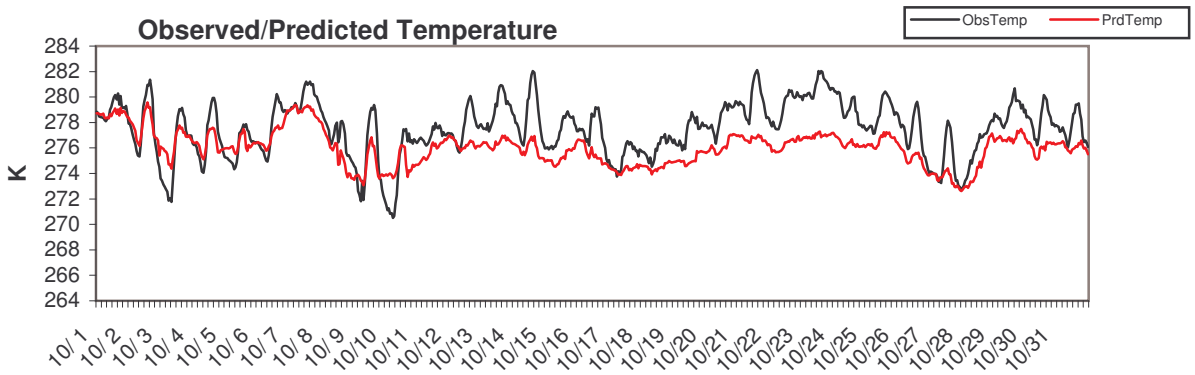


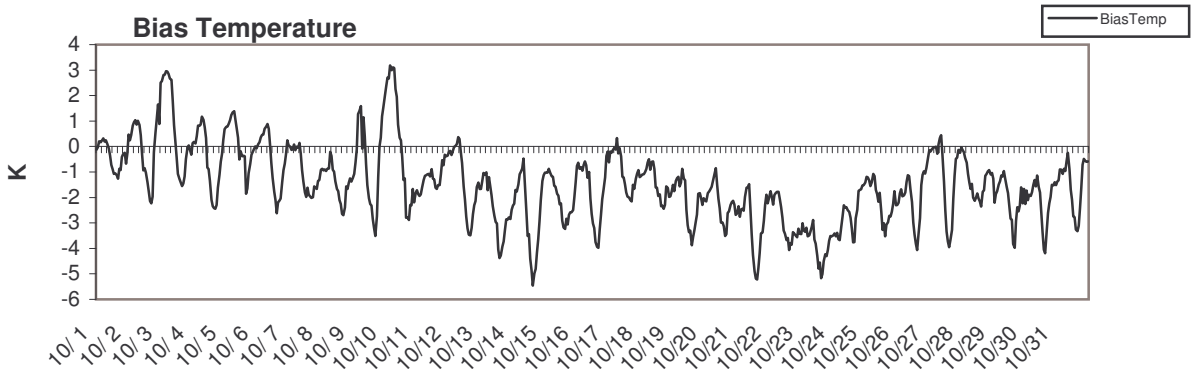


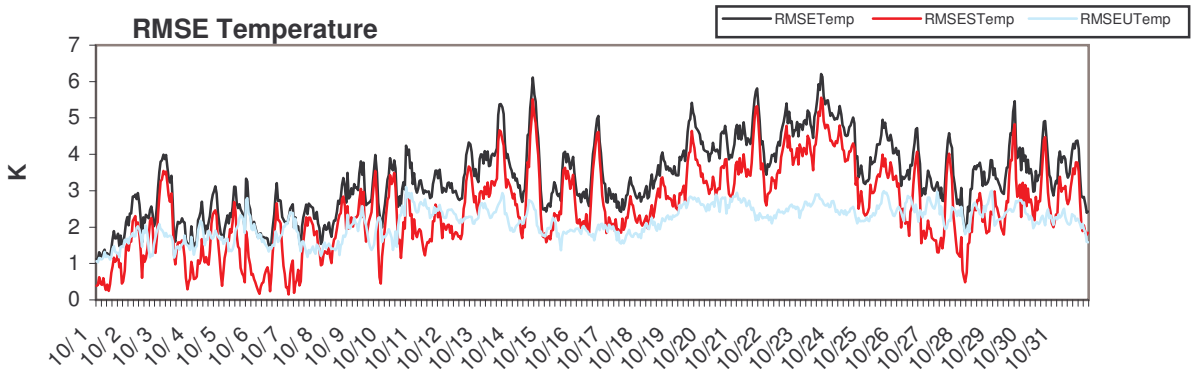


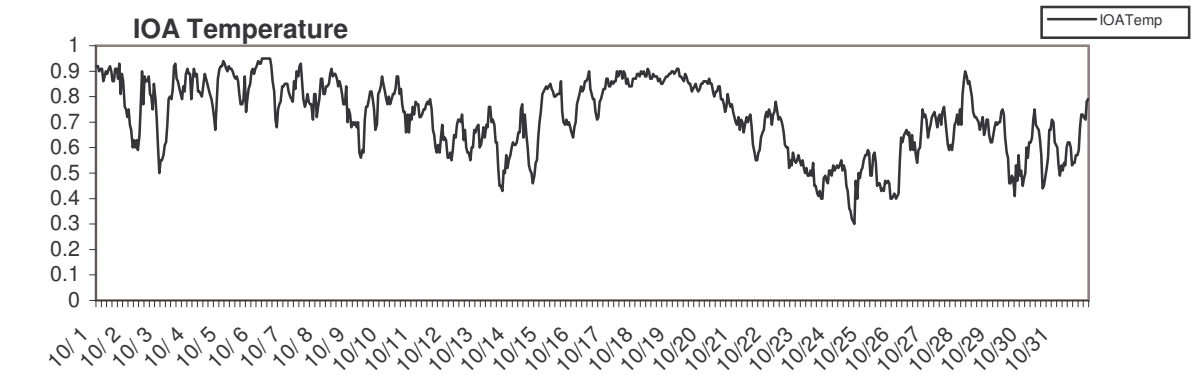


Alaska 5km 2002-10









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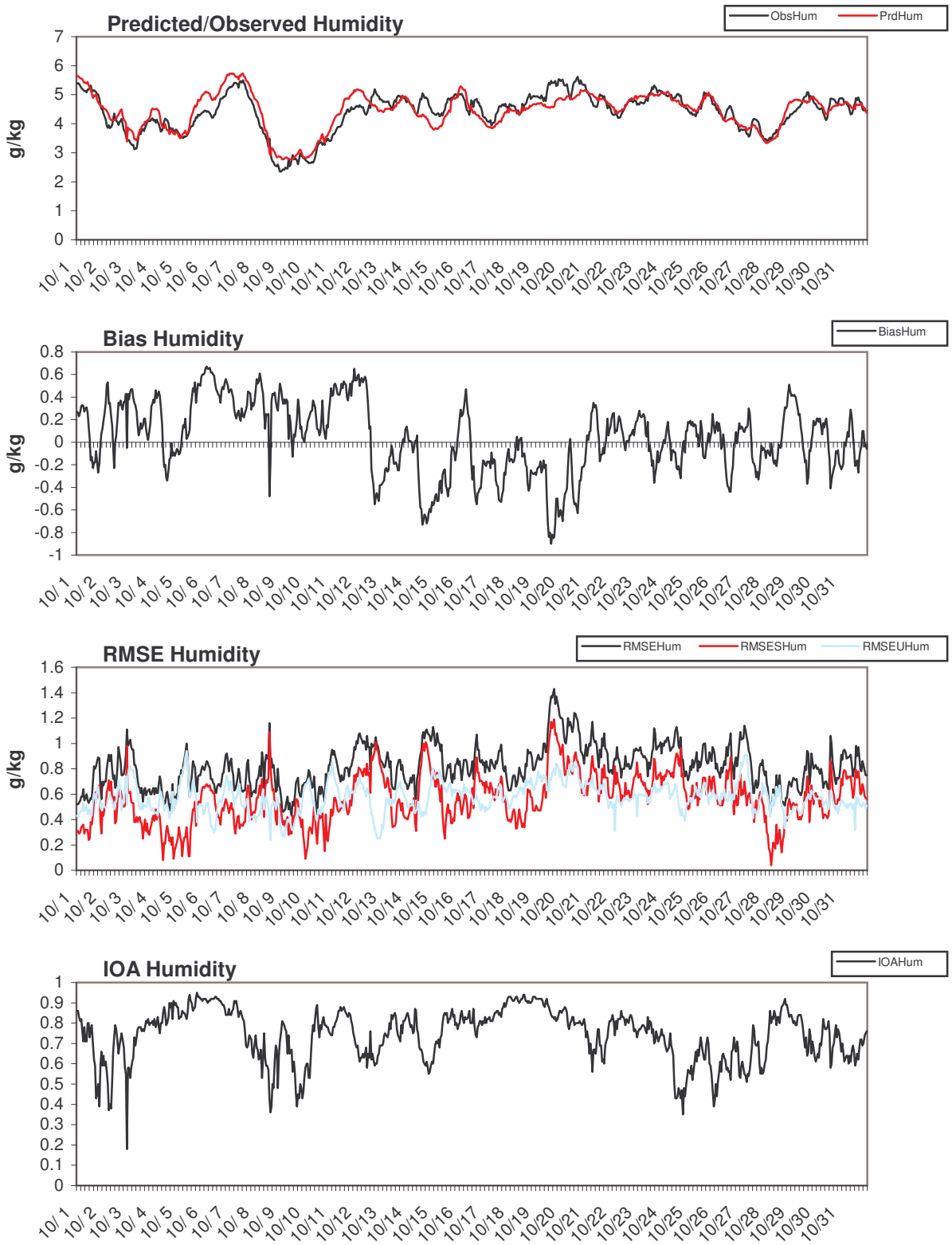
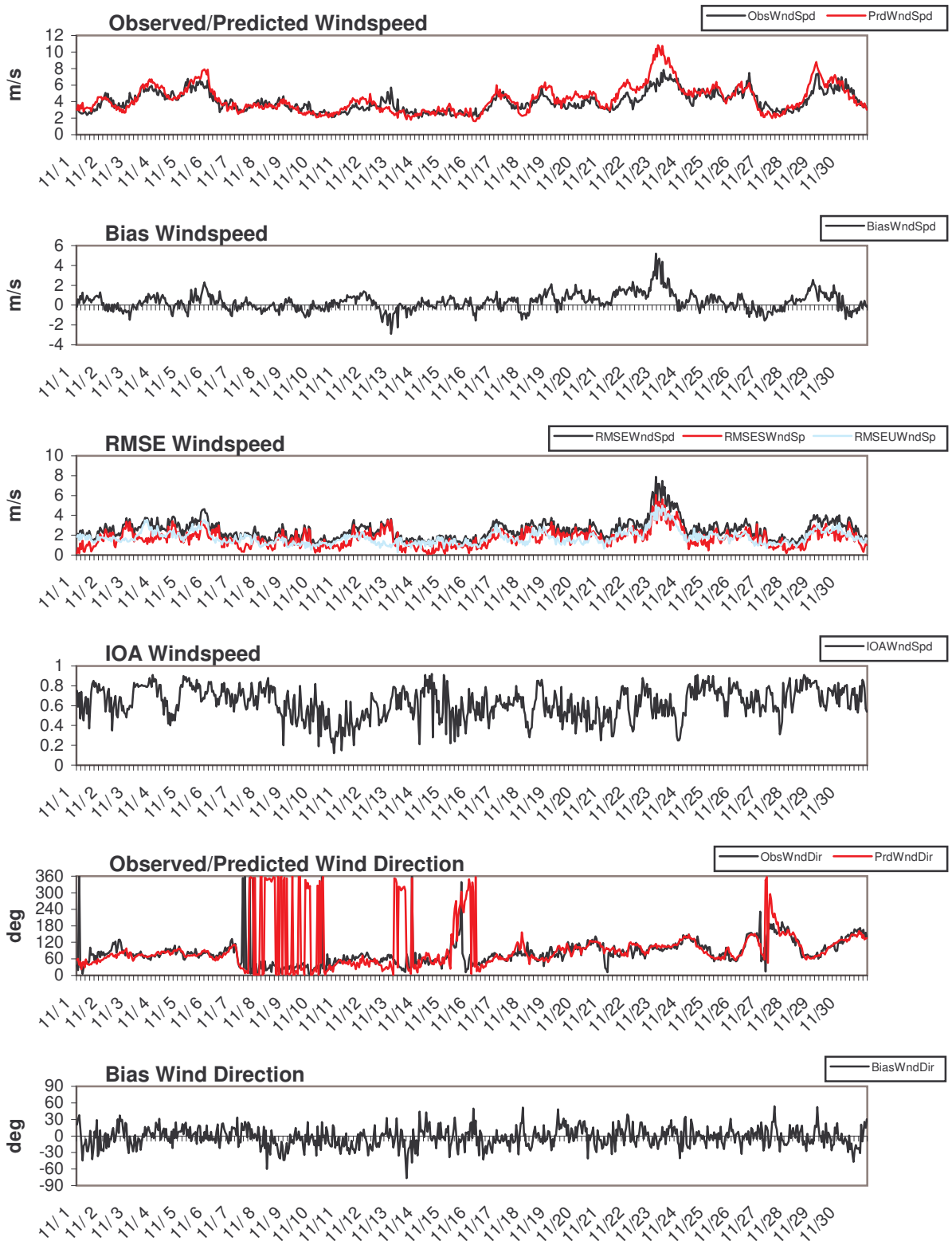
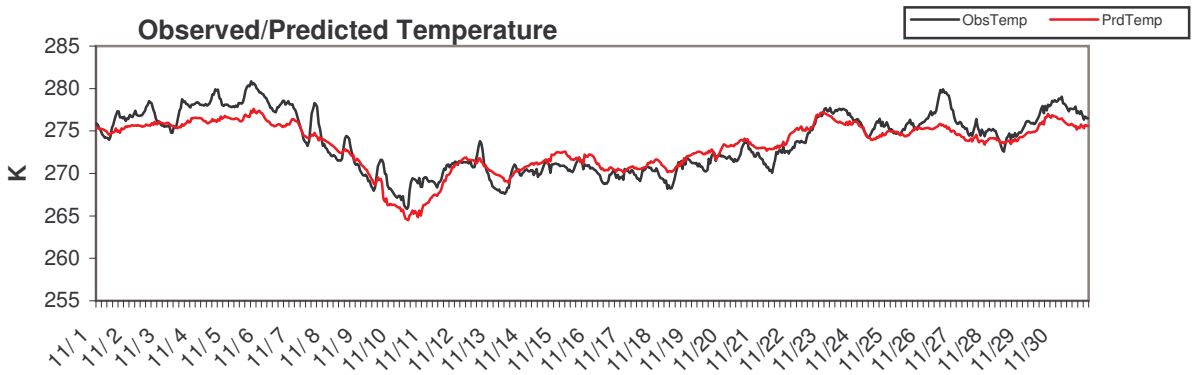
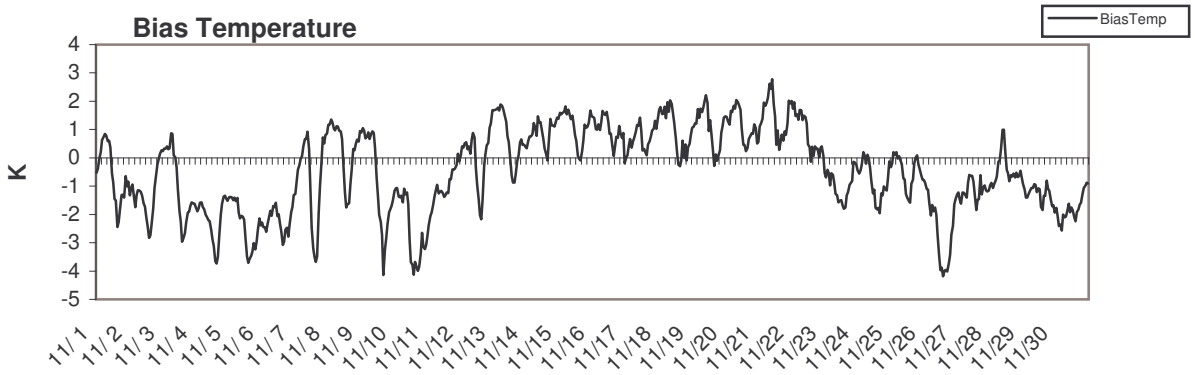


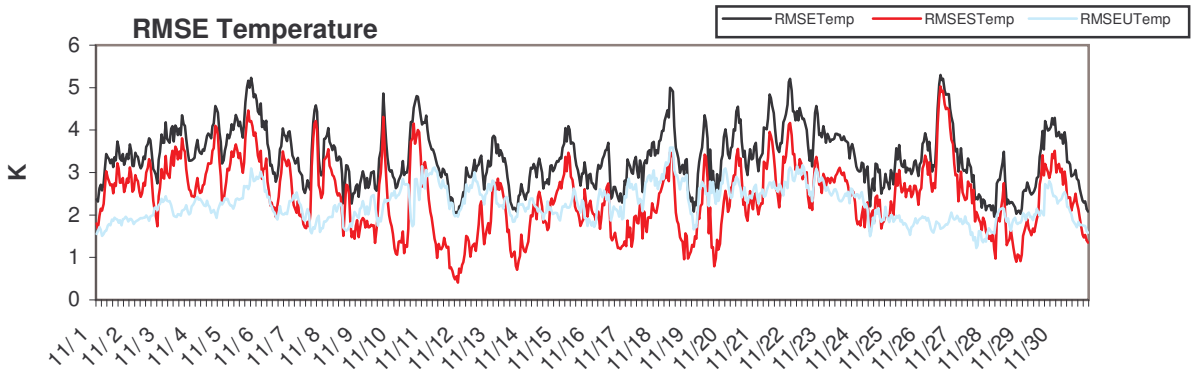
Alaska 5km 2002-11

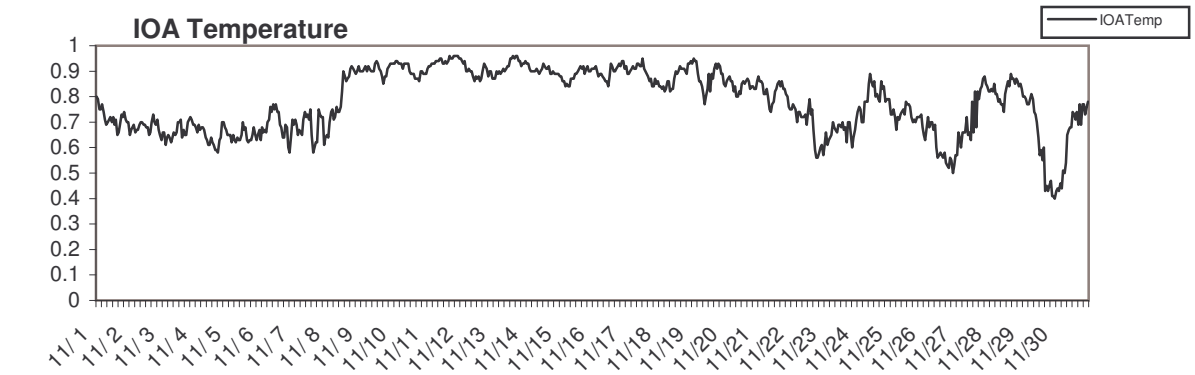


Alaska 5km 2002-11









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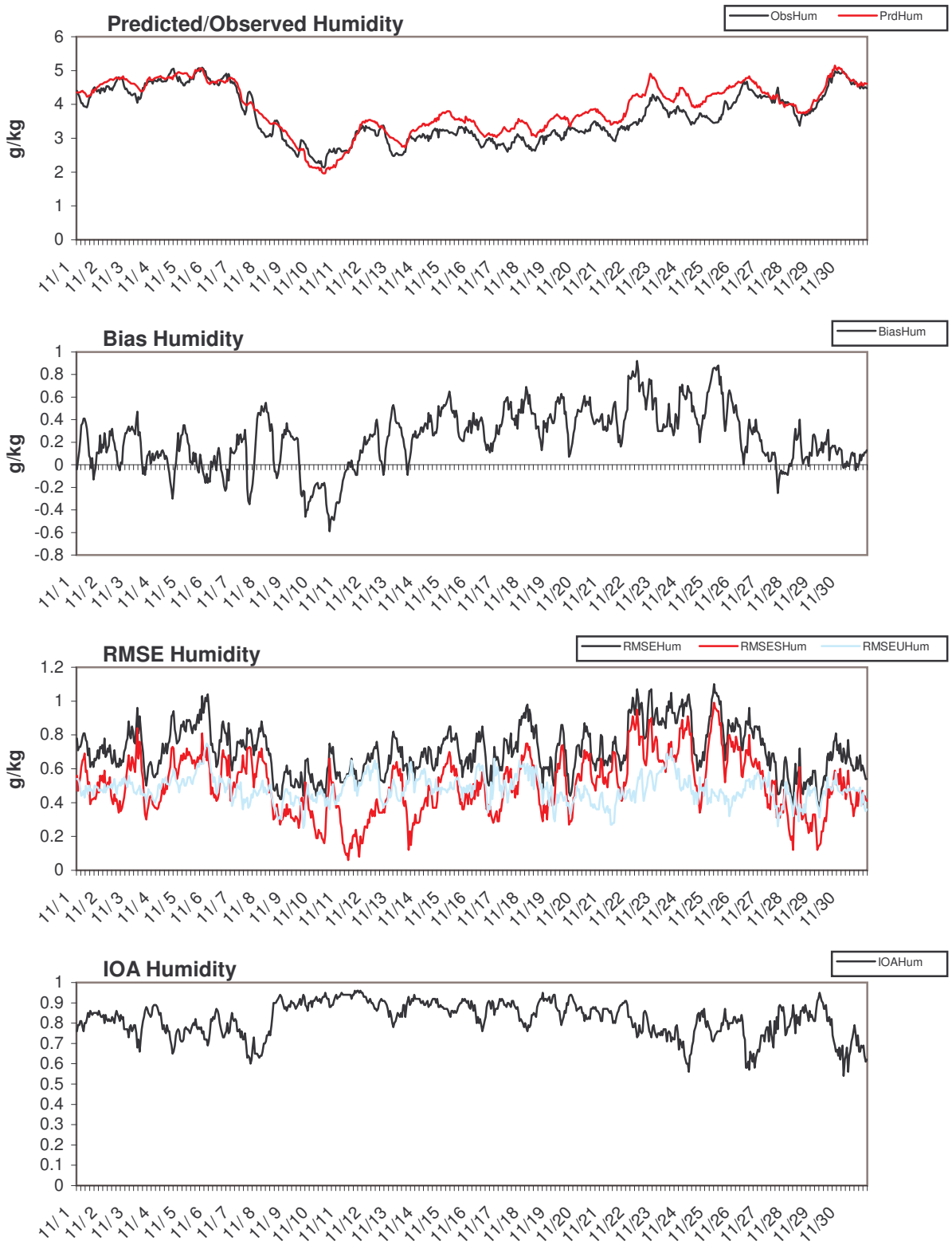

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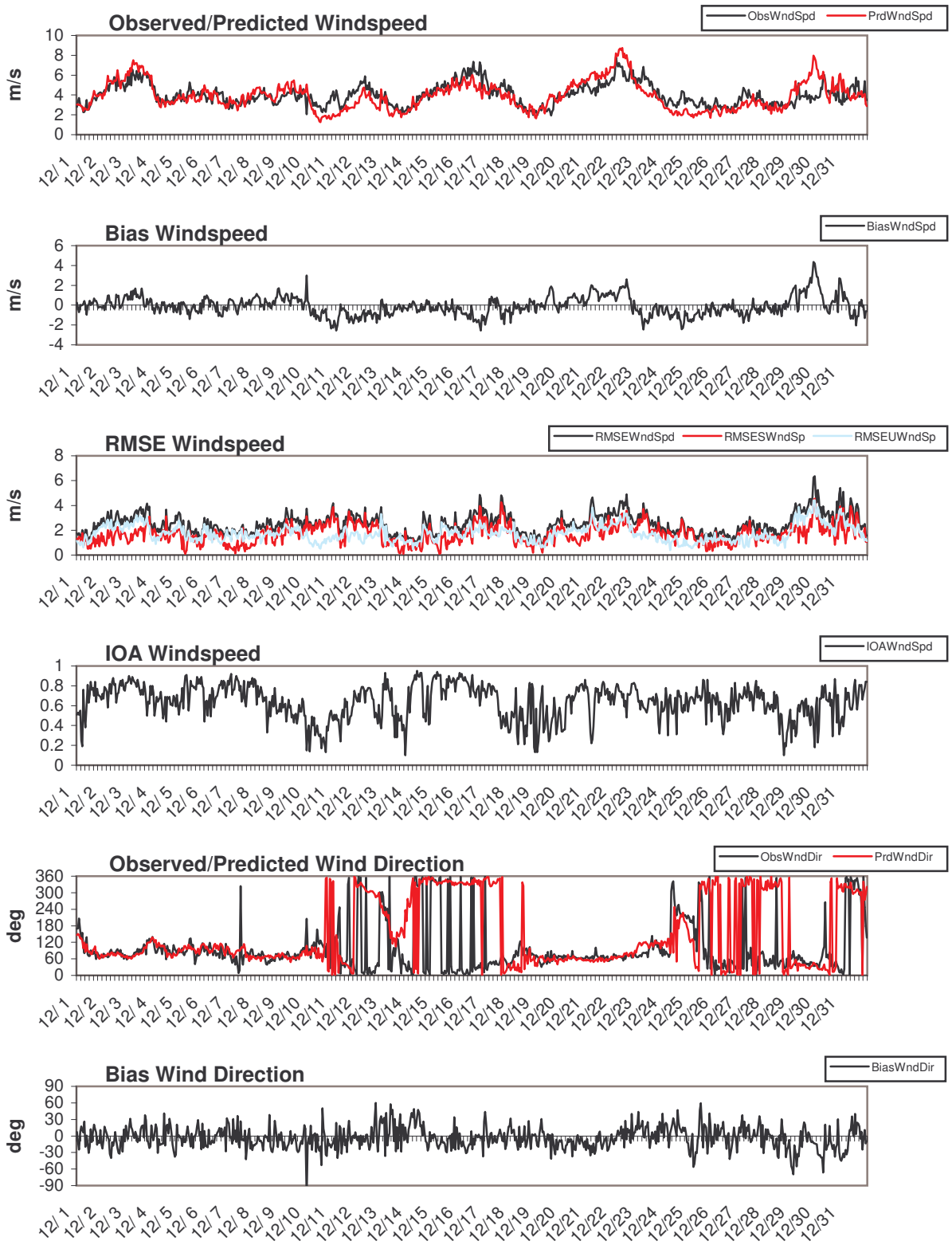

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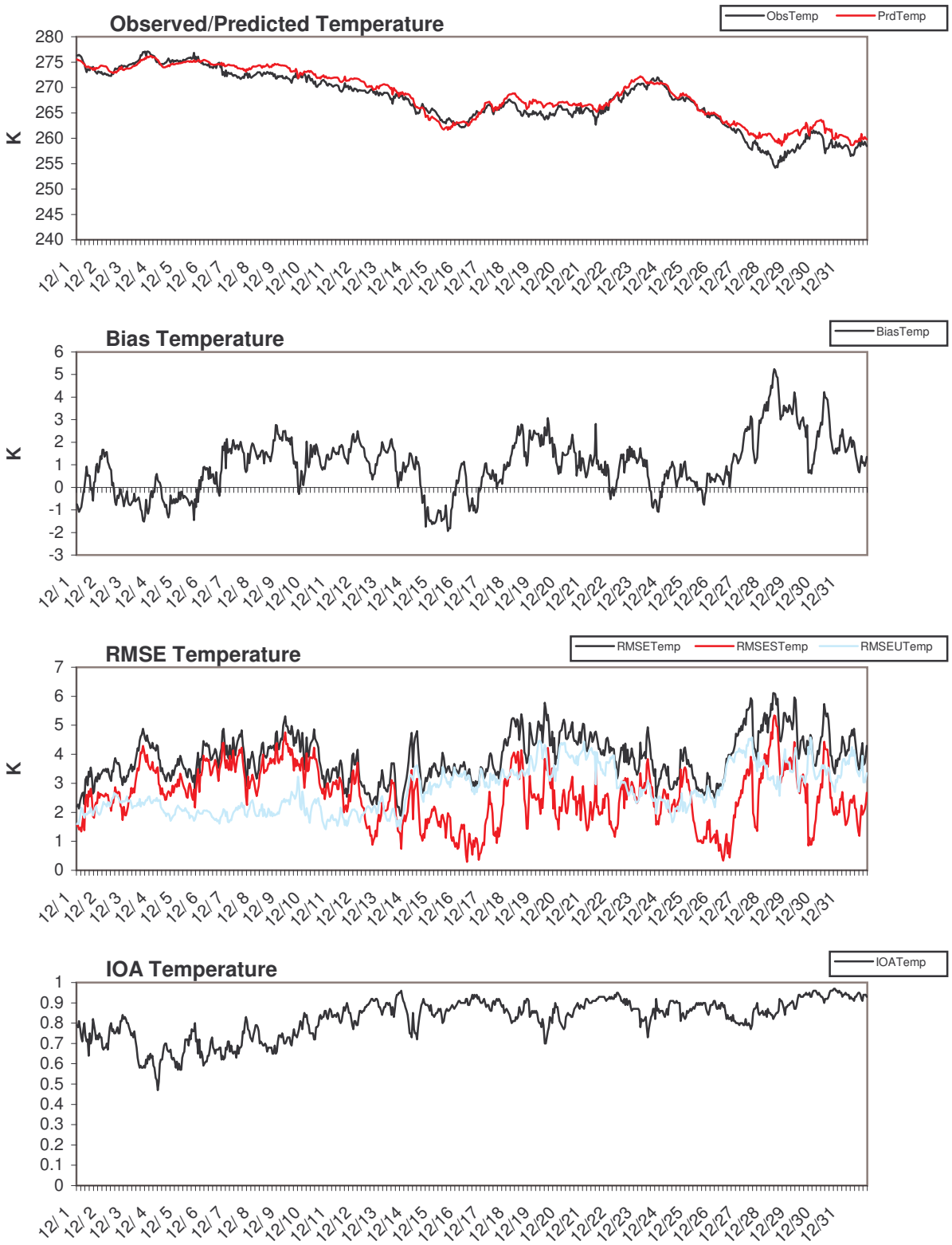

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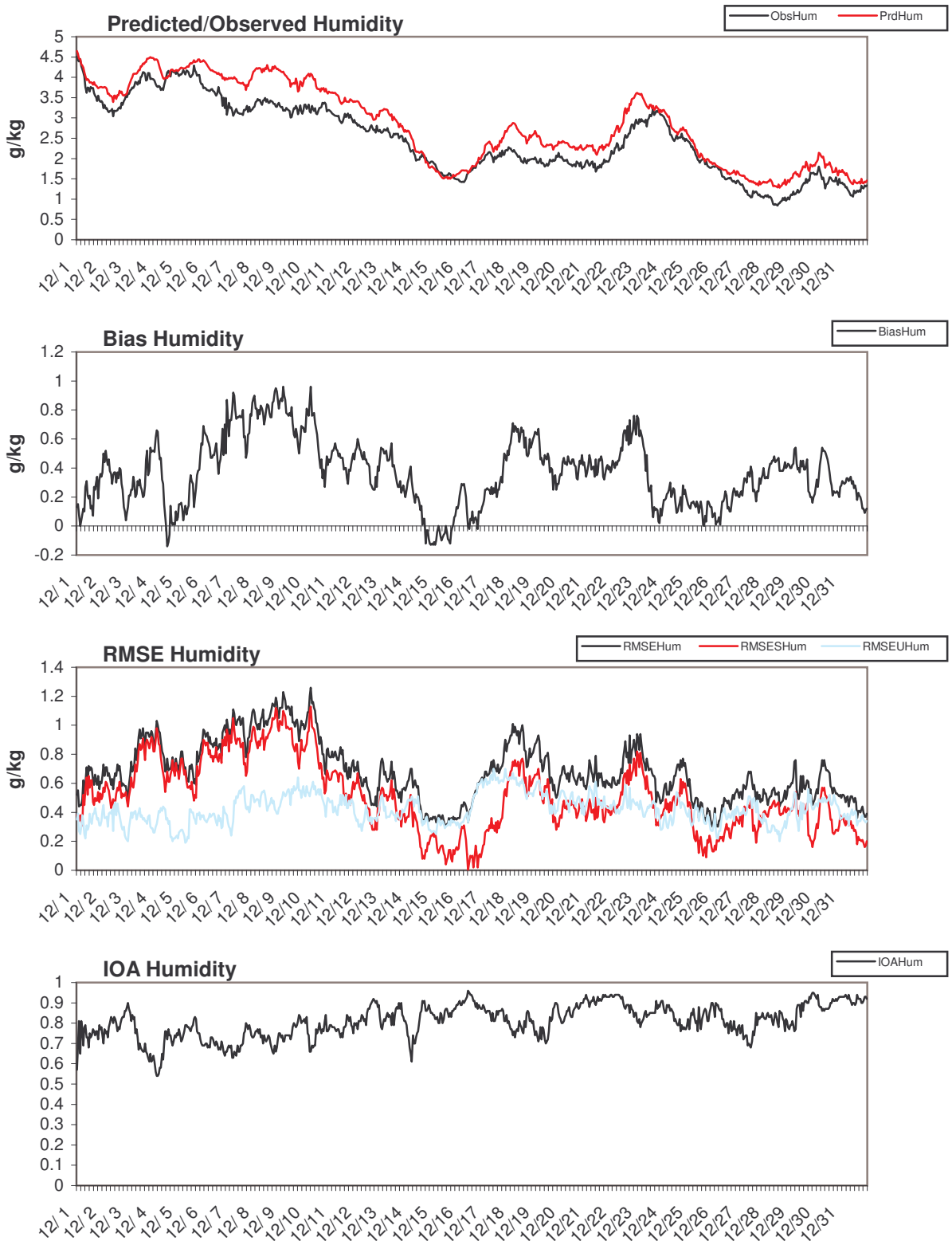
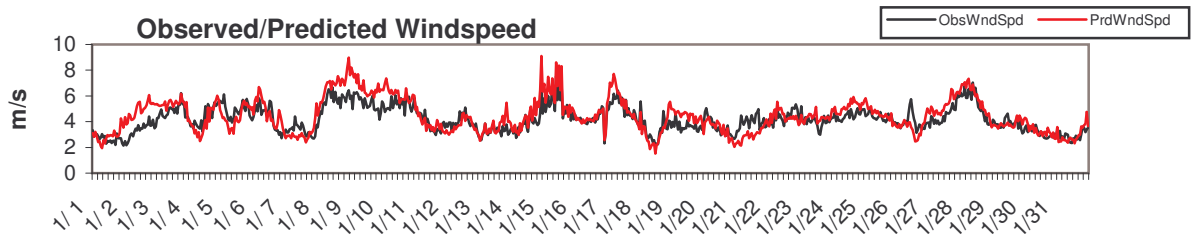
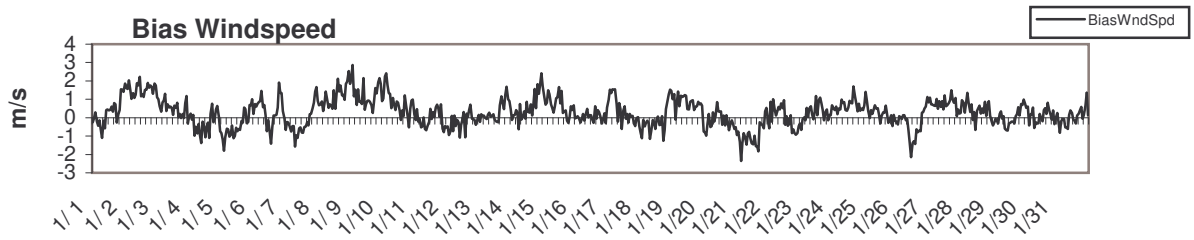
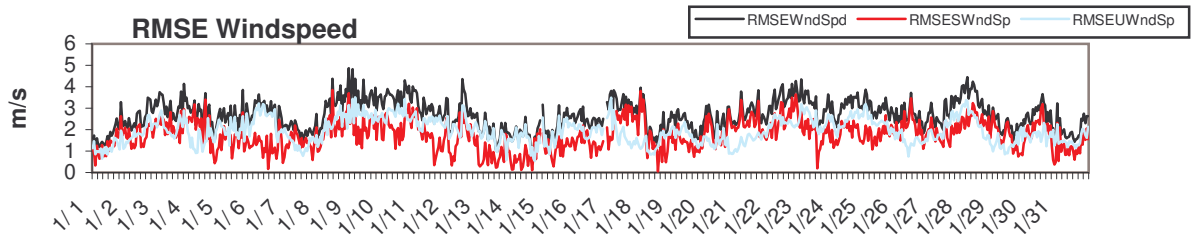
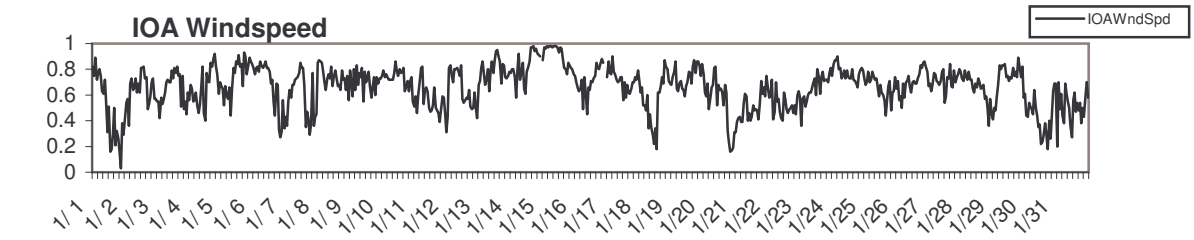


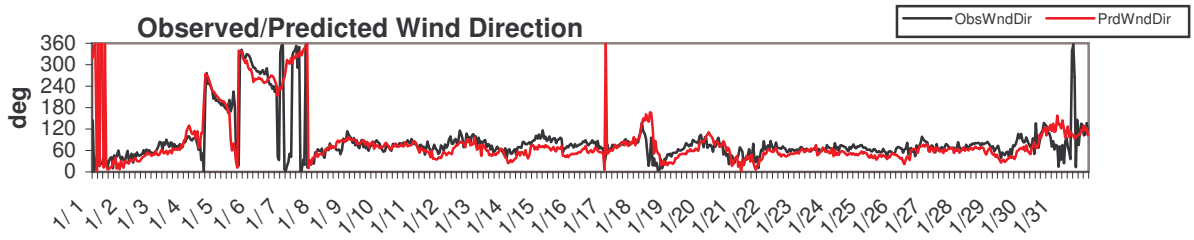
Alaska 5km 2003-01

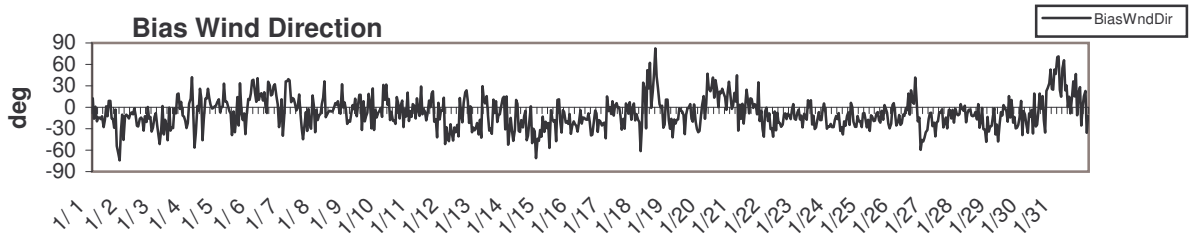












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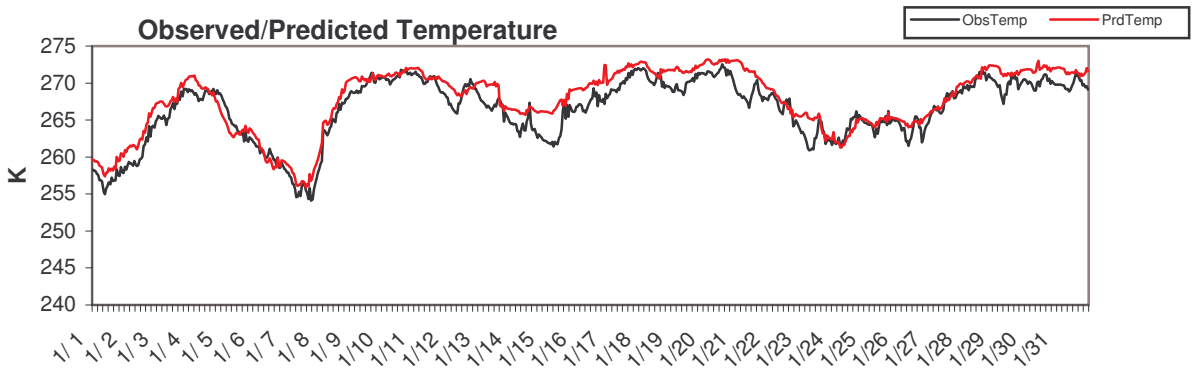
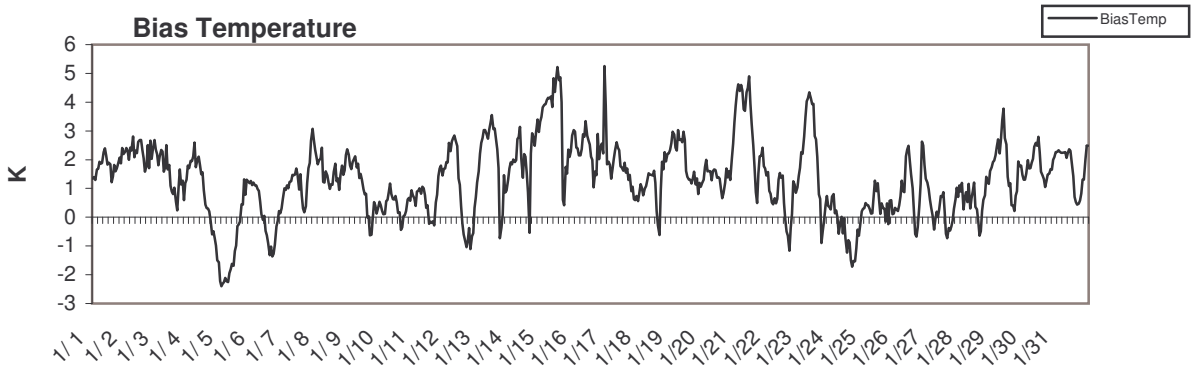
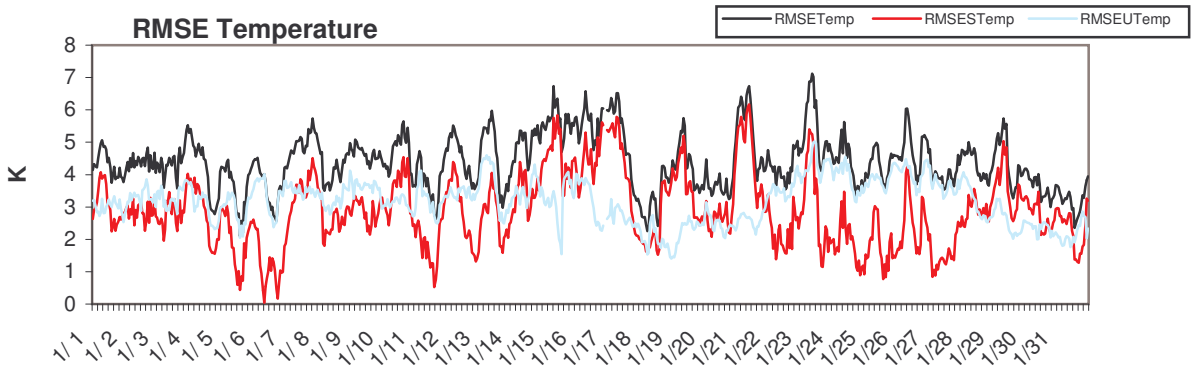
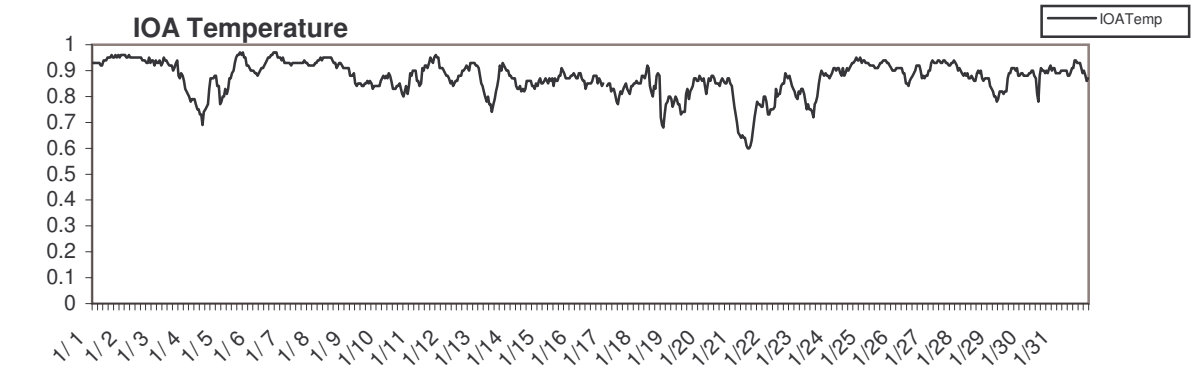
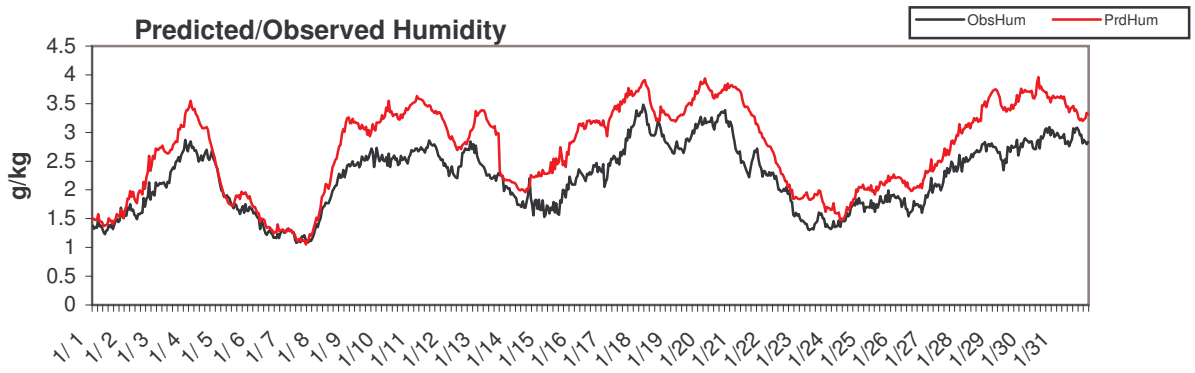


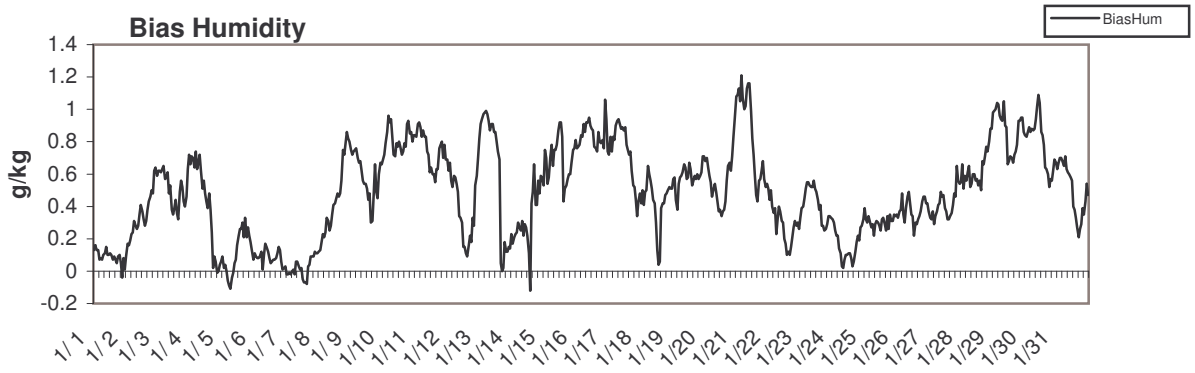


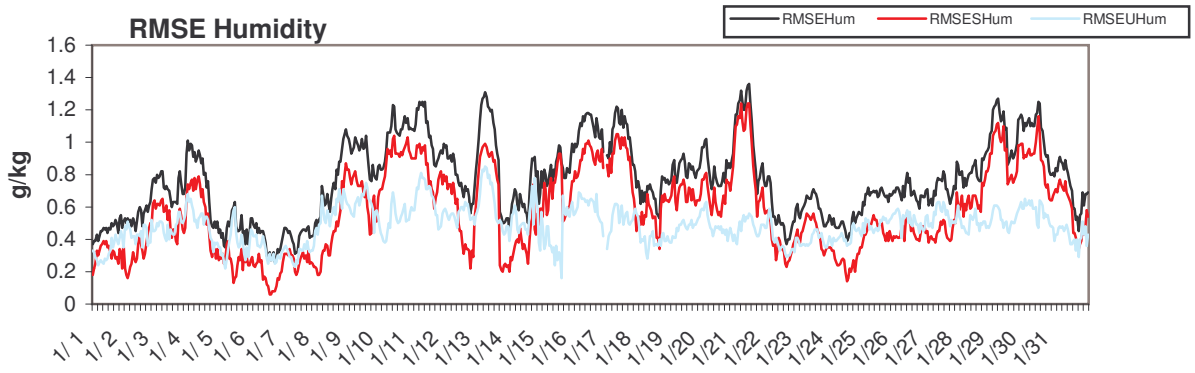


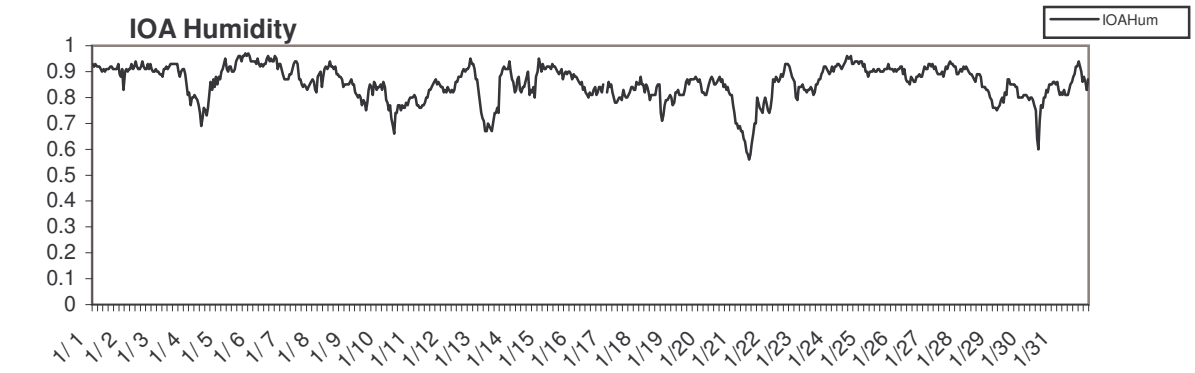


Alaska 5km 2003-01

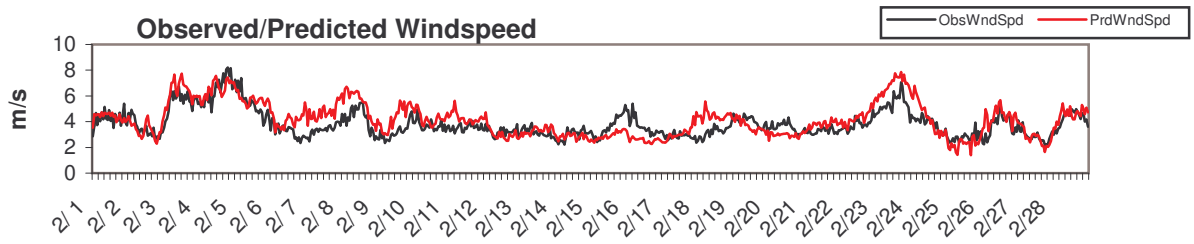


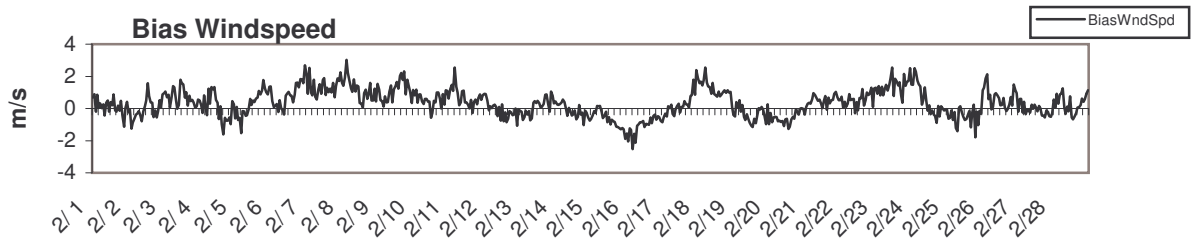


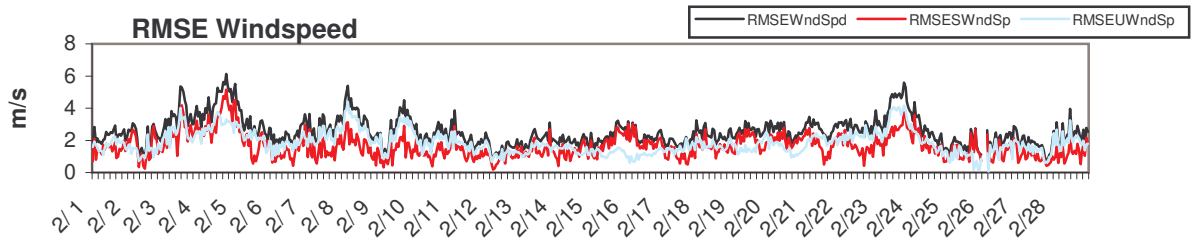


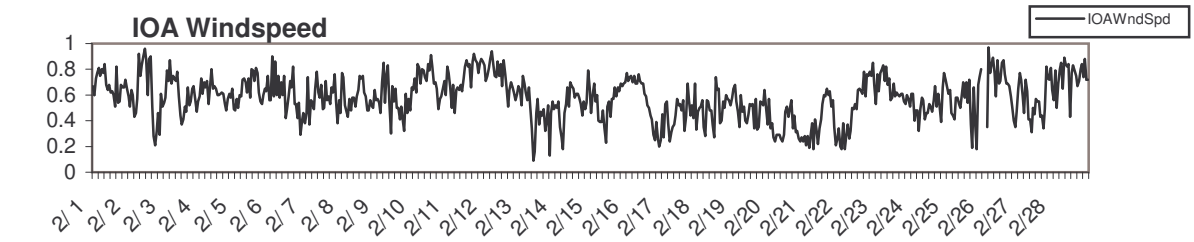


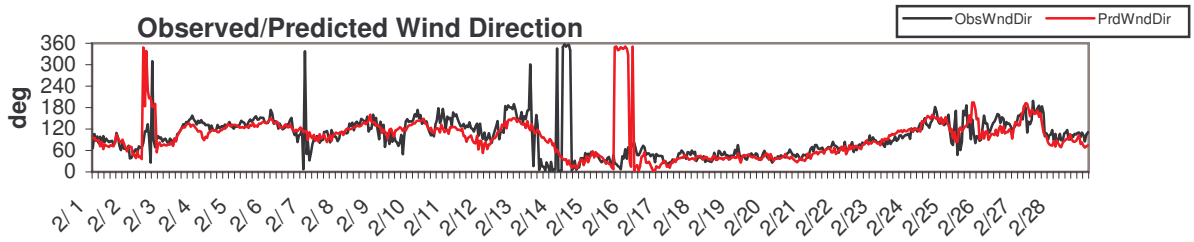
Alaska 5km 2003-02

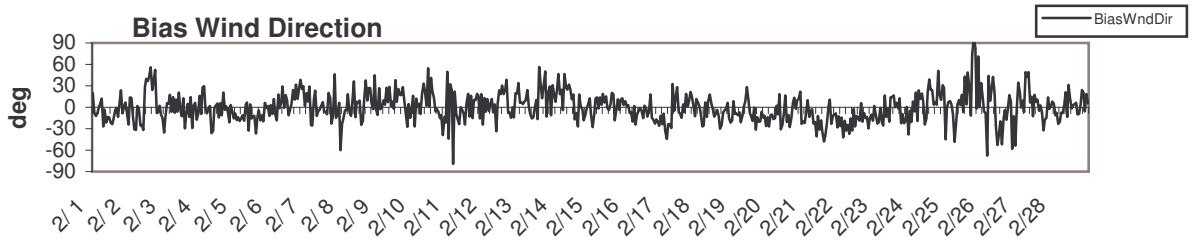




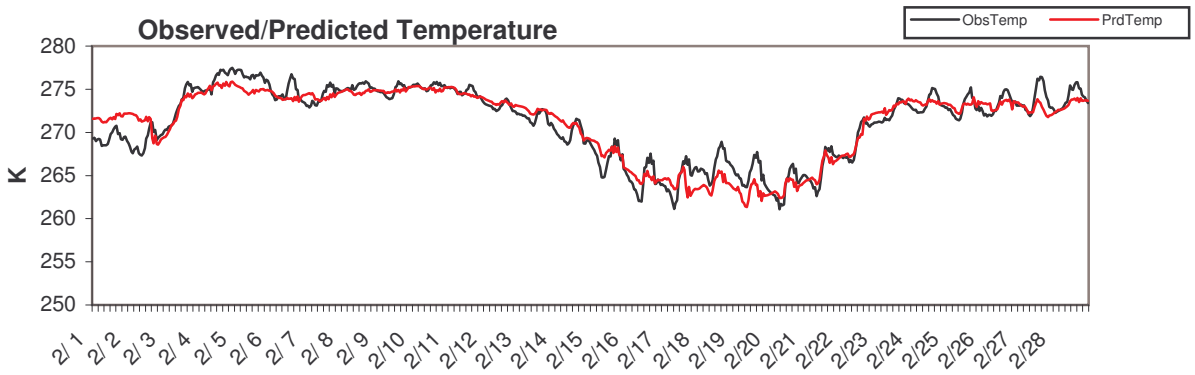


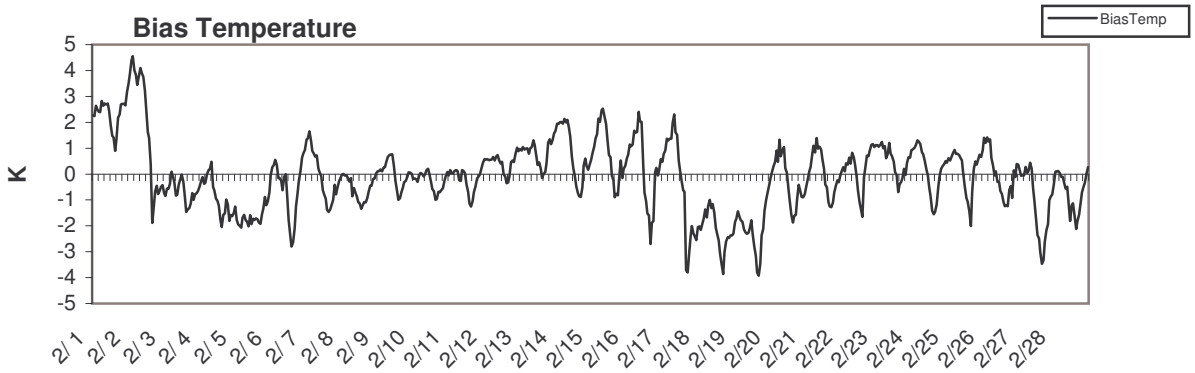


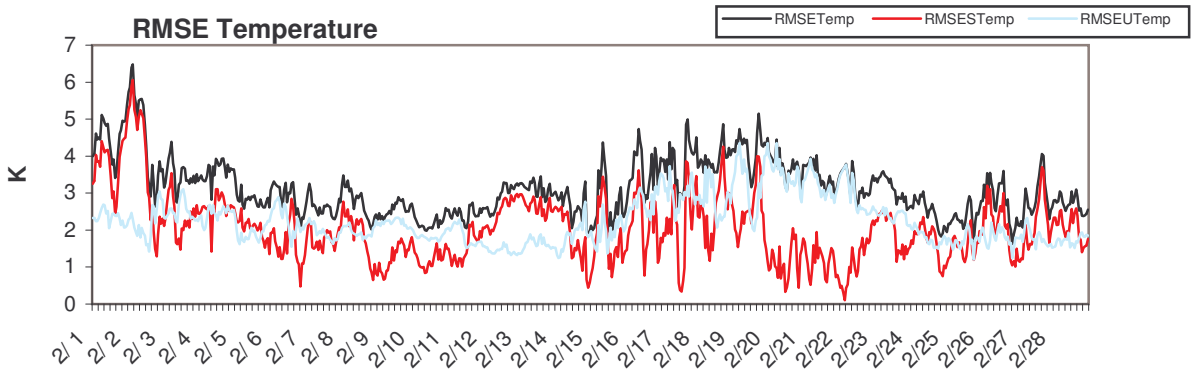


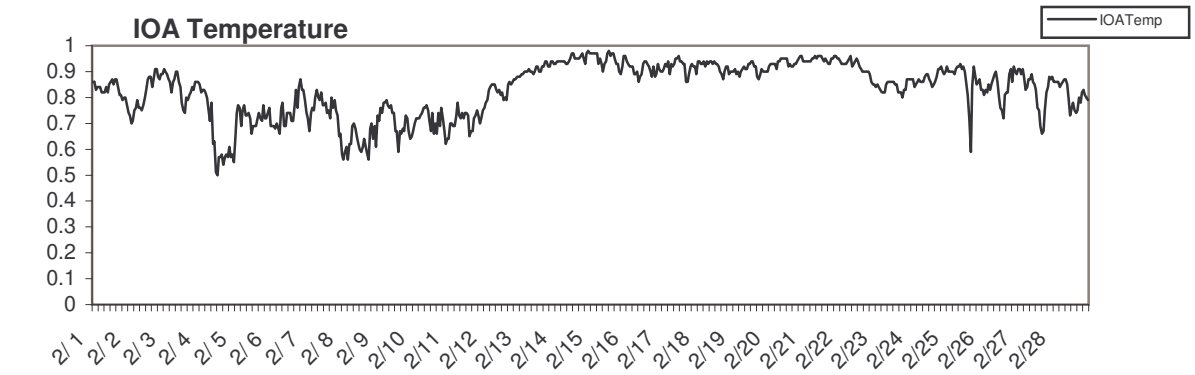


Alaska 5km 2003-02

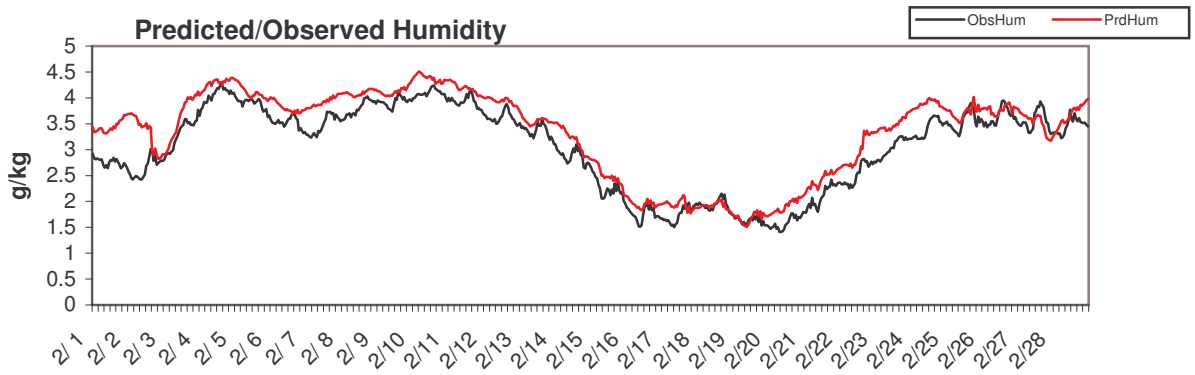


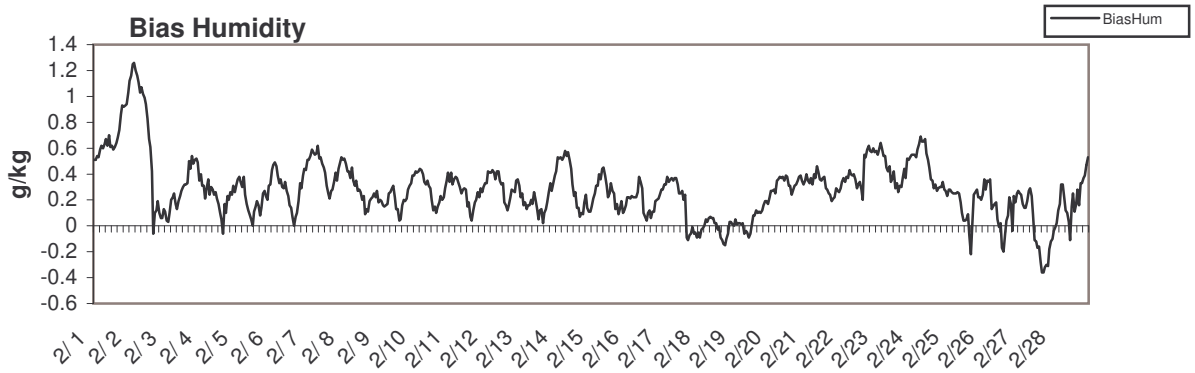


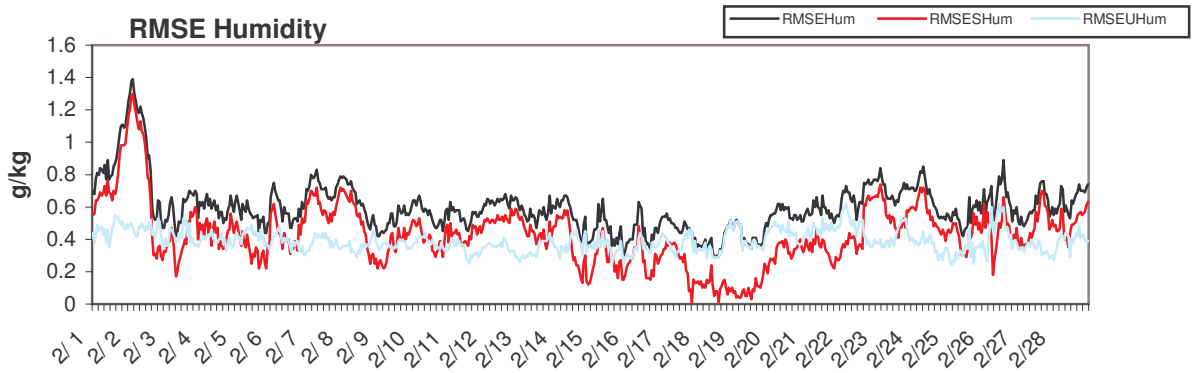


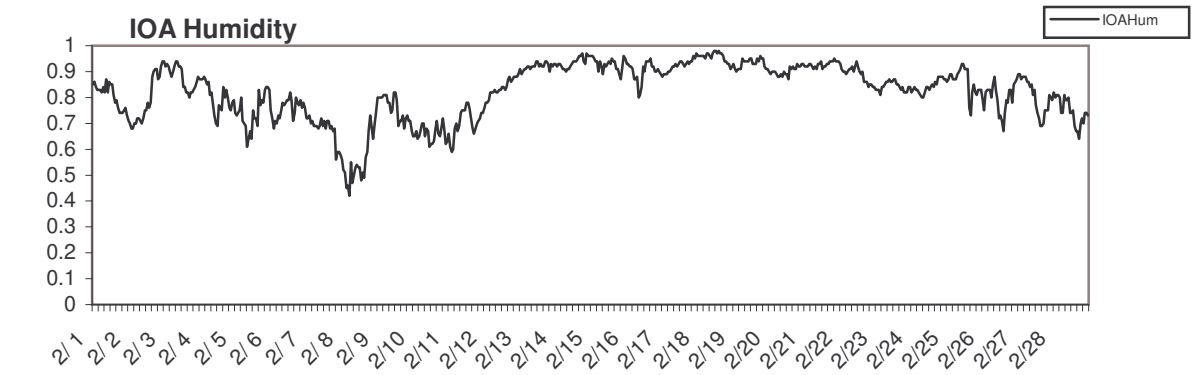


Alaska 5km 2003-02

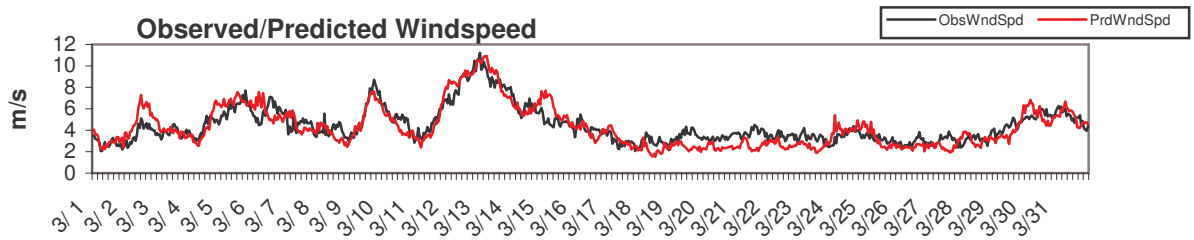


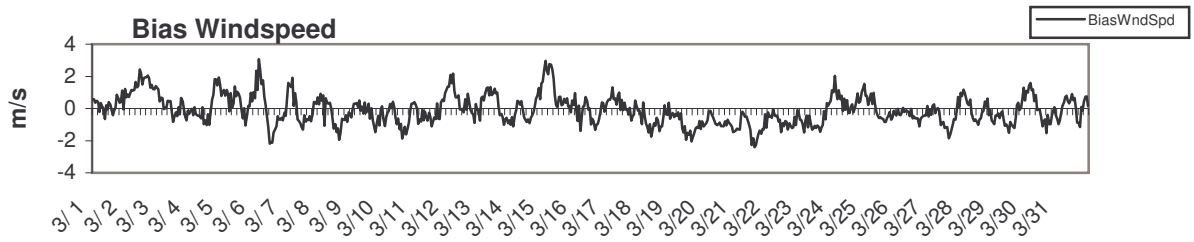


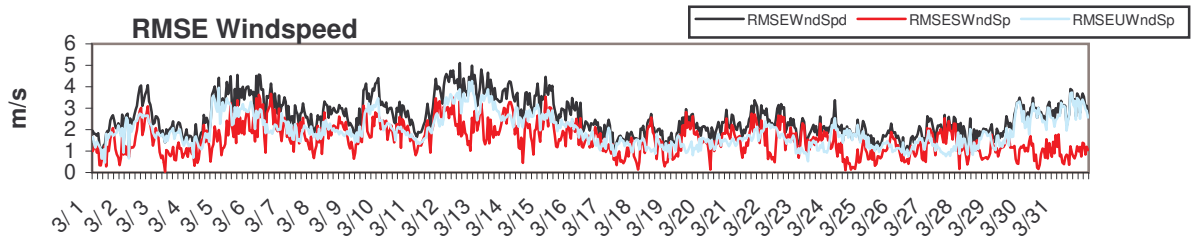


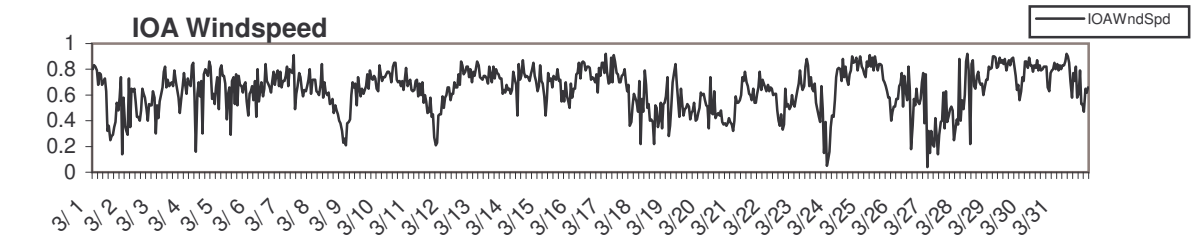


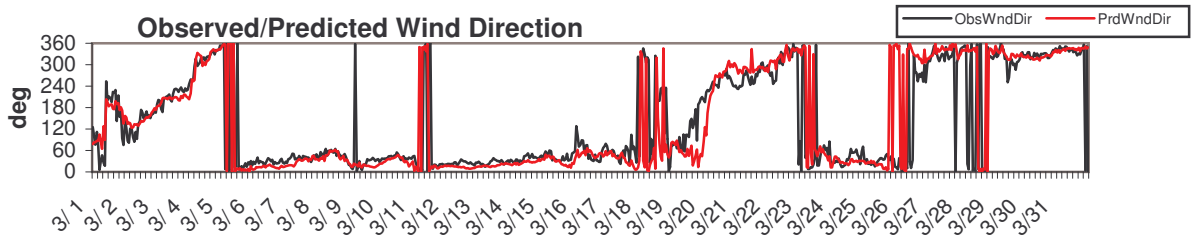
Alaska 5km 2003-03

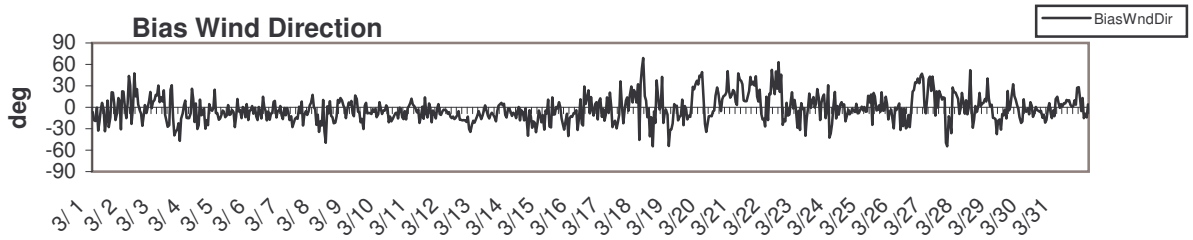




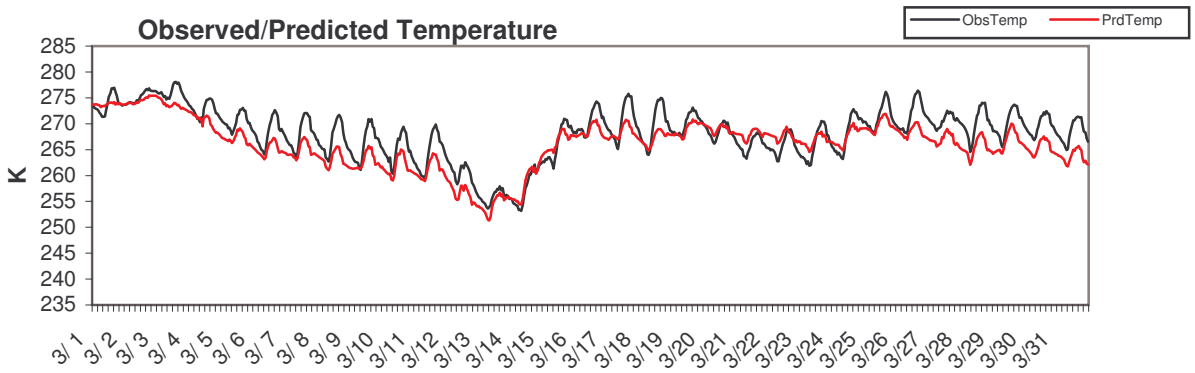


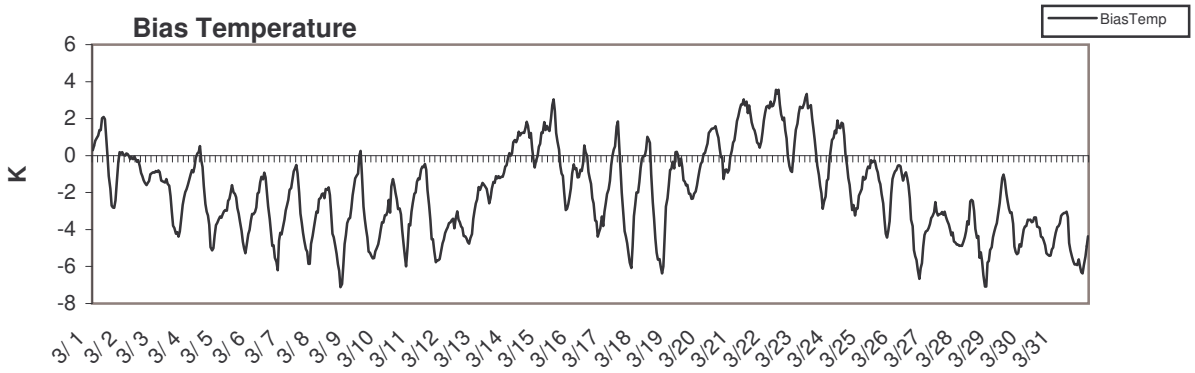


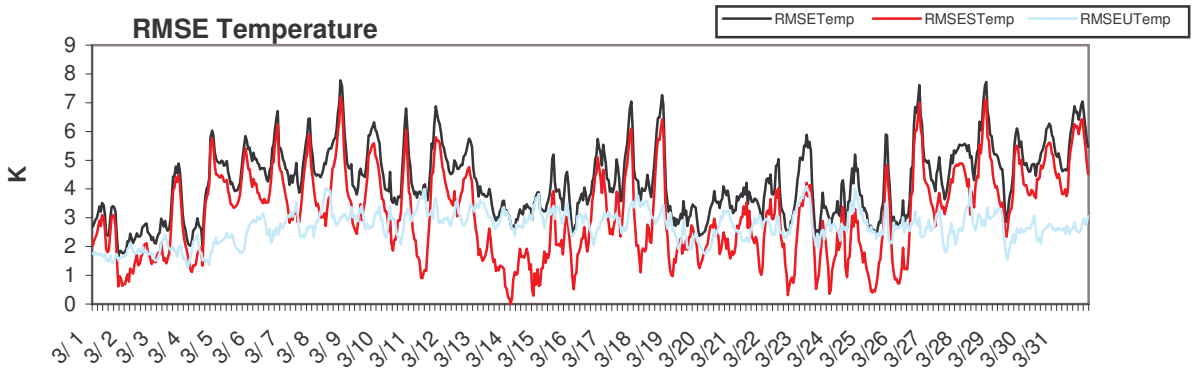


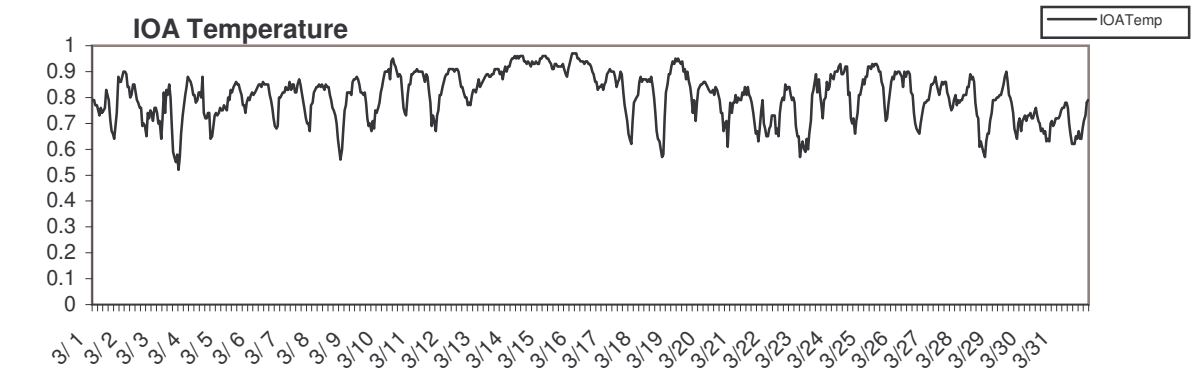


Alaska 5km 2003-03

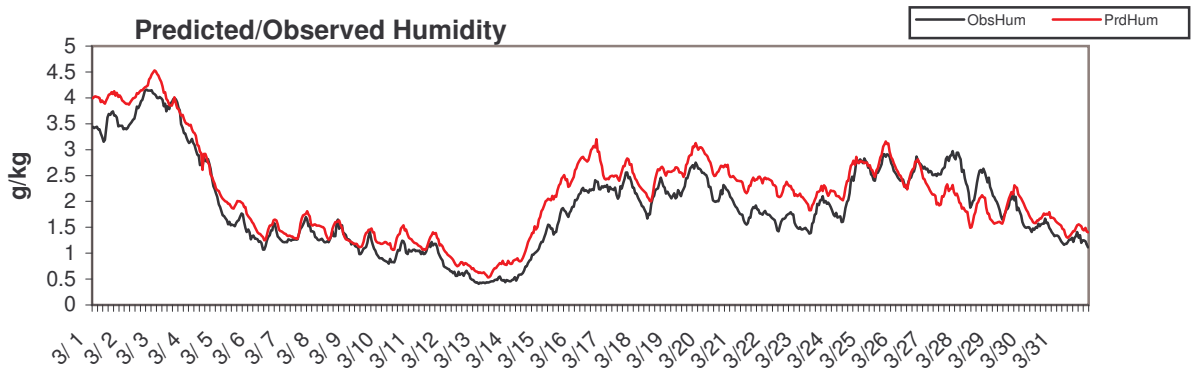


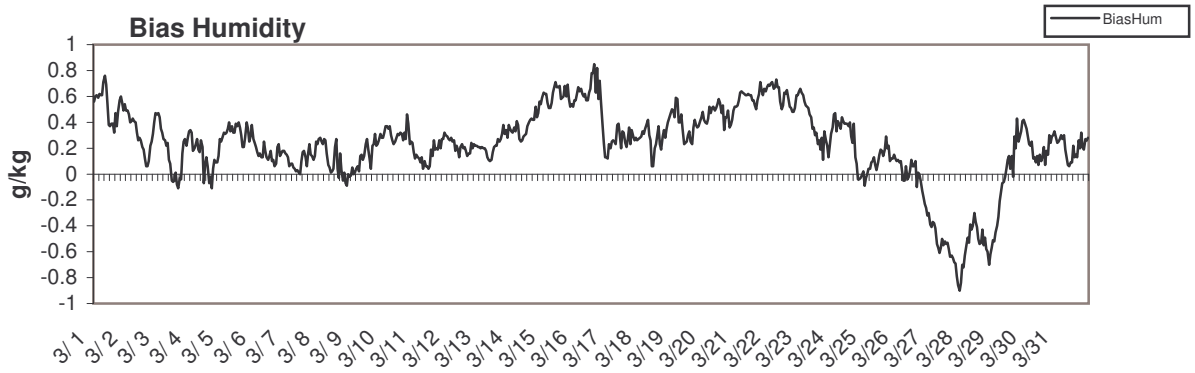


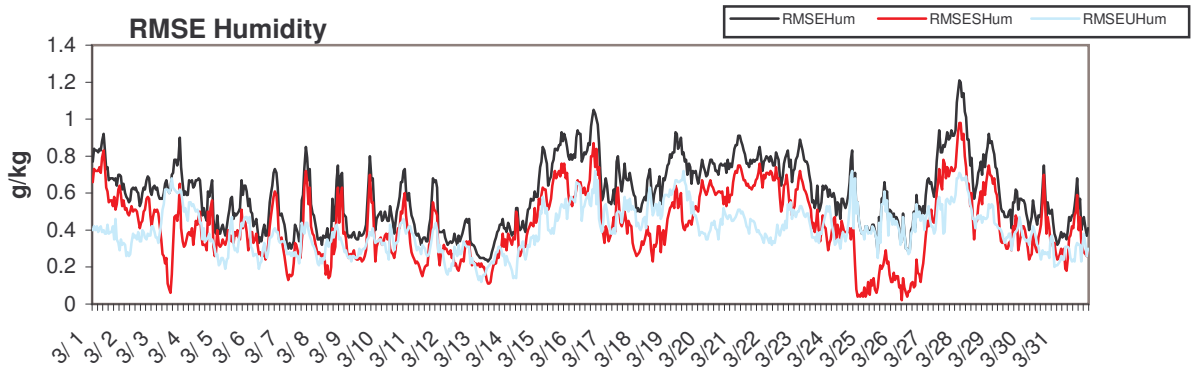


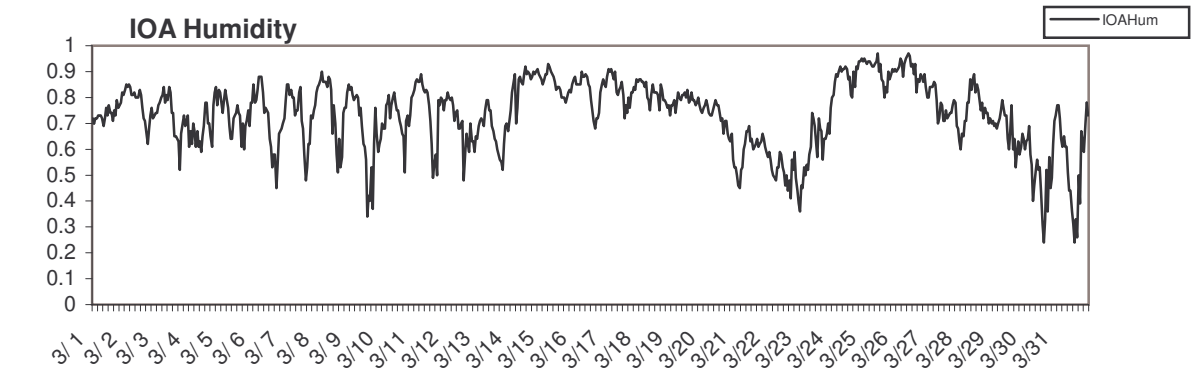


Alaska 5km 2003-03

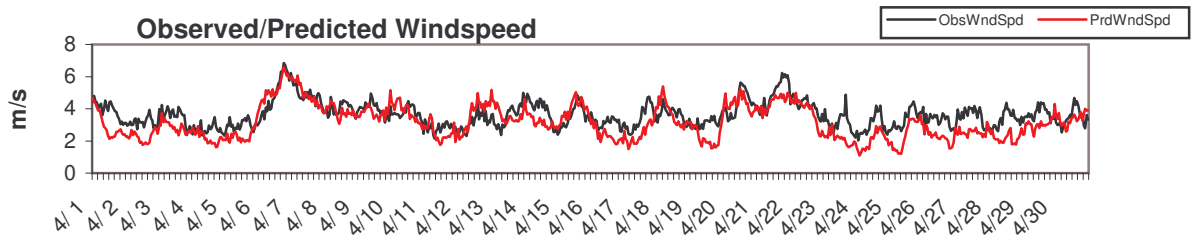


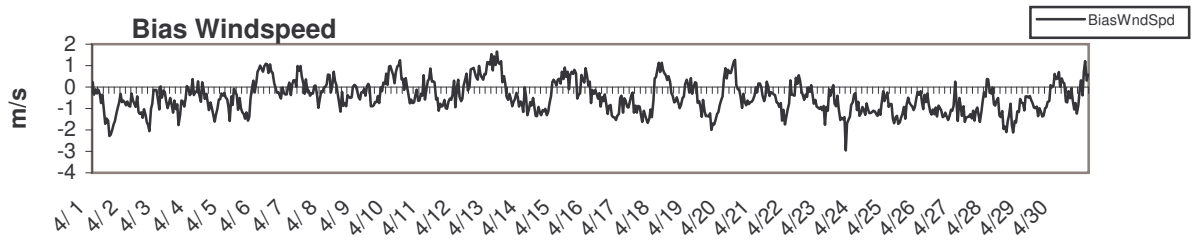


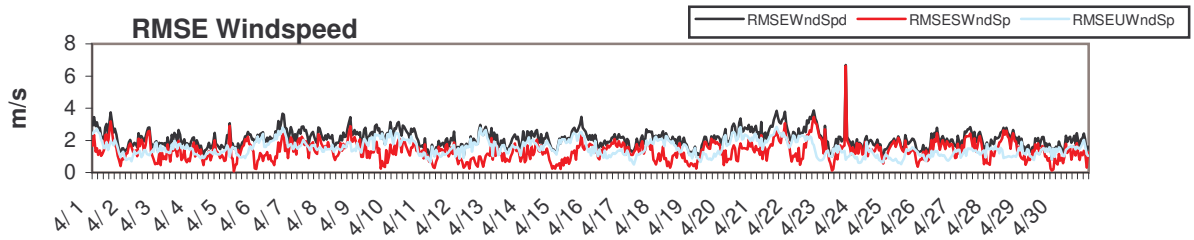


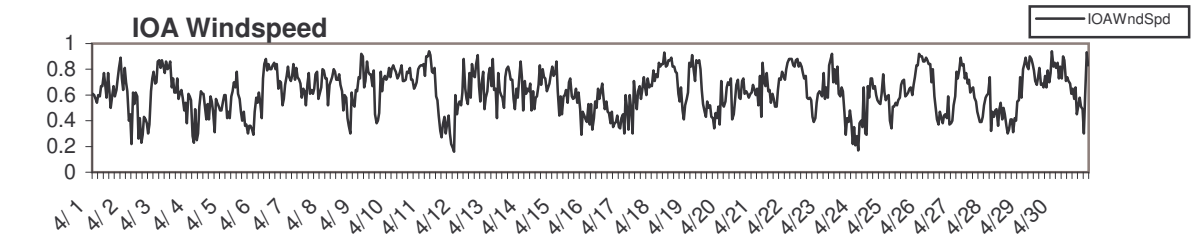


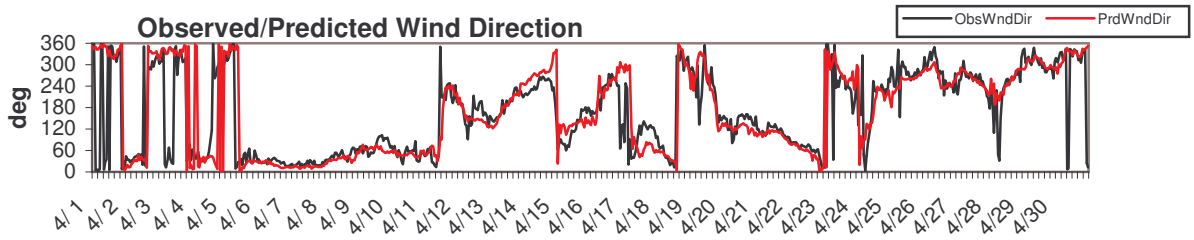
Alaska 5km 2003-04

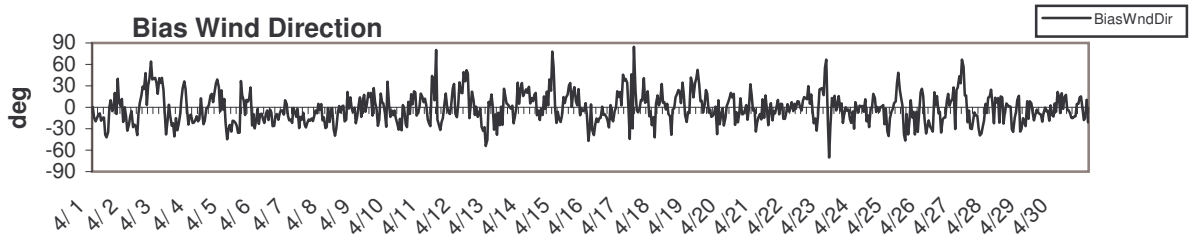




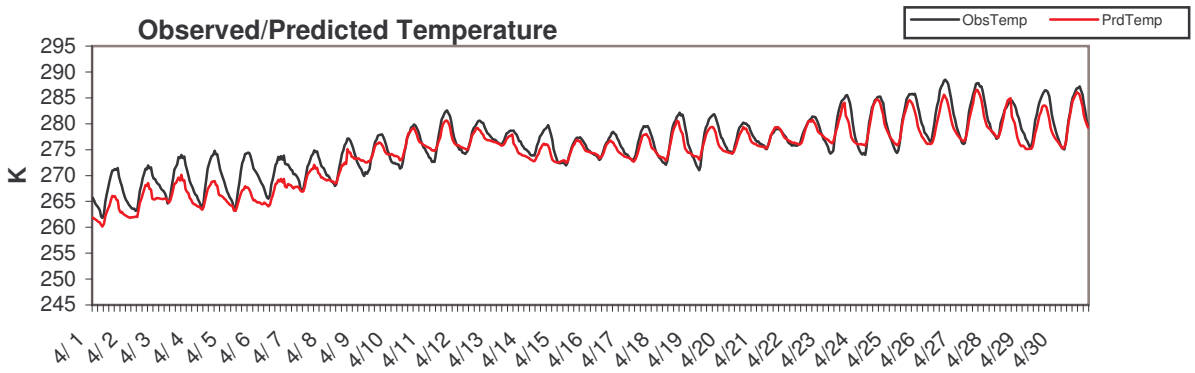


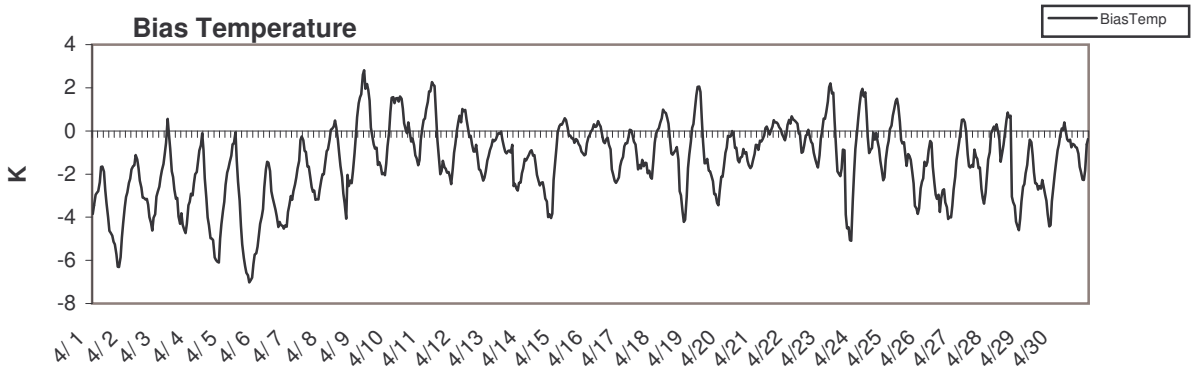


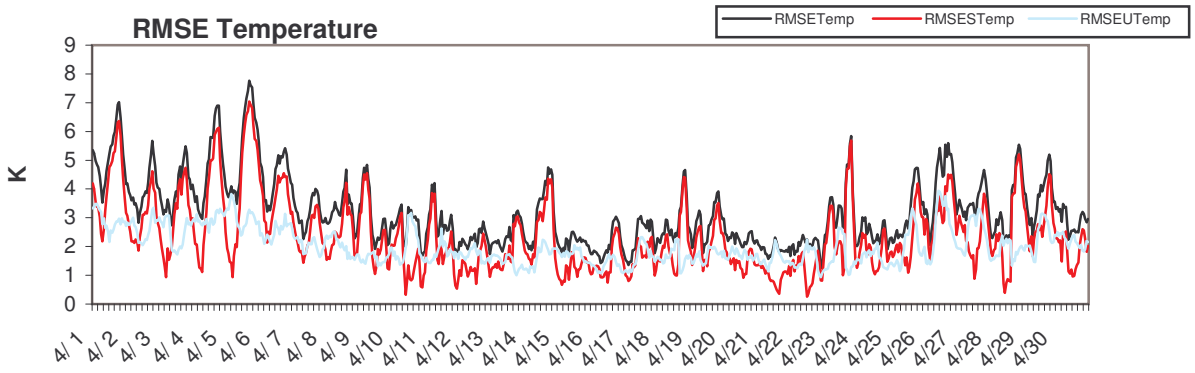


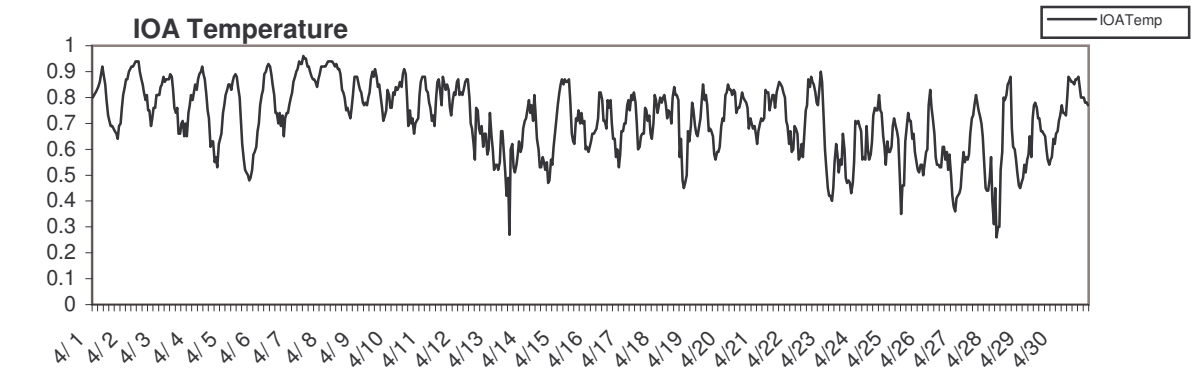


Alaska 5km 2003-04

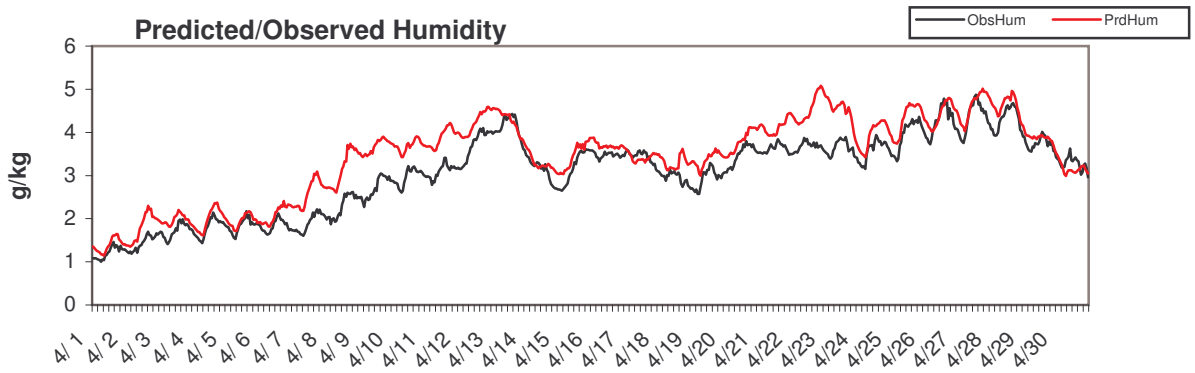


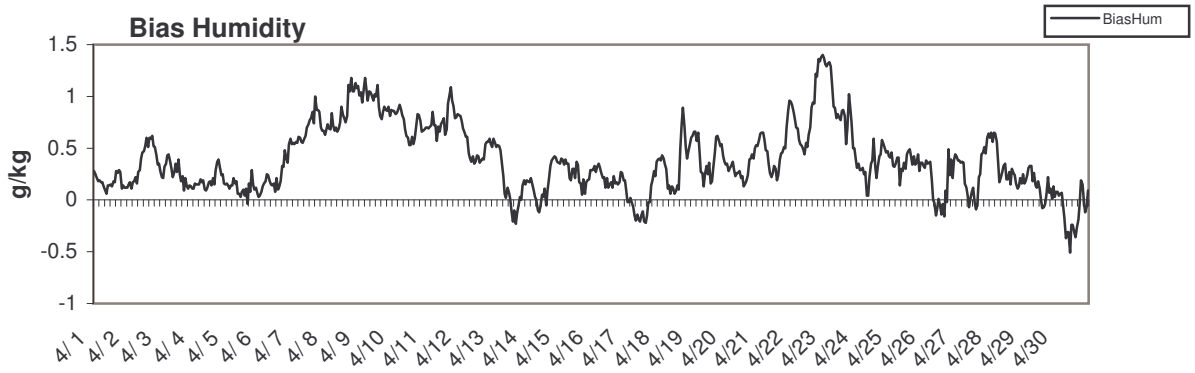


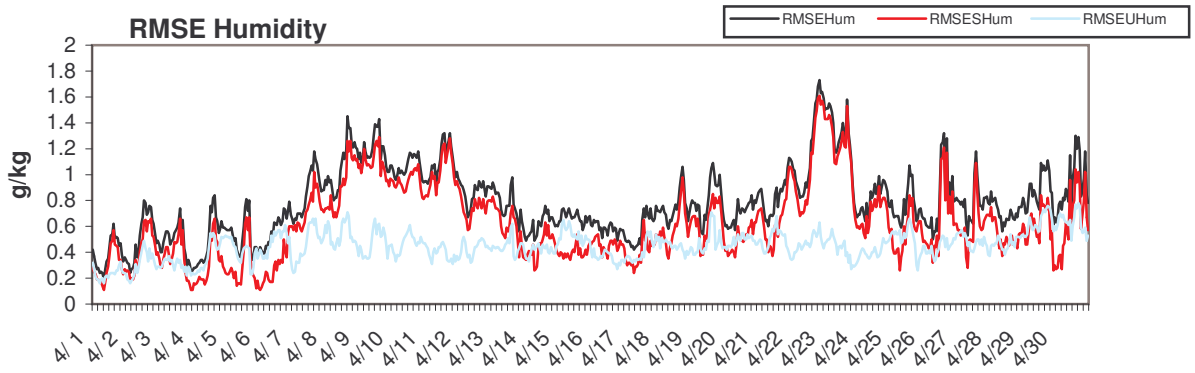


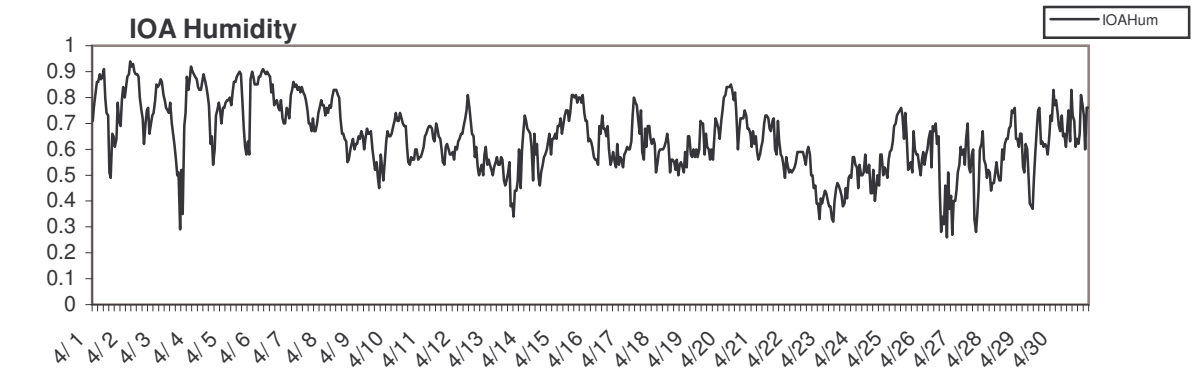


Alaska 5km 2003-04

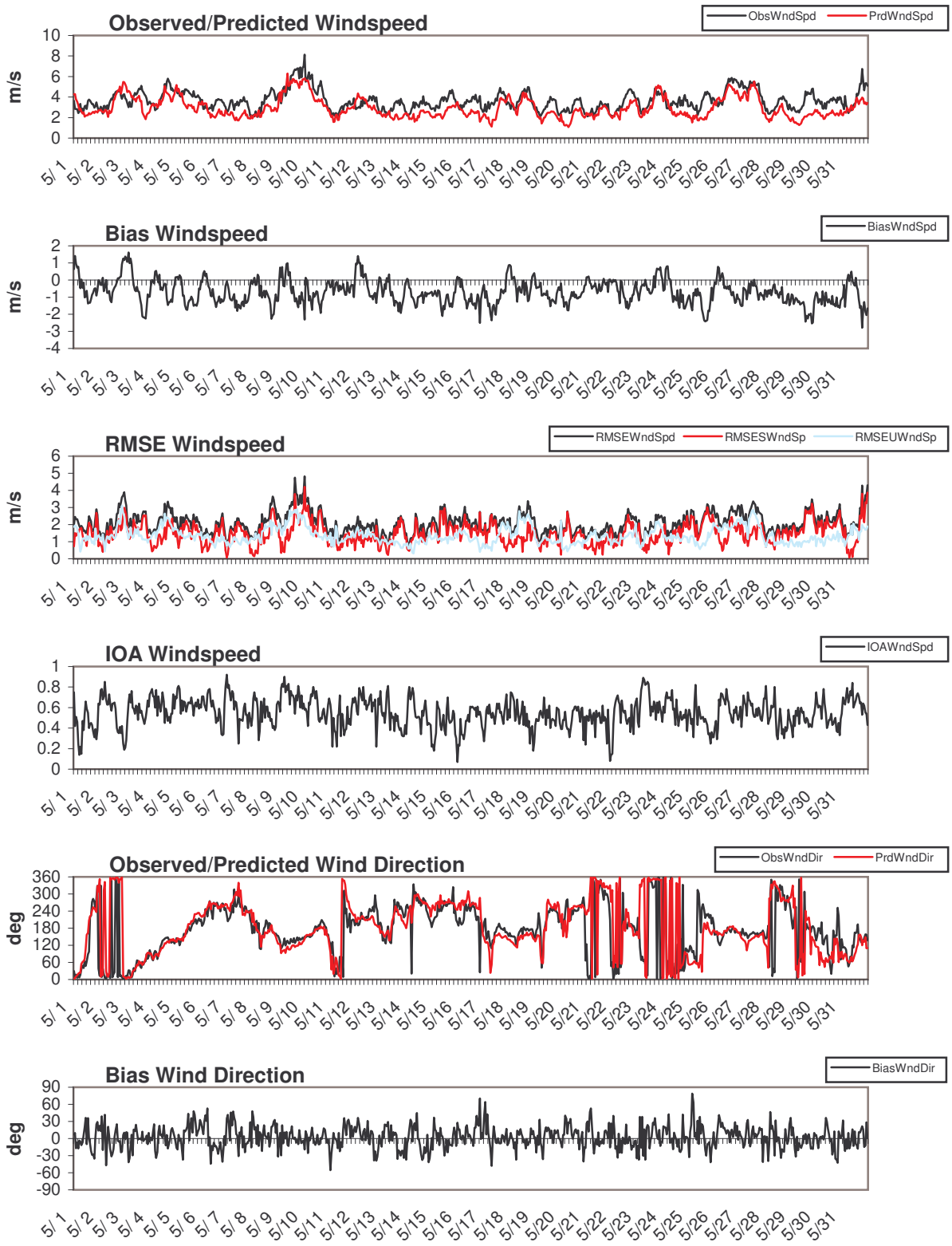




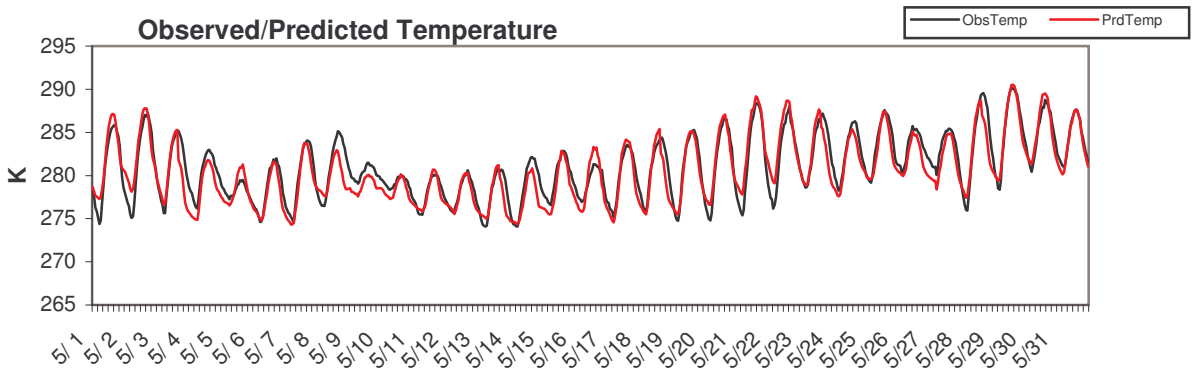


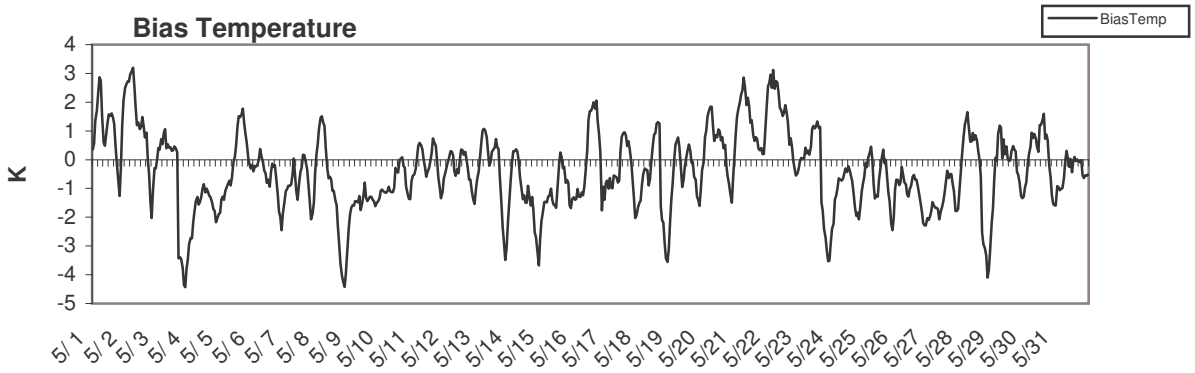


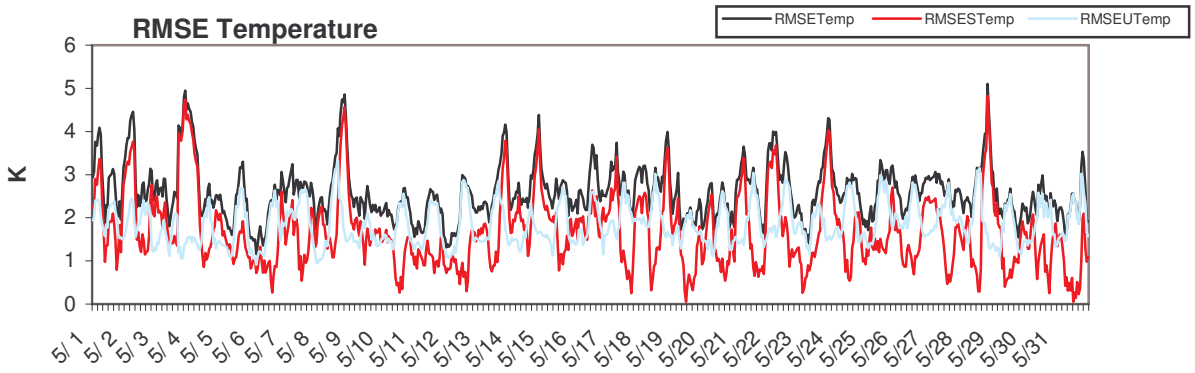
Alaska 5km 2003-05

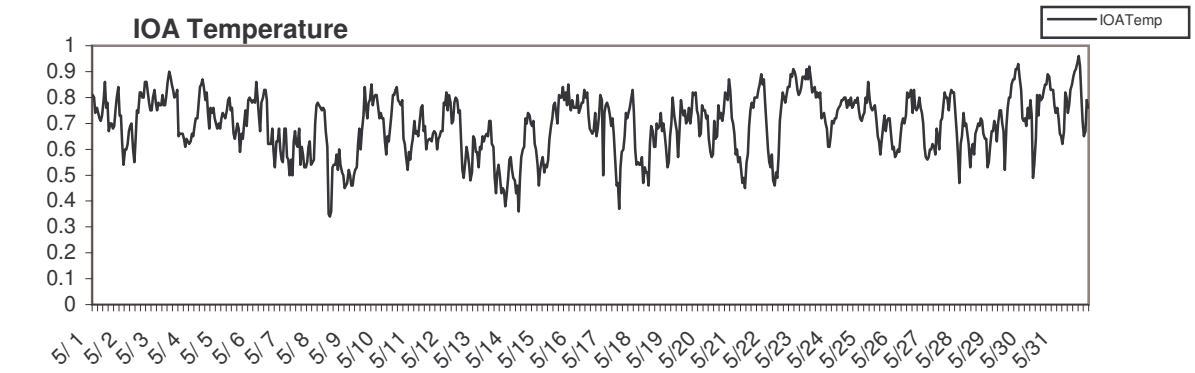


Alaska 5km 2003-05

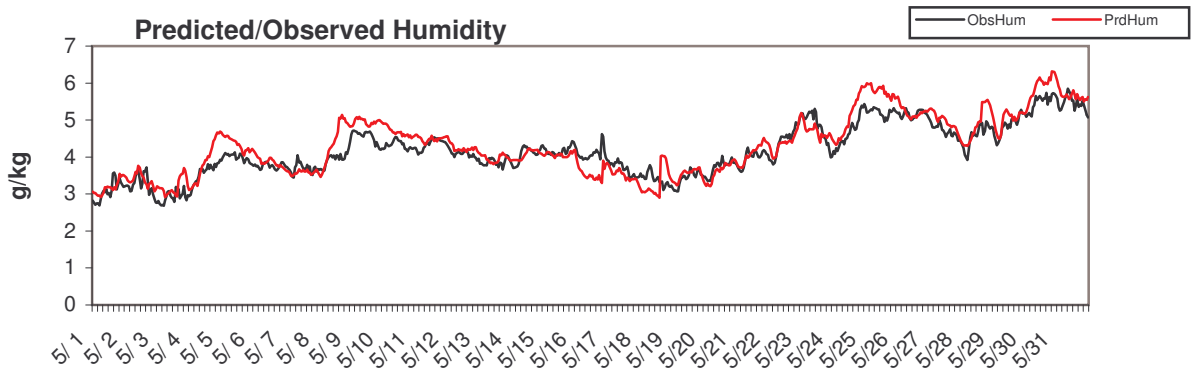


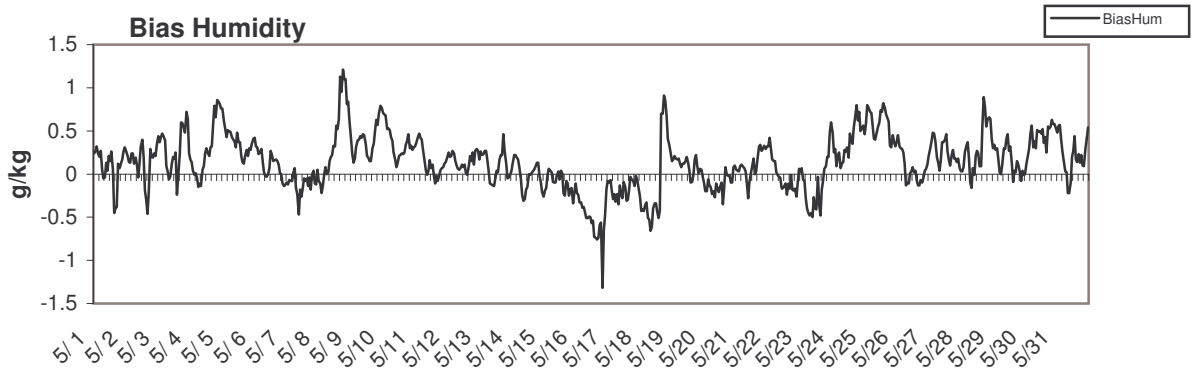


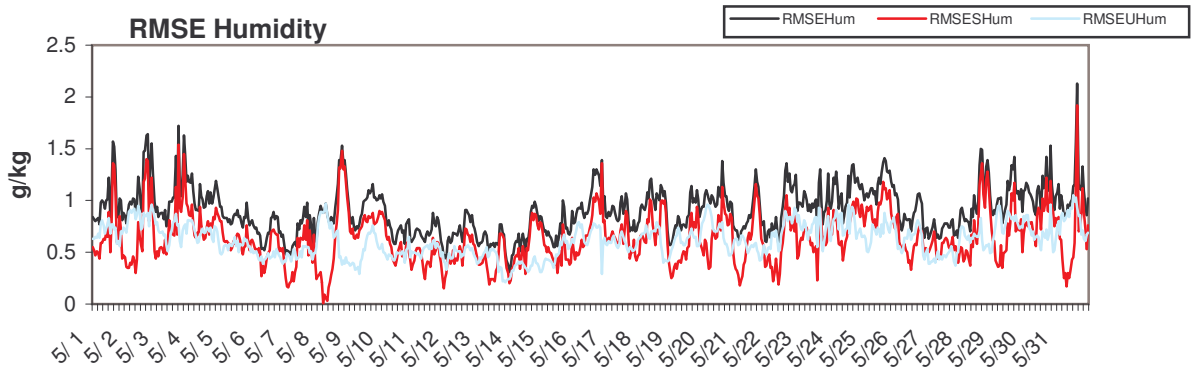


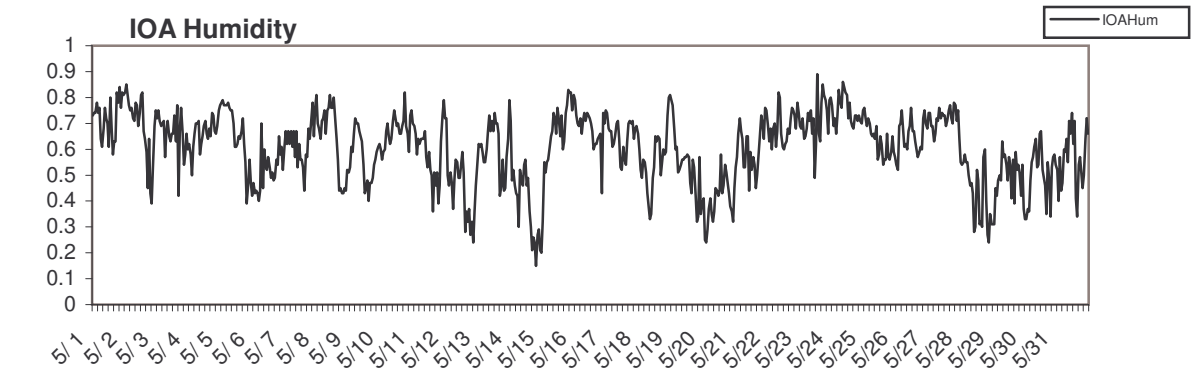


Alaska 5km 2003-05

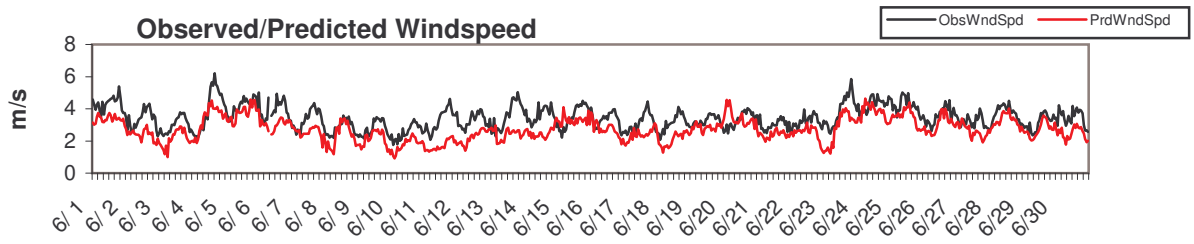


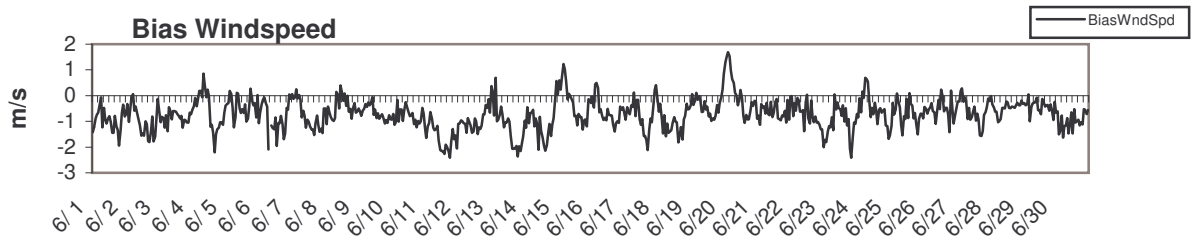


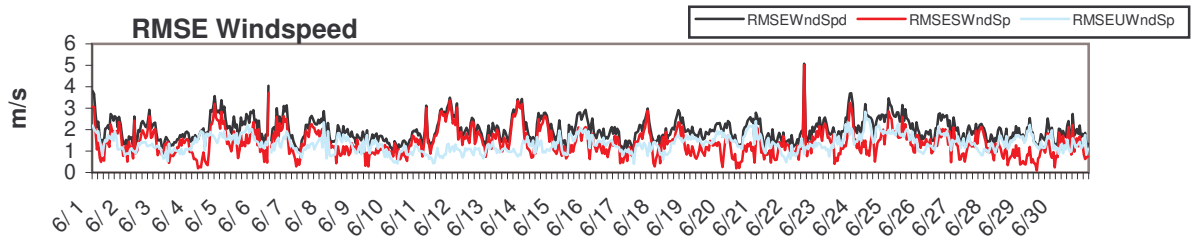


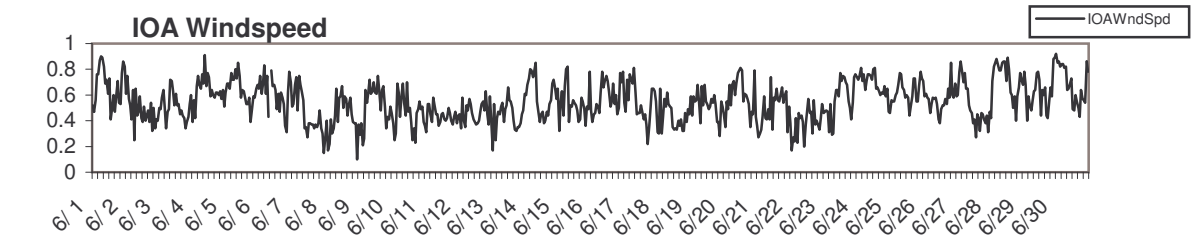


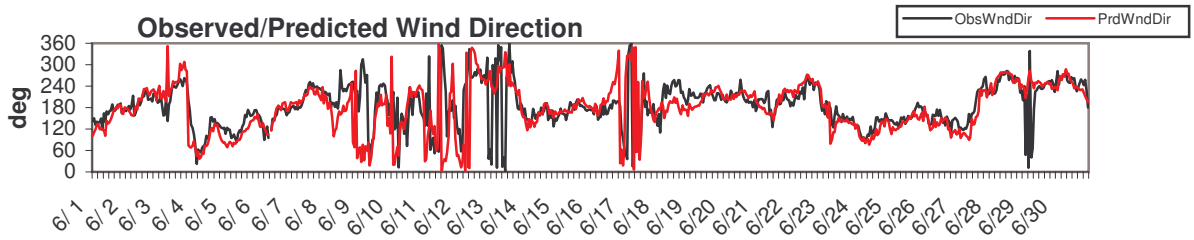
Alaska 5km 2003-06

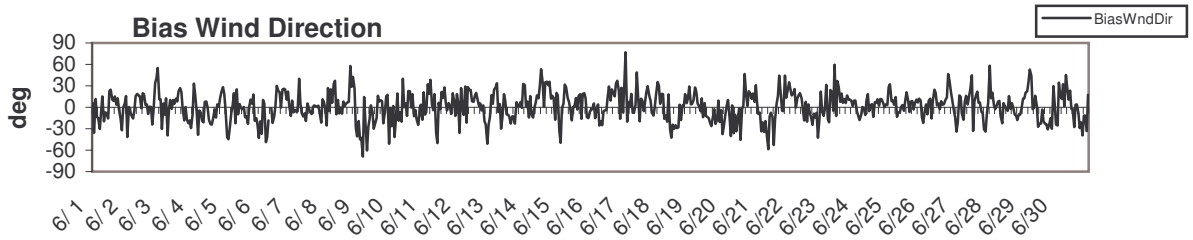




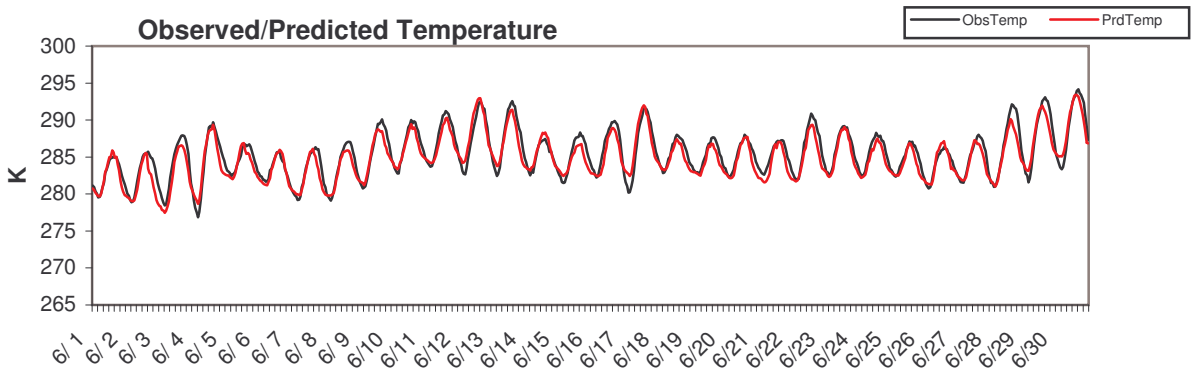


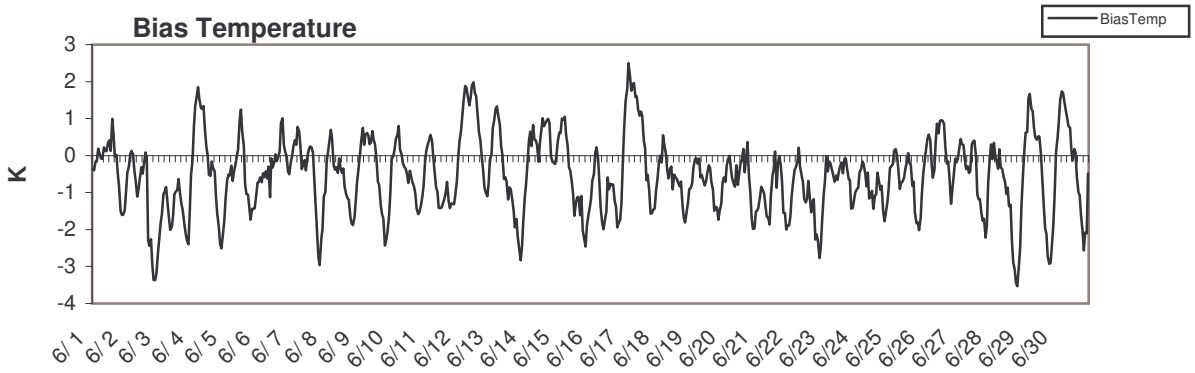


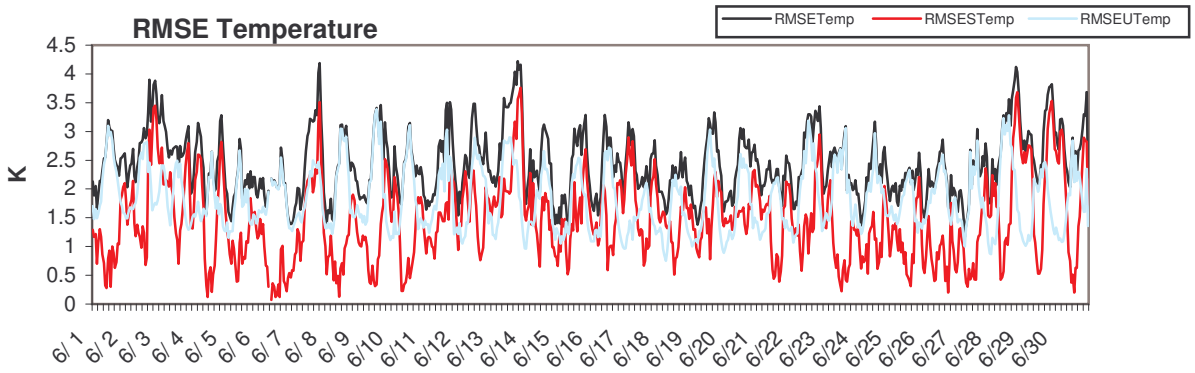


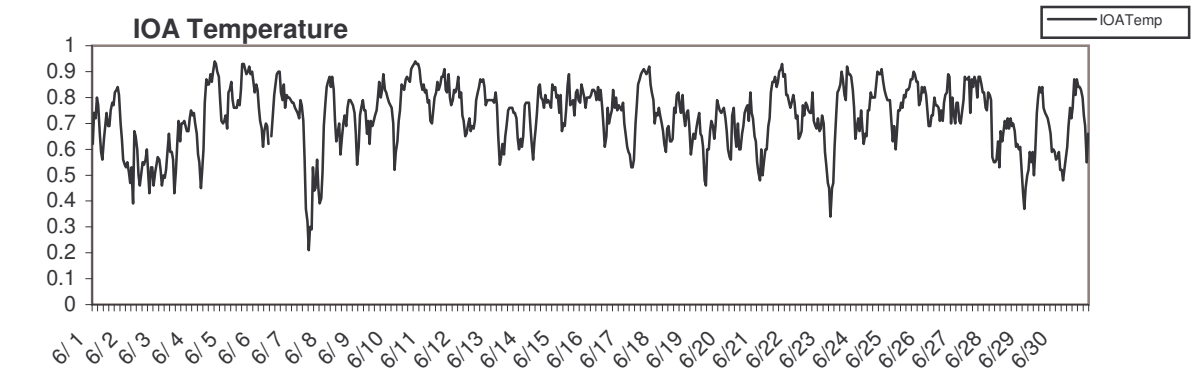


Alaska 5km 2003-06

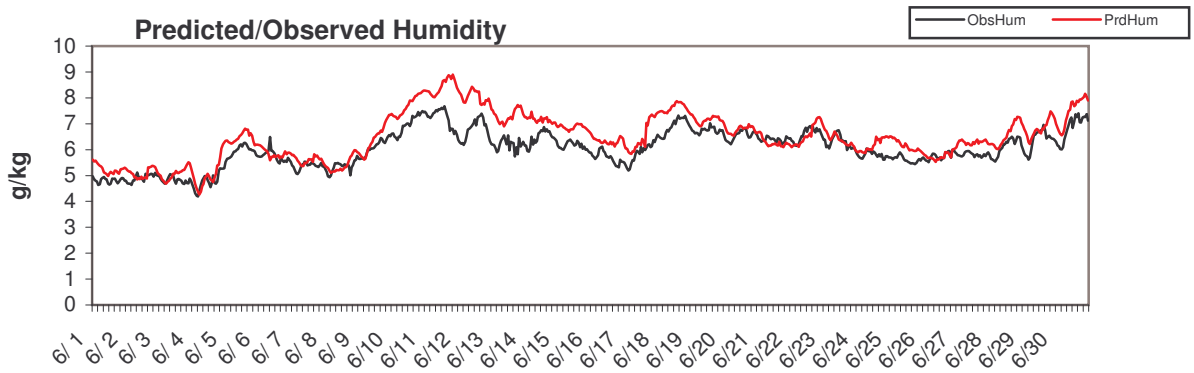


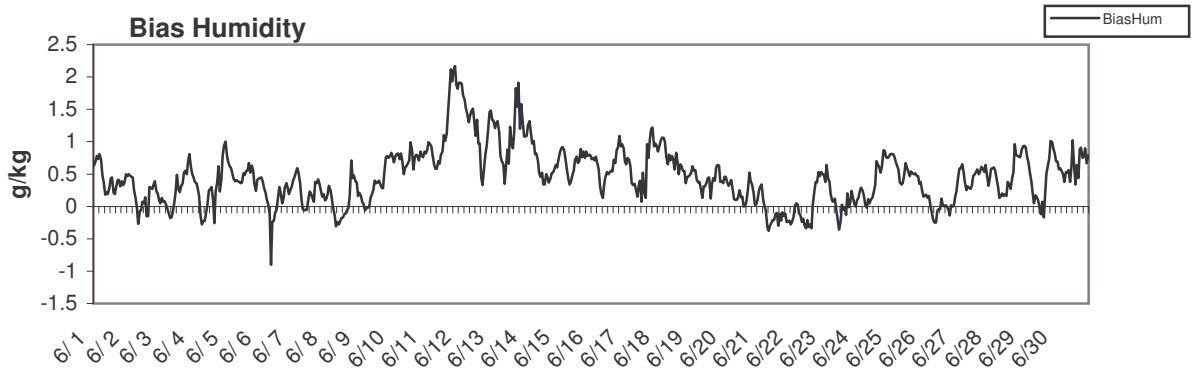


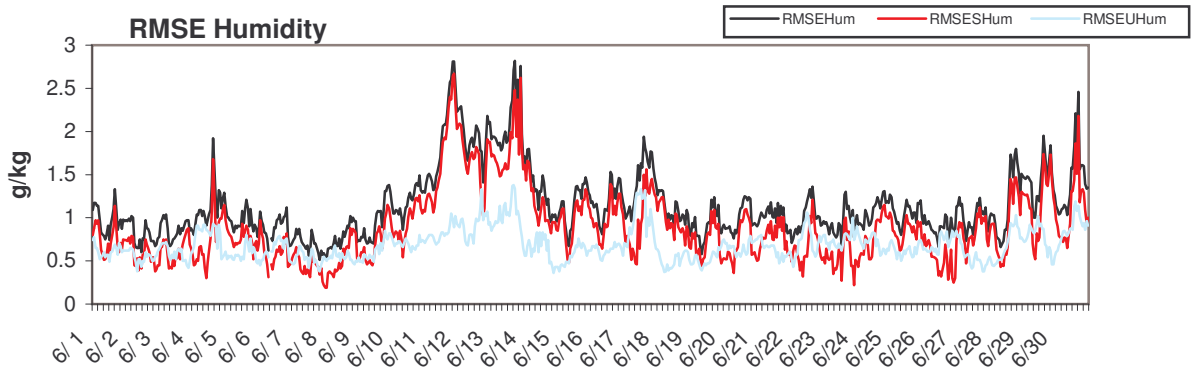


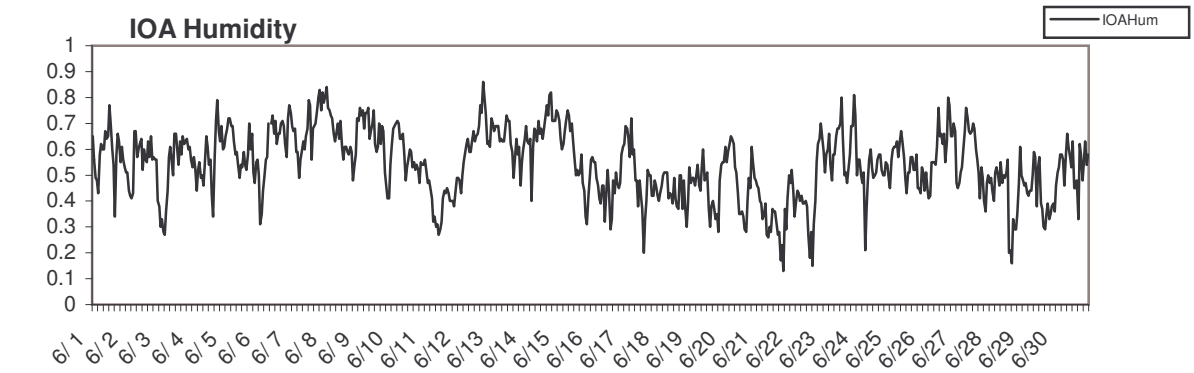


Alaska 5km 2003-06

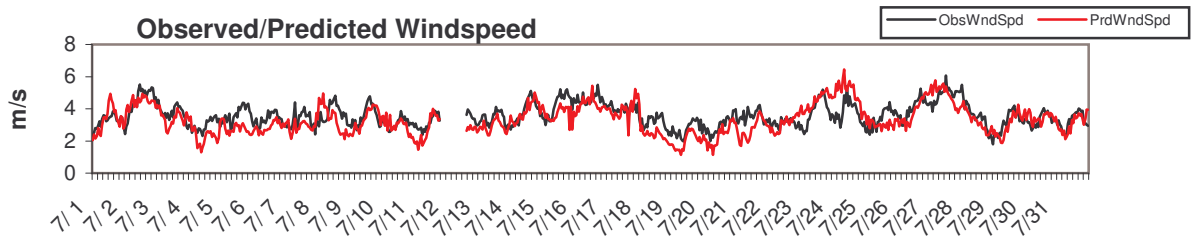


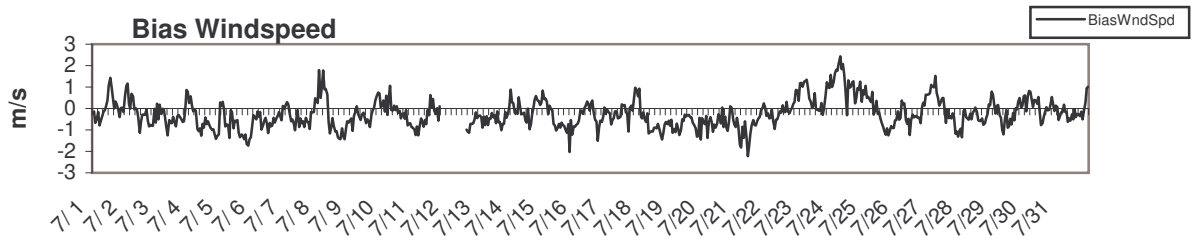


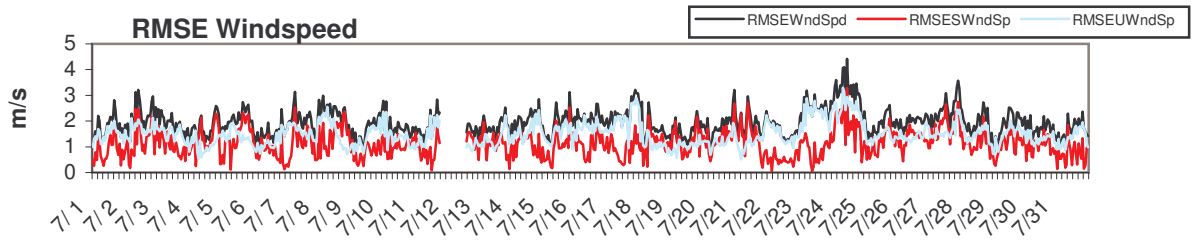


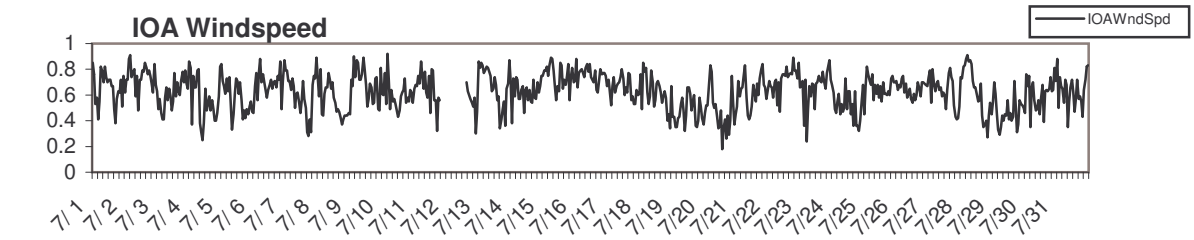


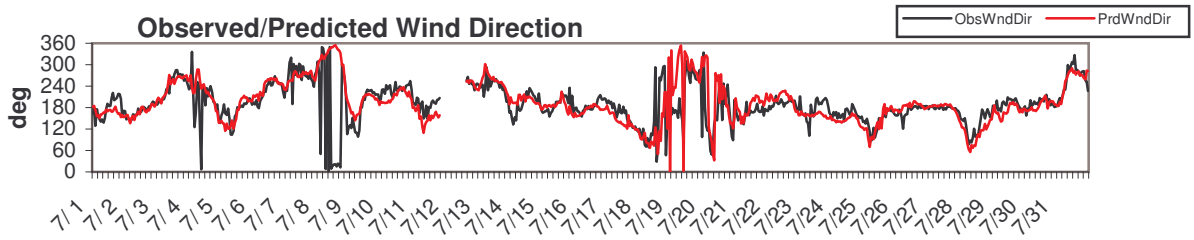
Alaska 5km 2003-07

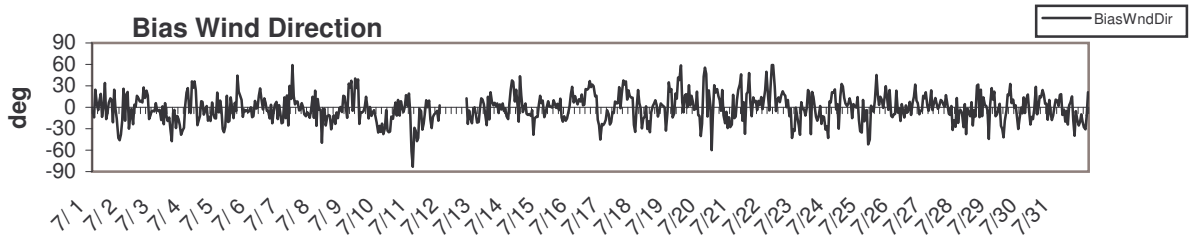




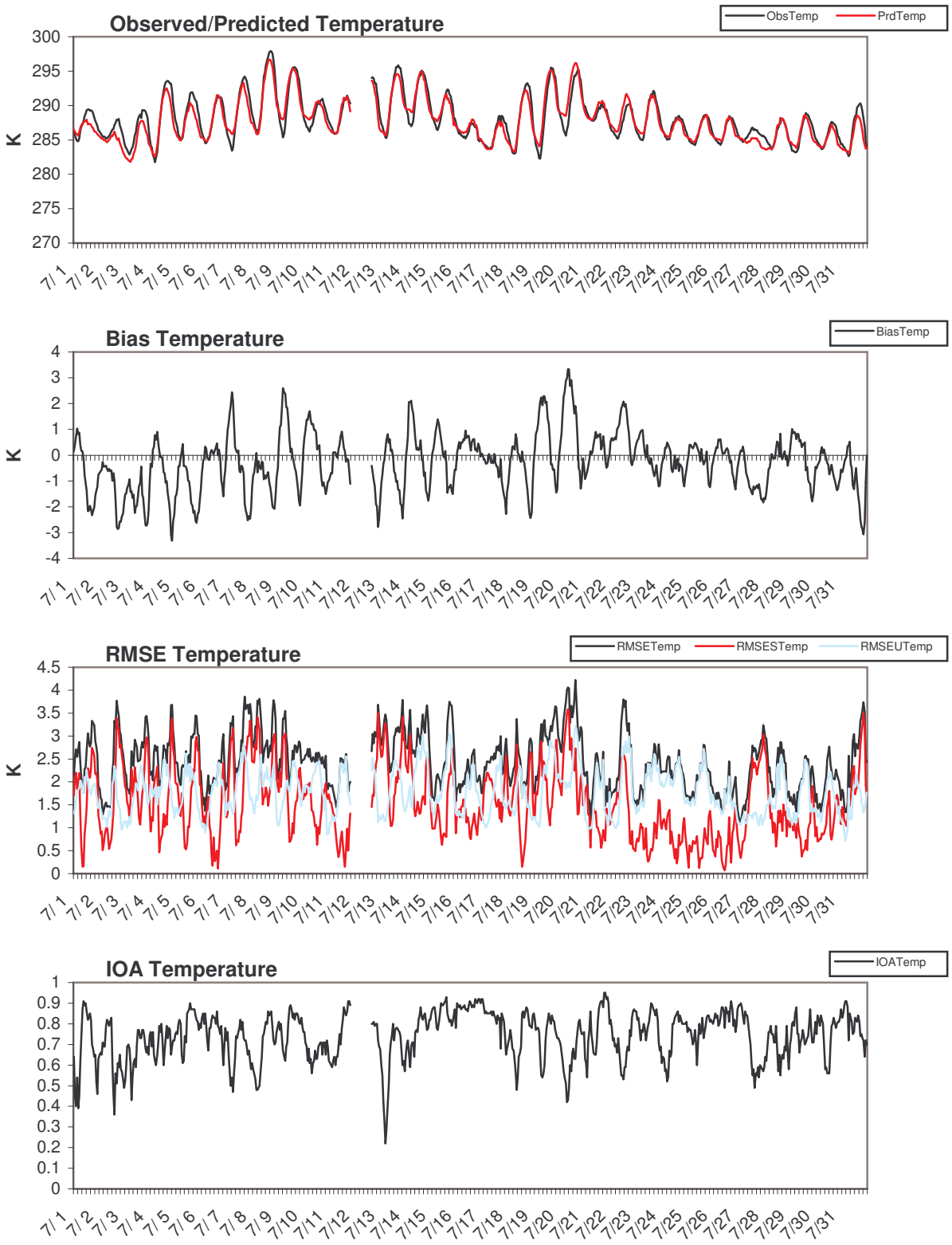




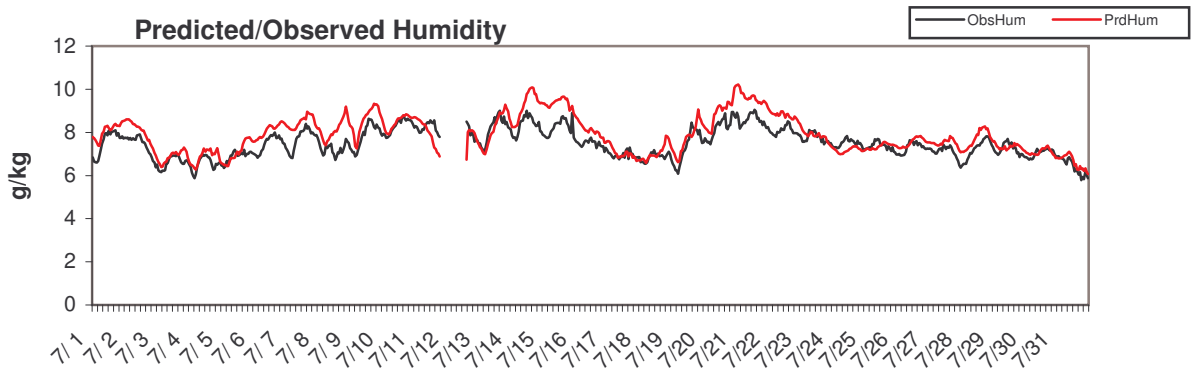


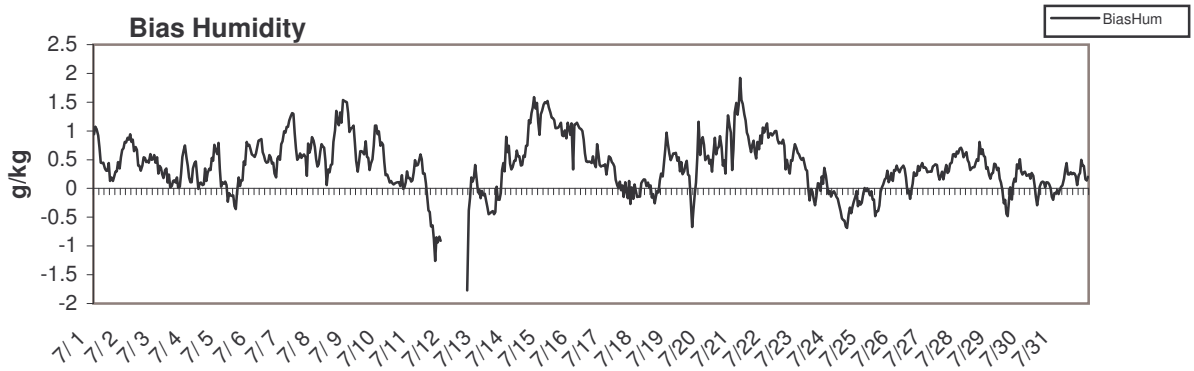


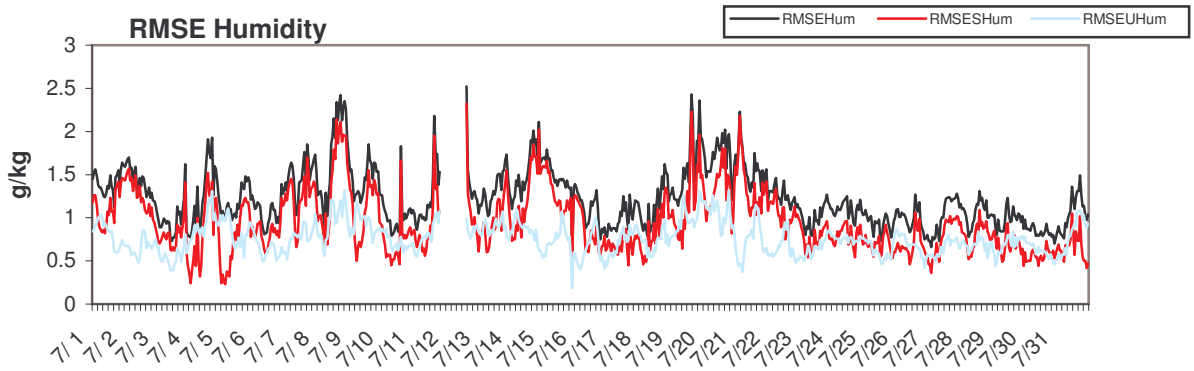
Alaska 5km 2003-07

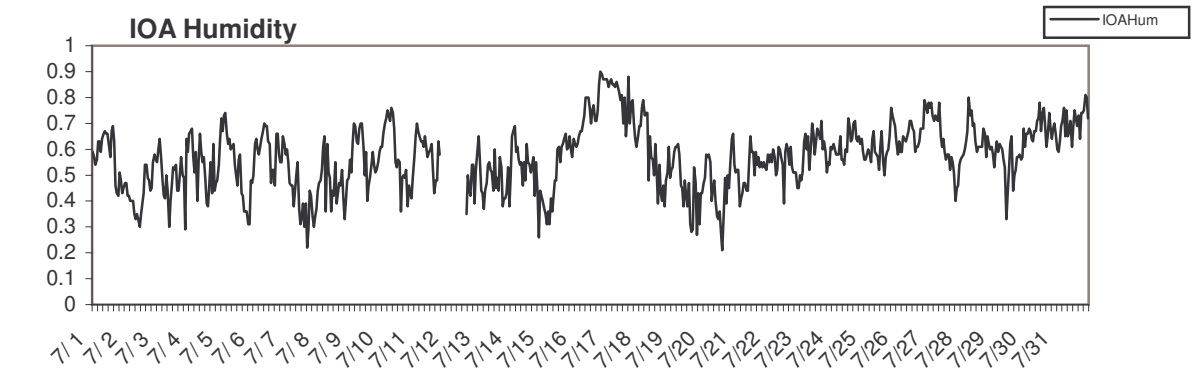


Alaska 5km 2003-07

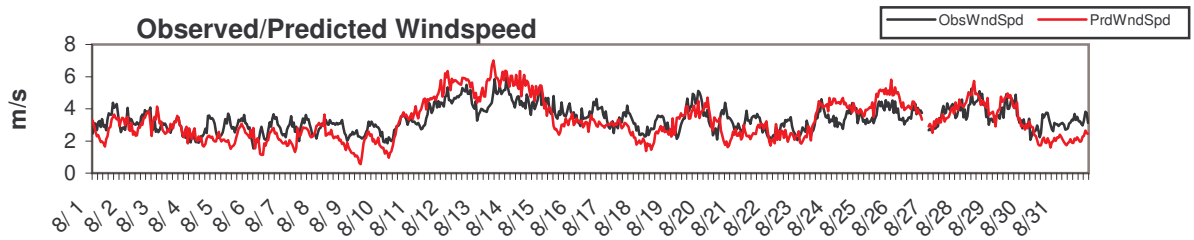


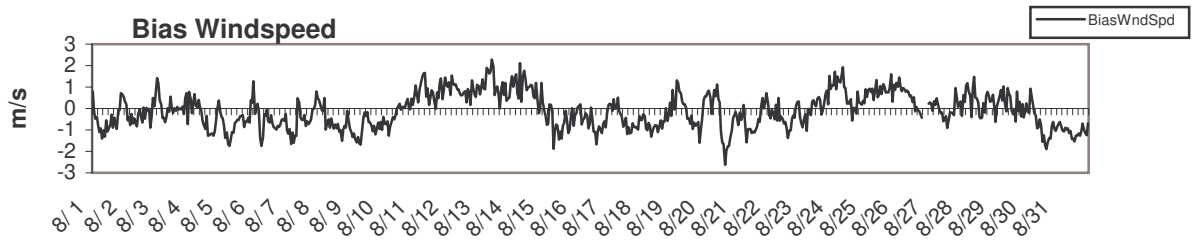


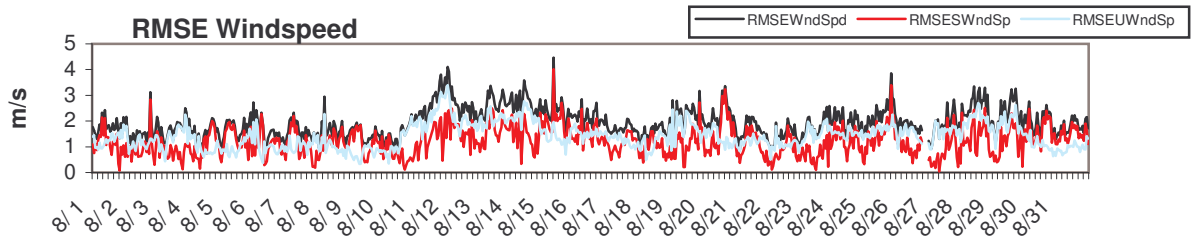


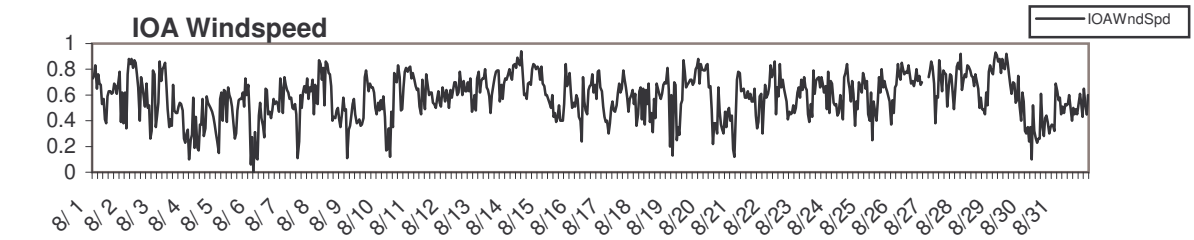


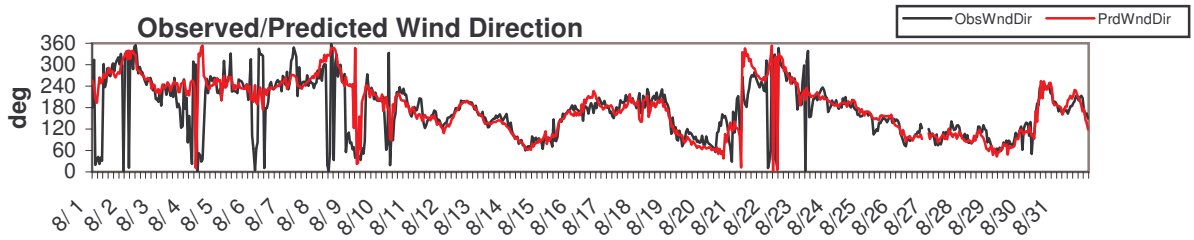
Alaska 5km 2003-08

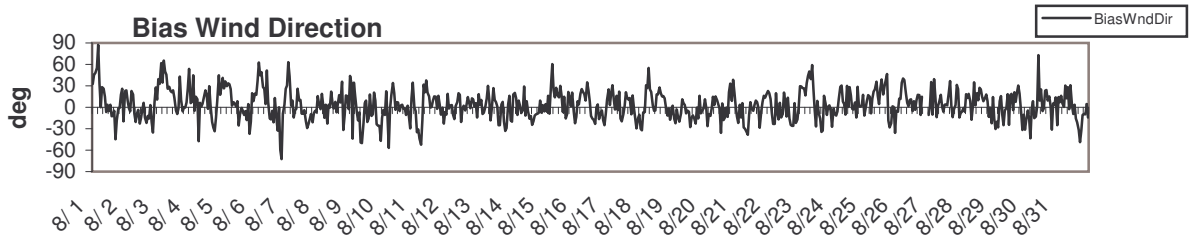




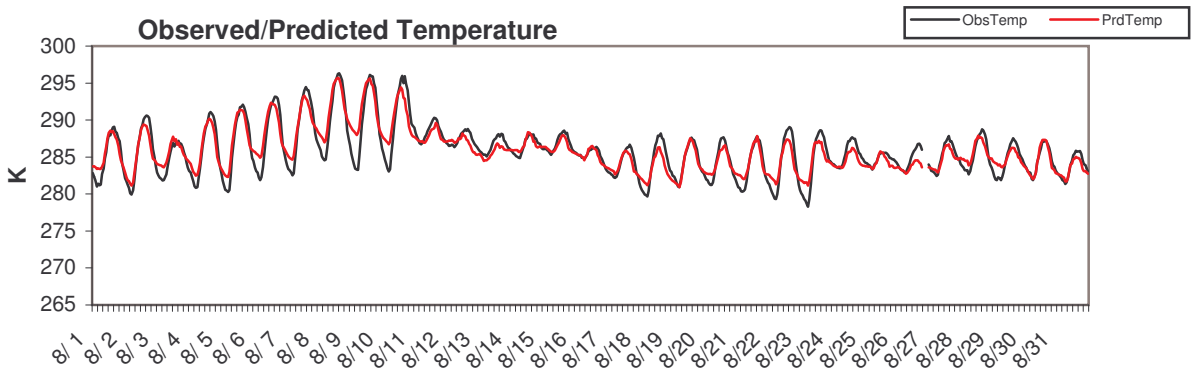


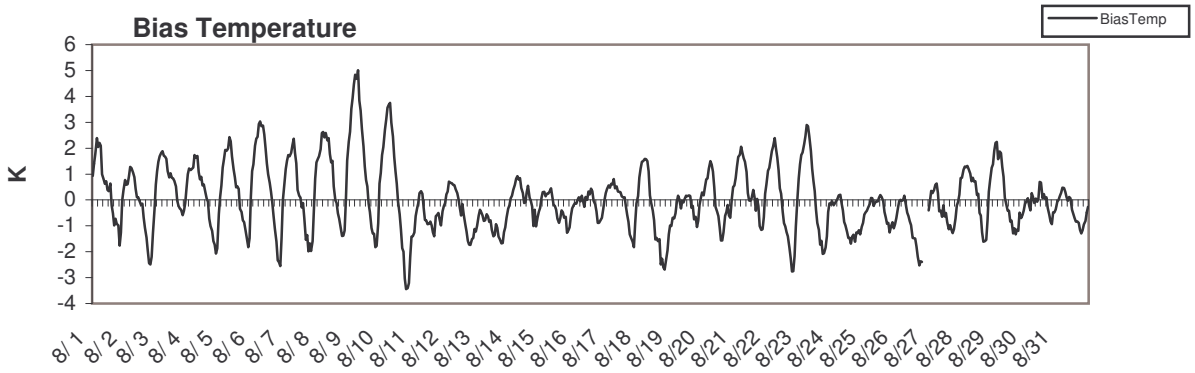


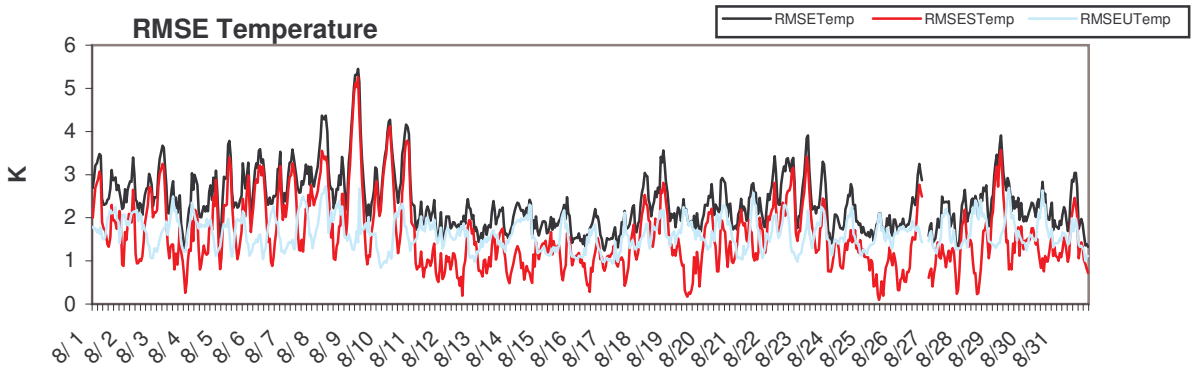


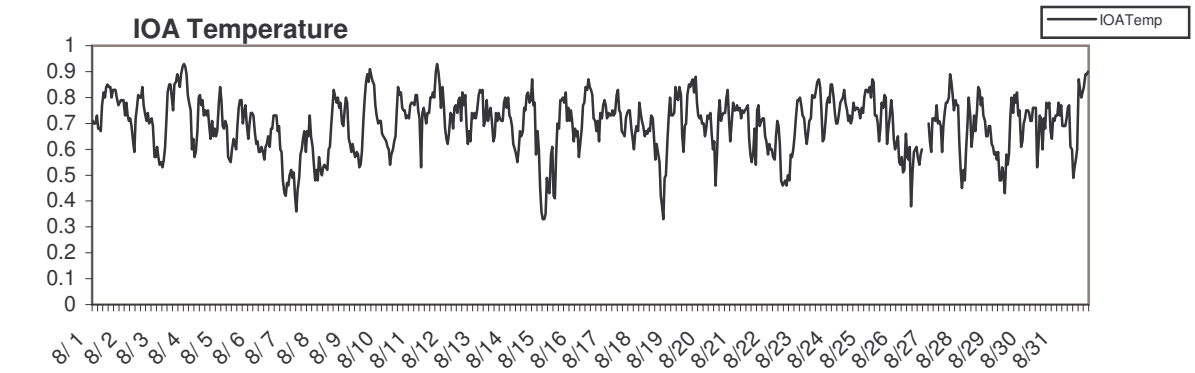


Alaska 5km 2003-08

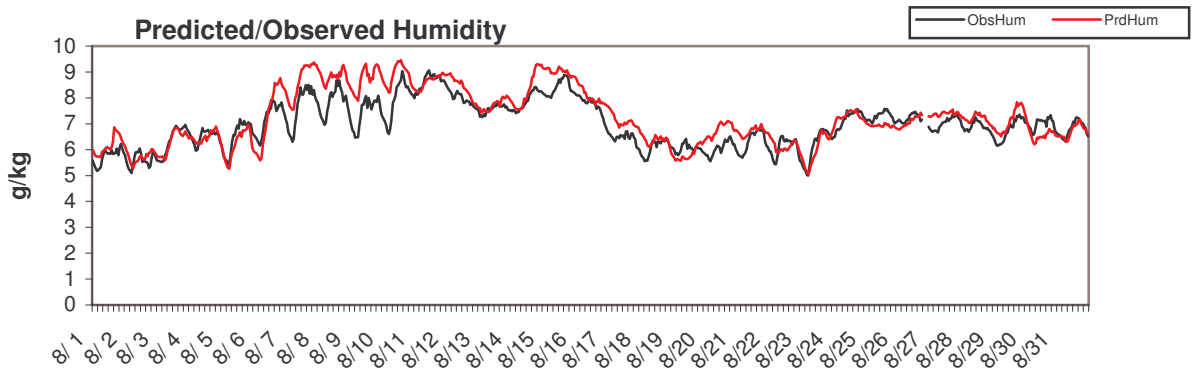


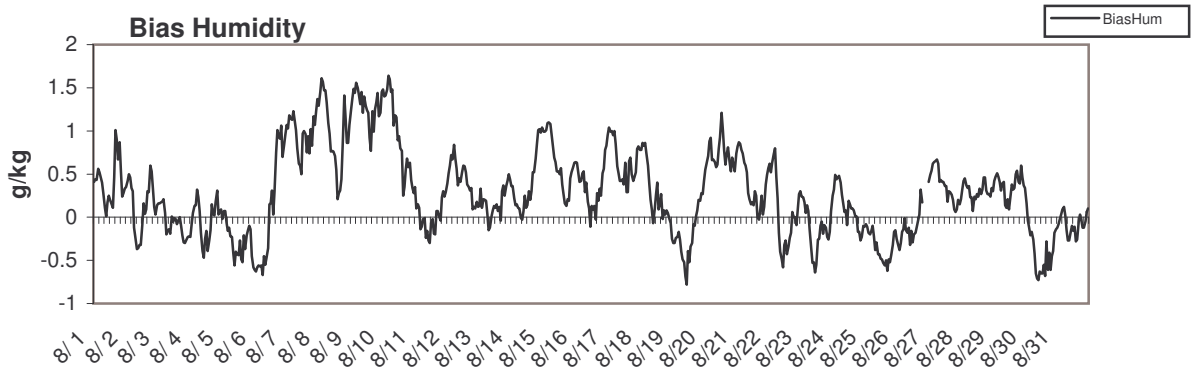


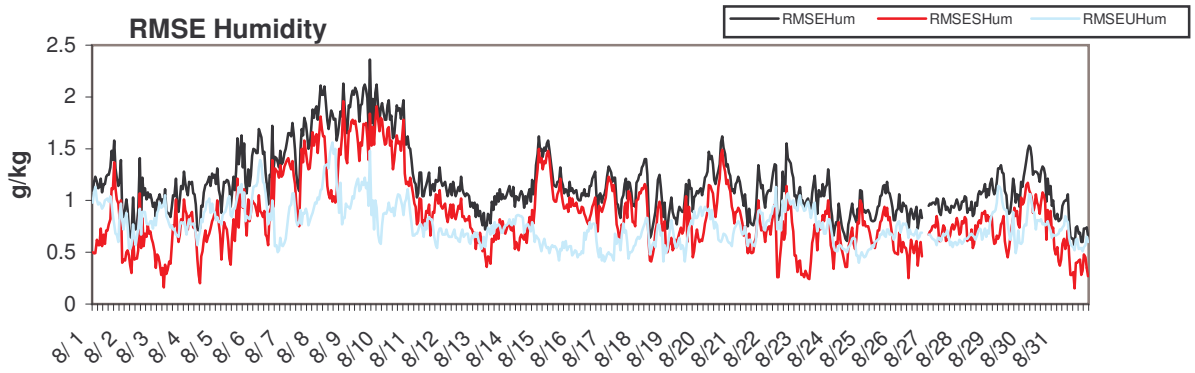


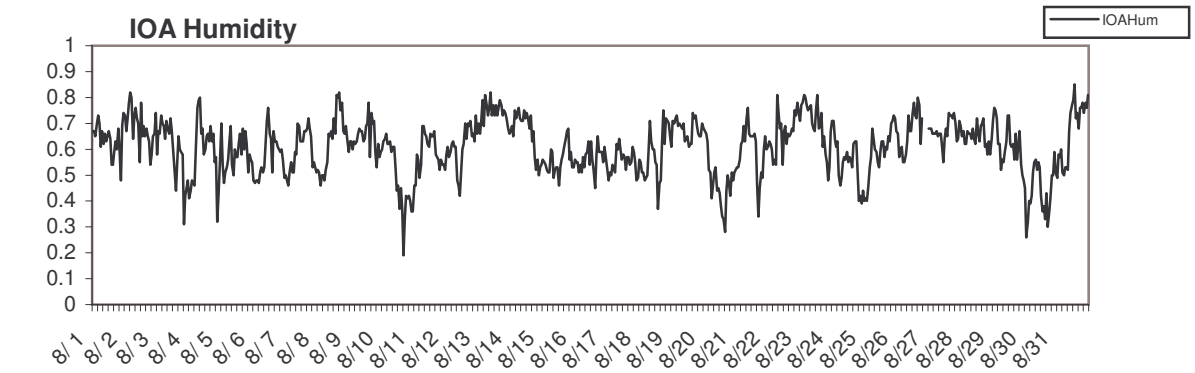


Alaska 5km 2003-08

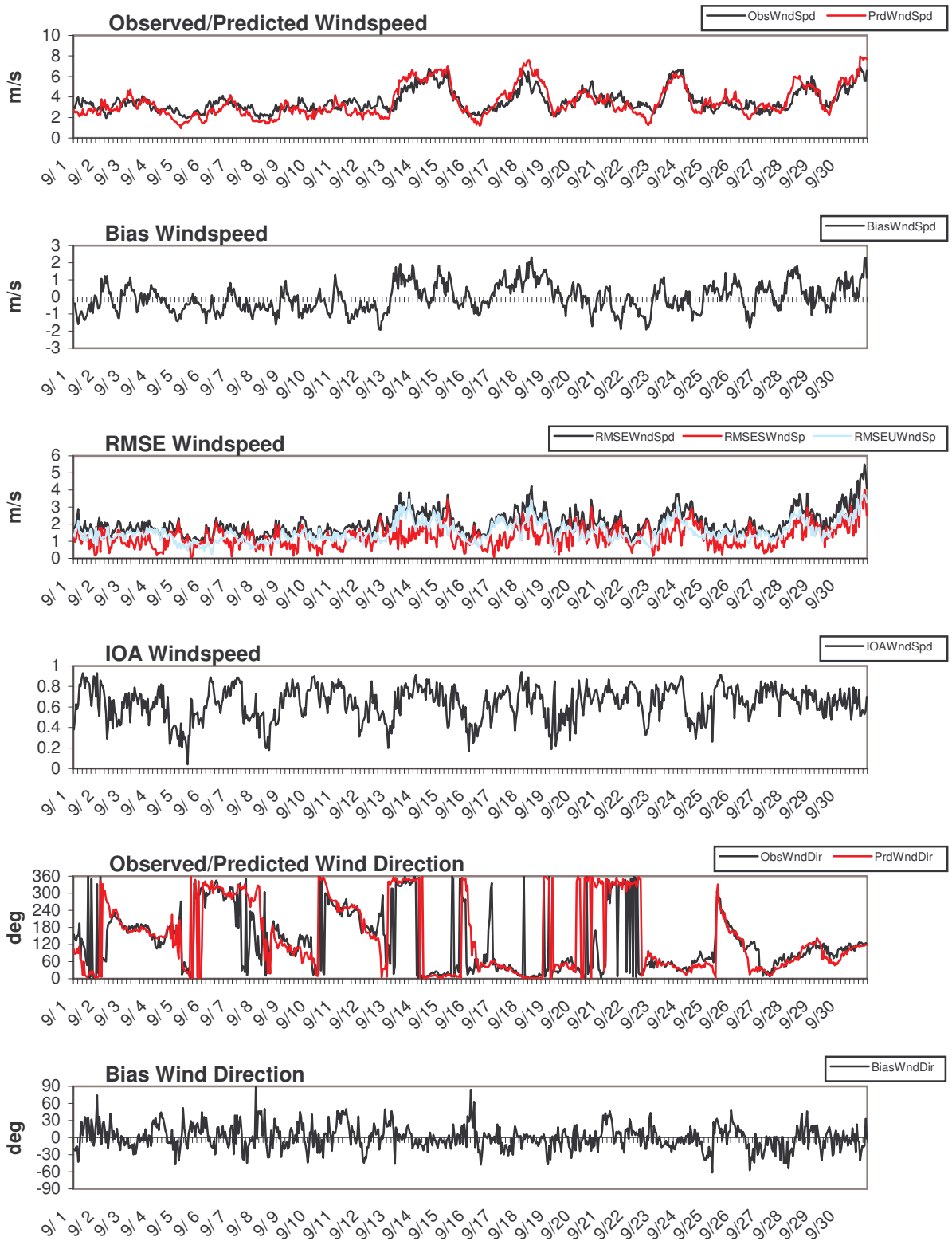








Alaska 5km 2003-09



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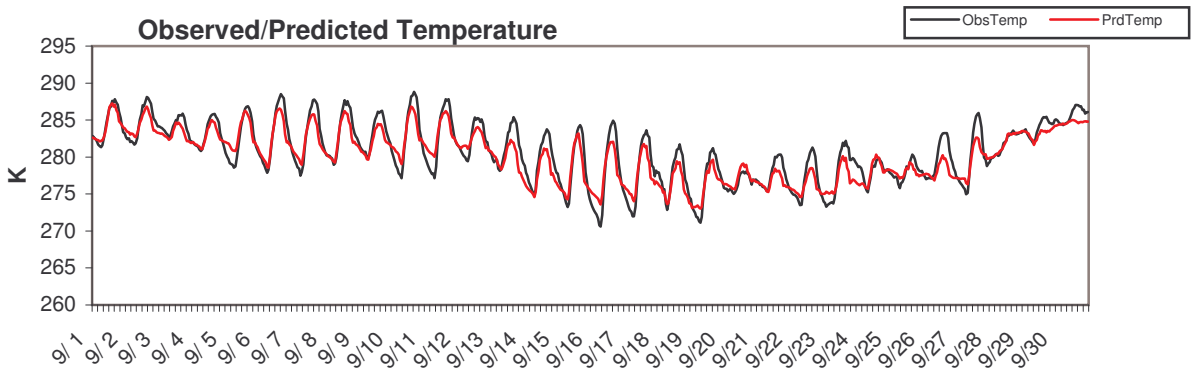

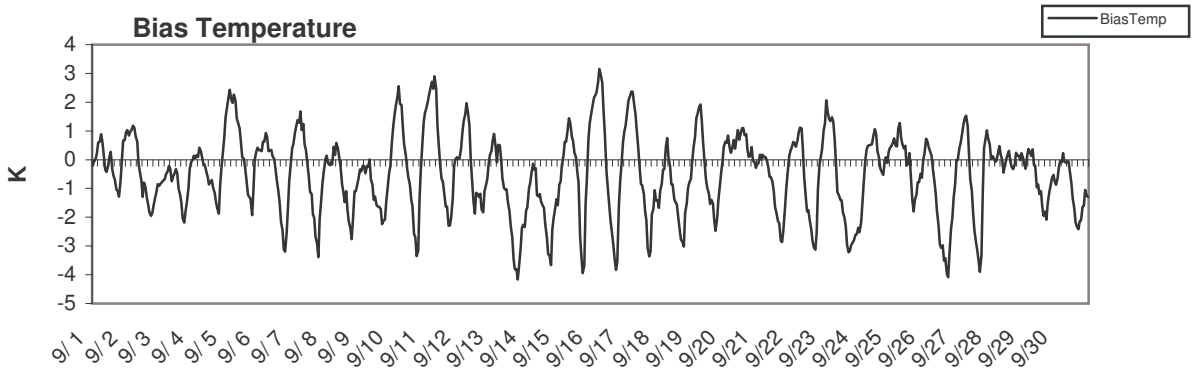

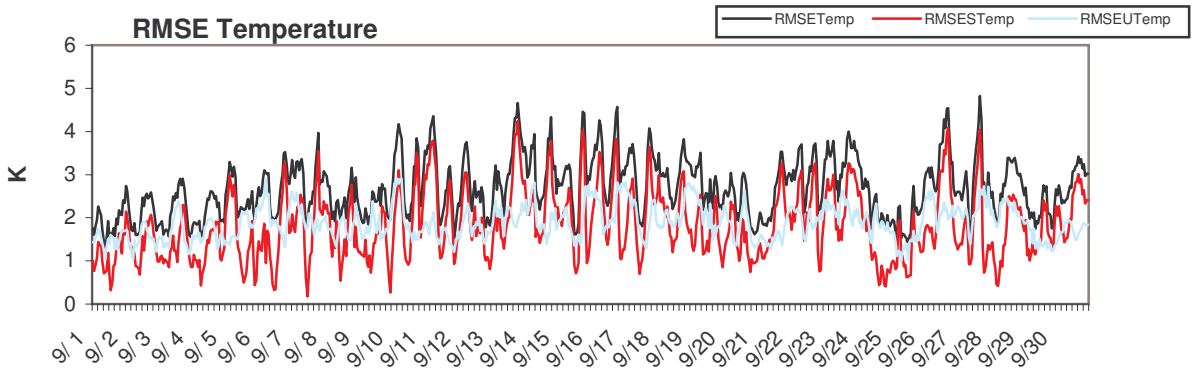

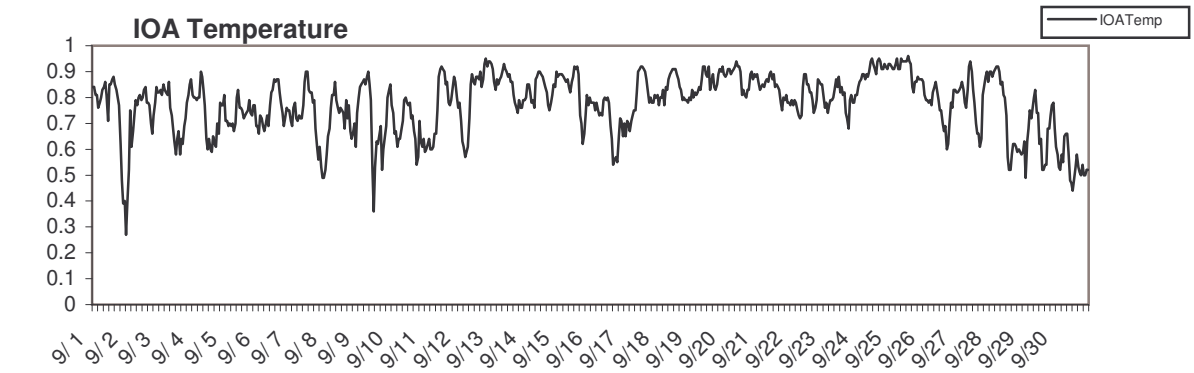

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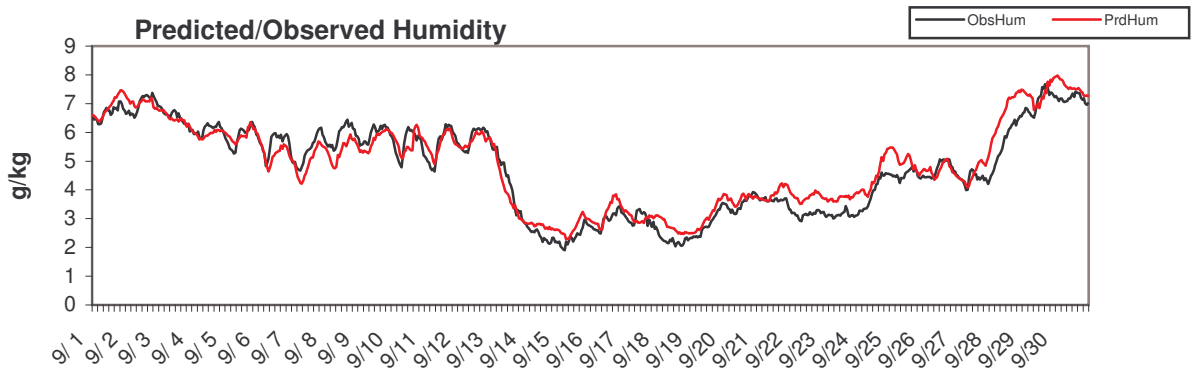
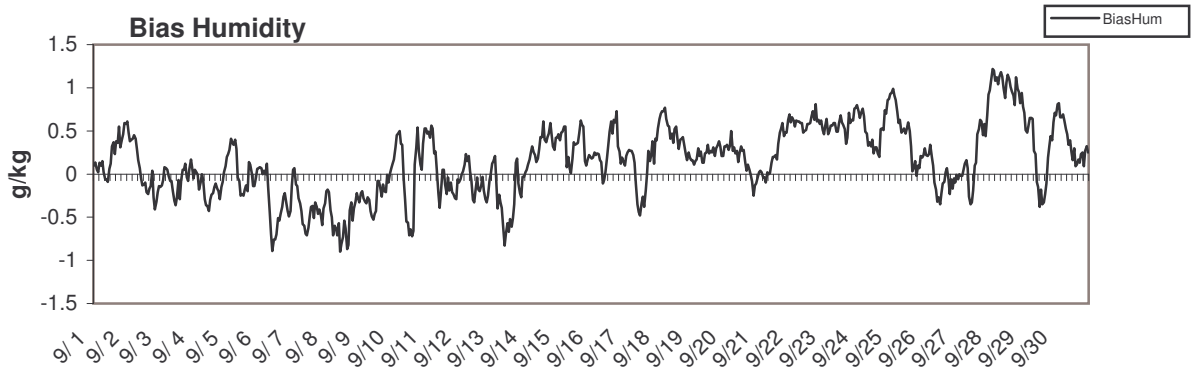
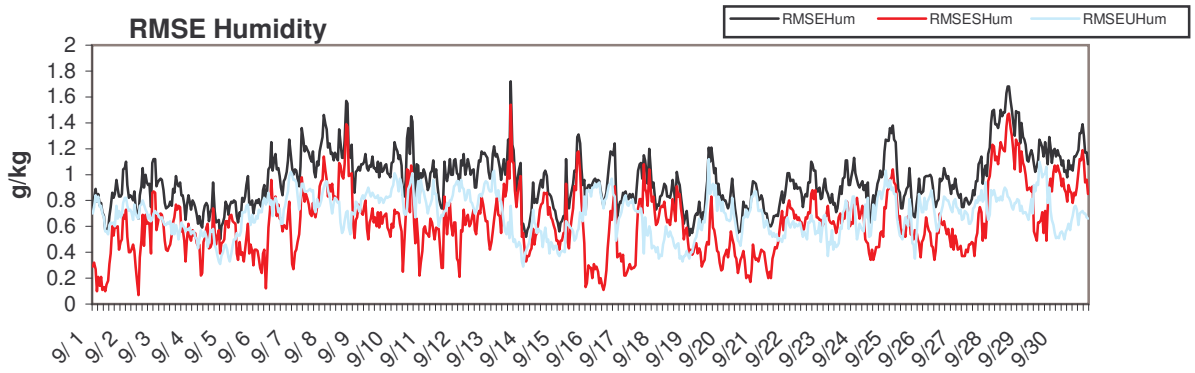
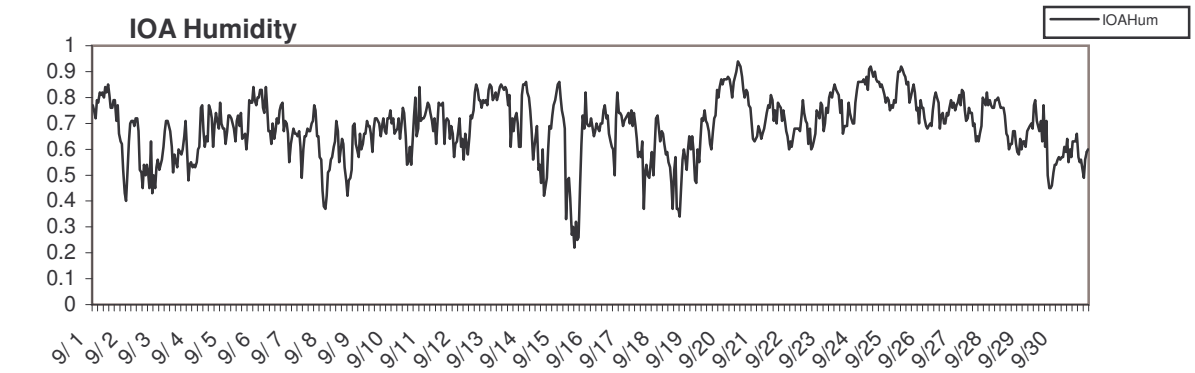
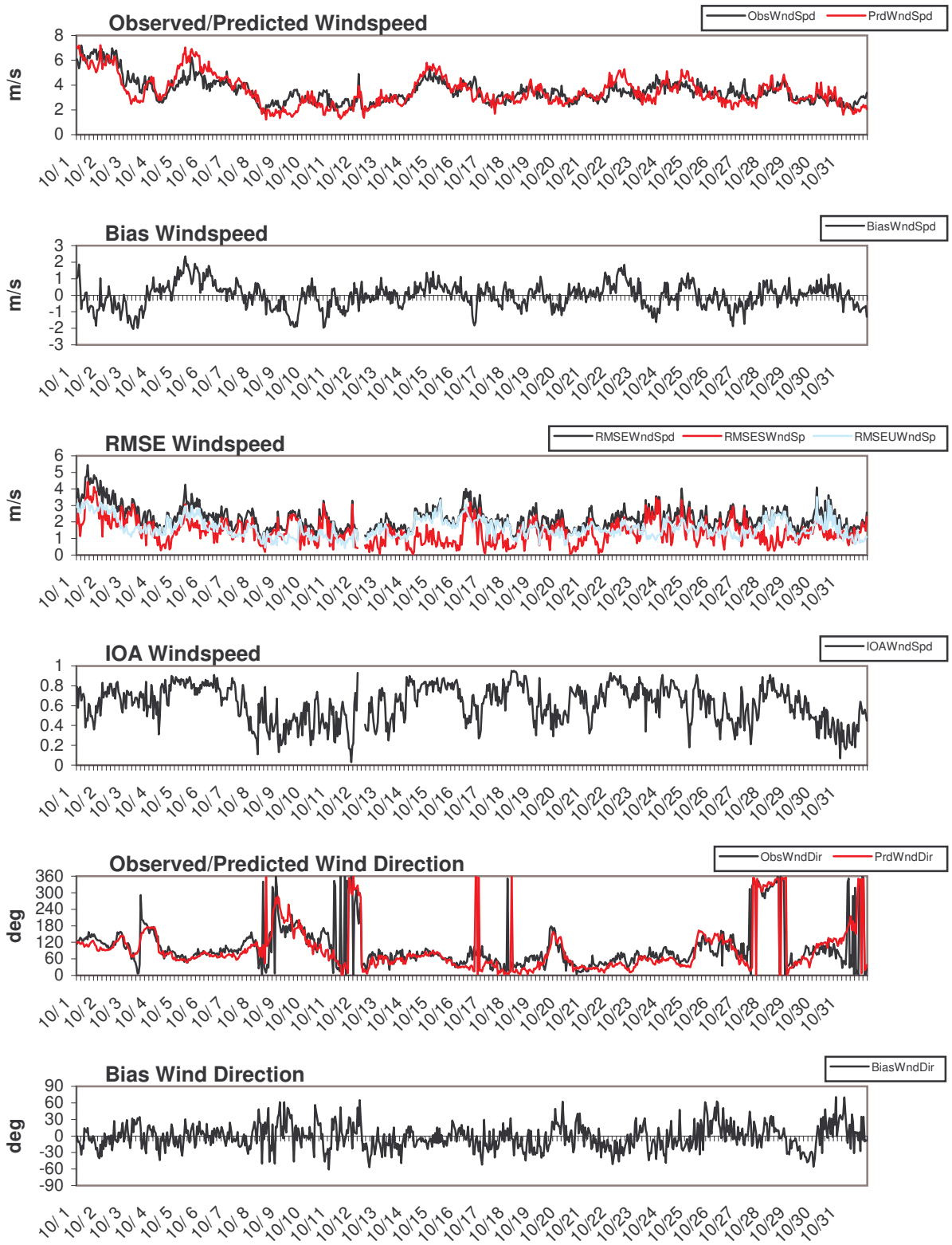




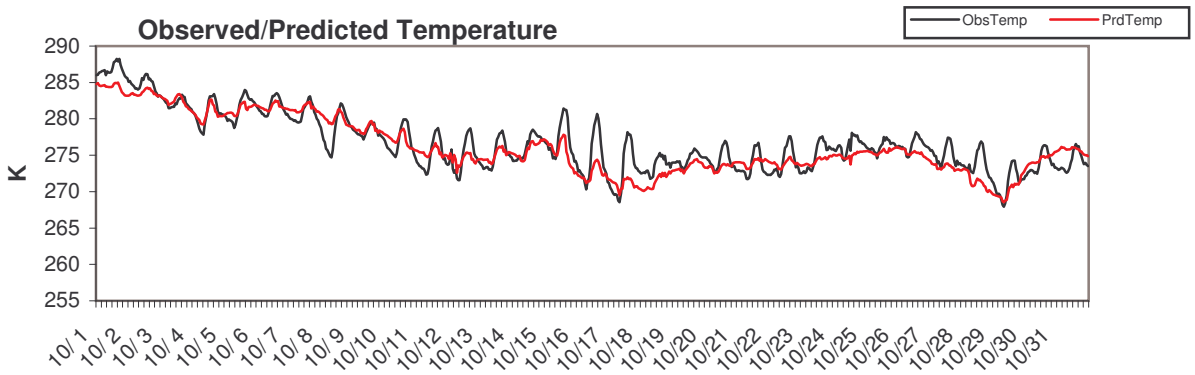


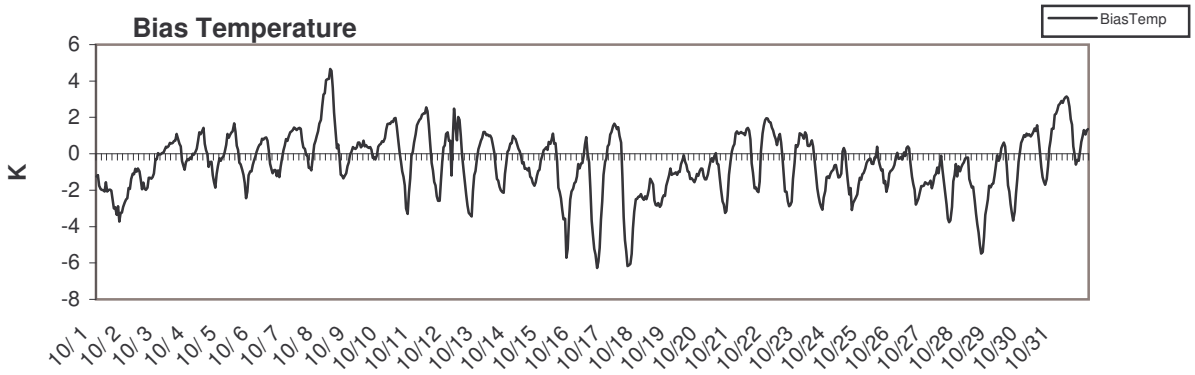


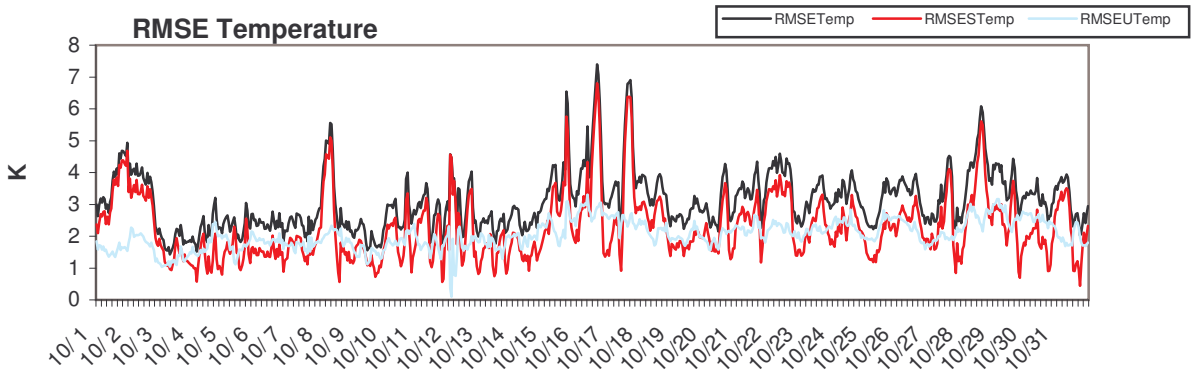
Alaska 5km 2003-10

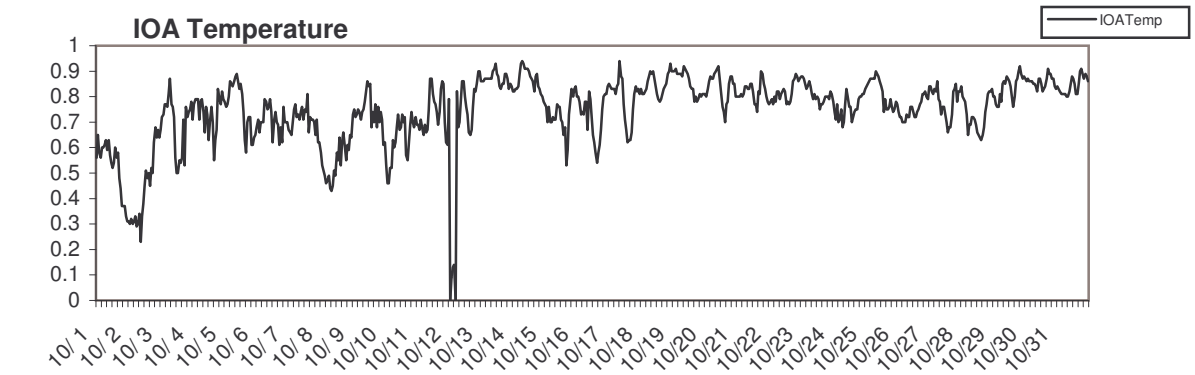


Alaska 5km 2003-10









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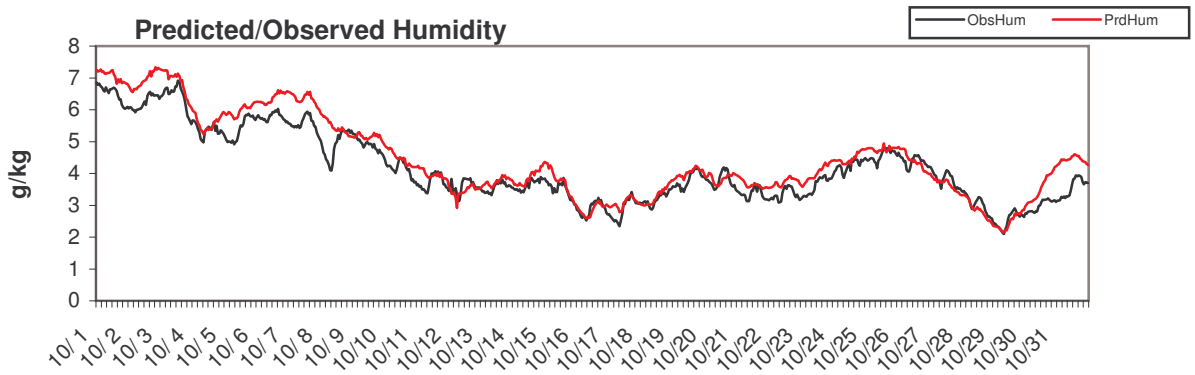
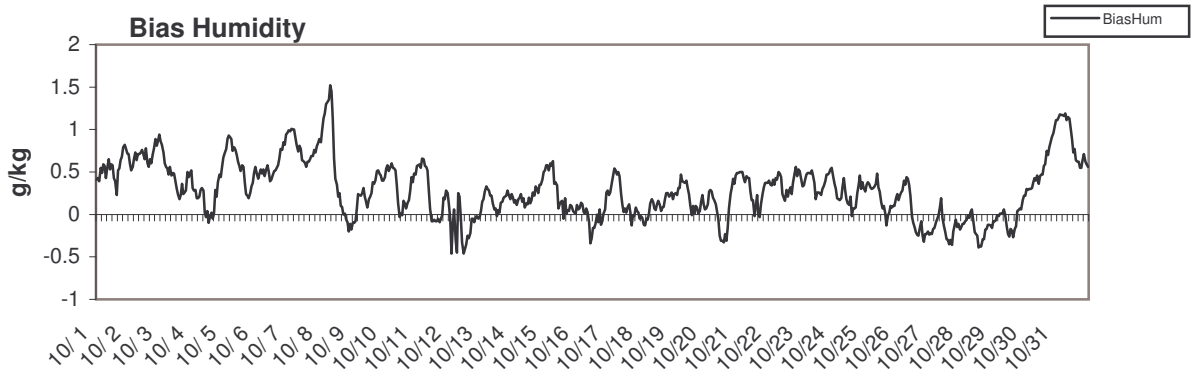
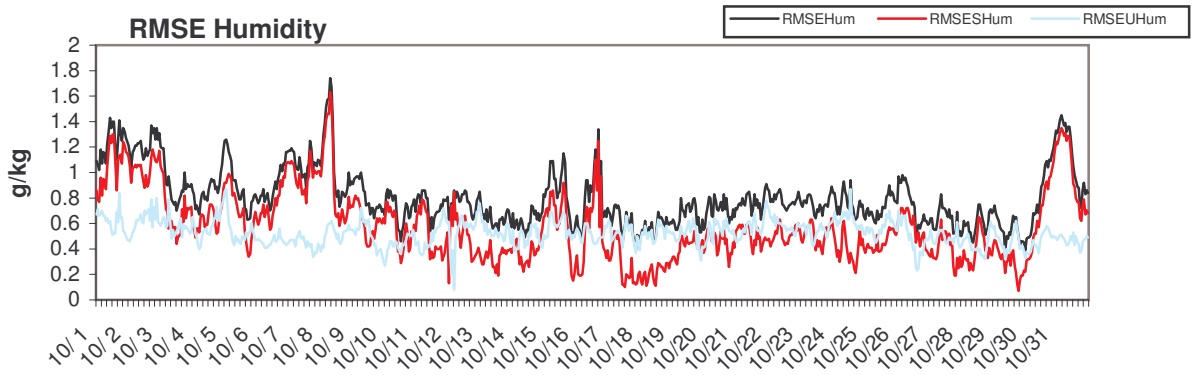
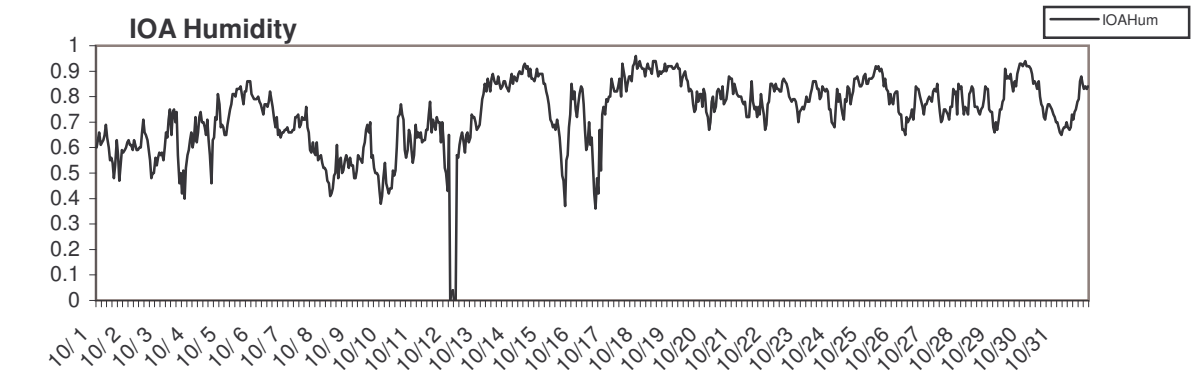
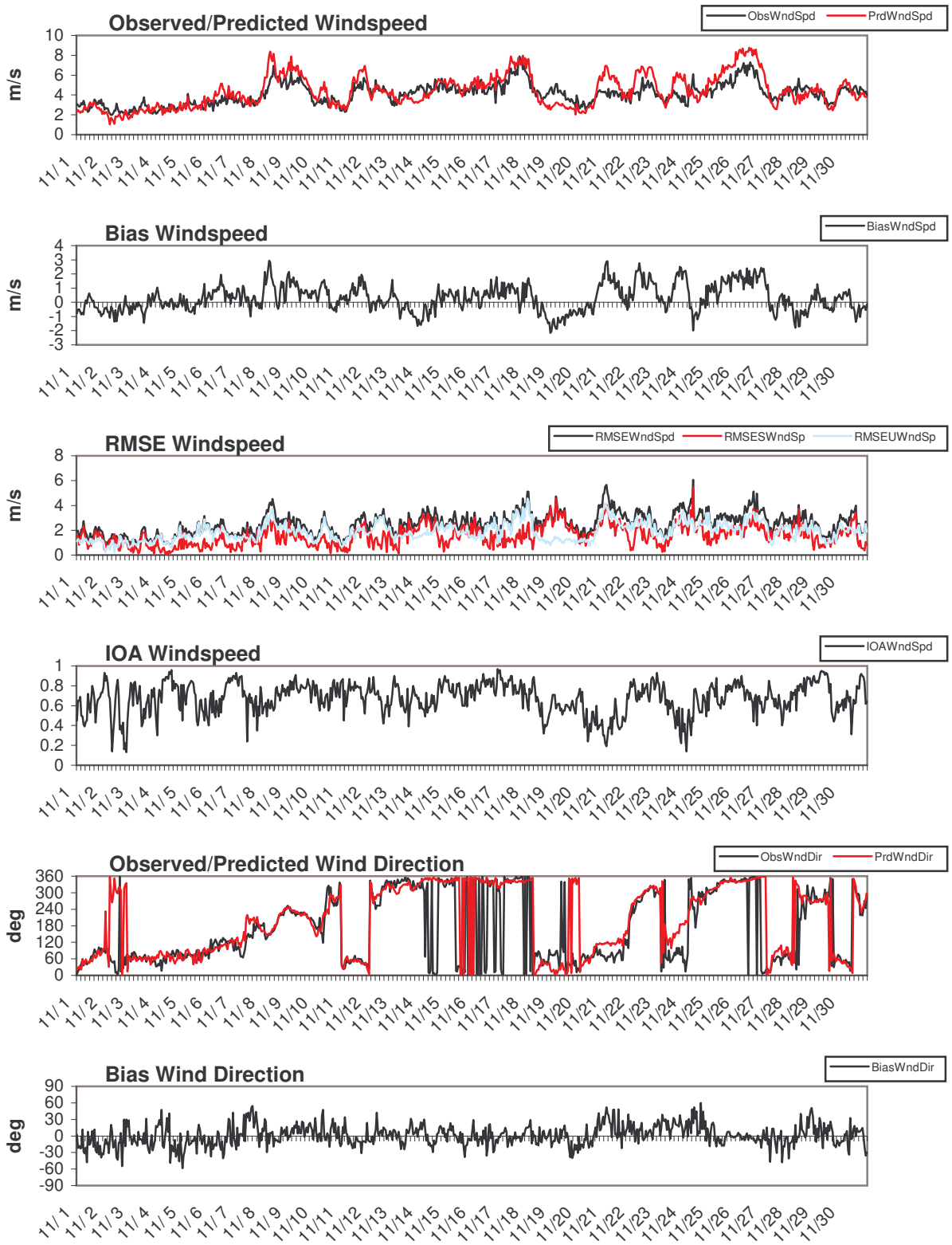








Alaska 5km 2003-11



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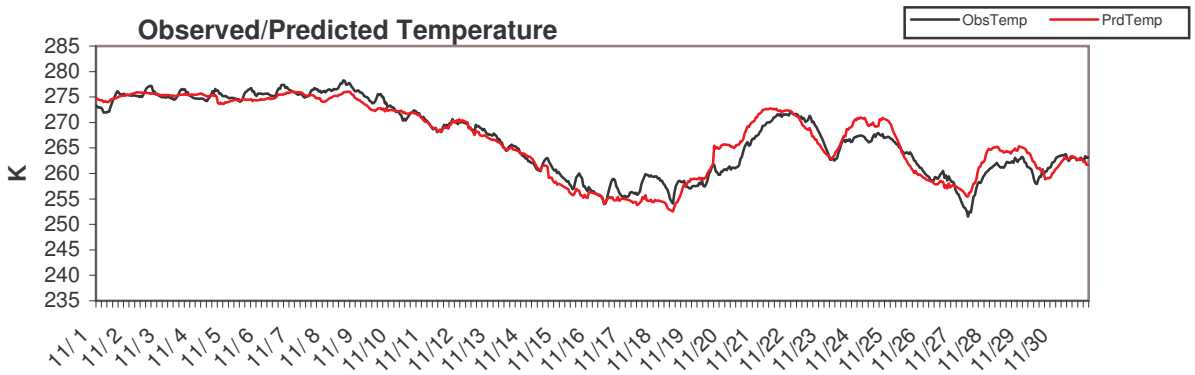

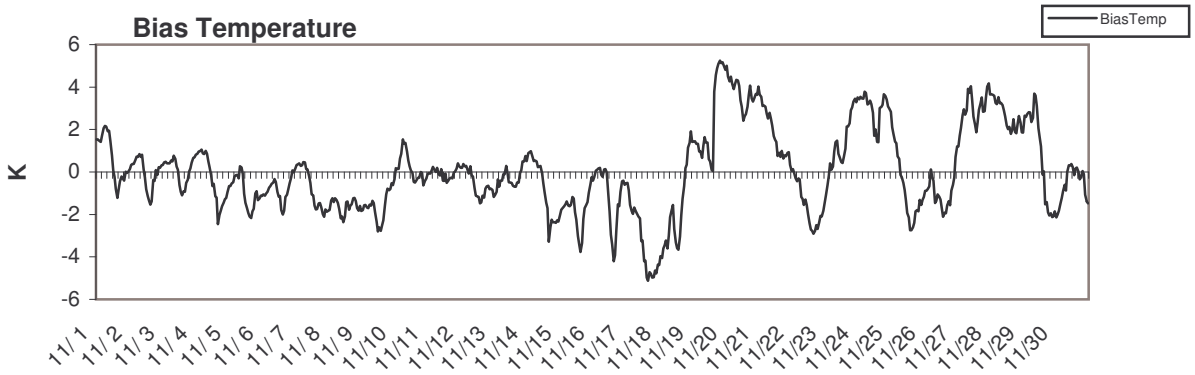

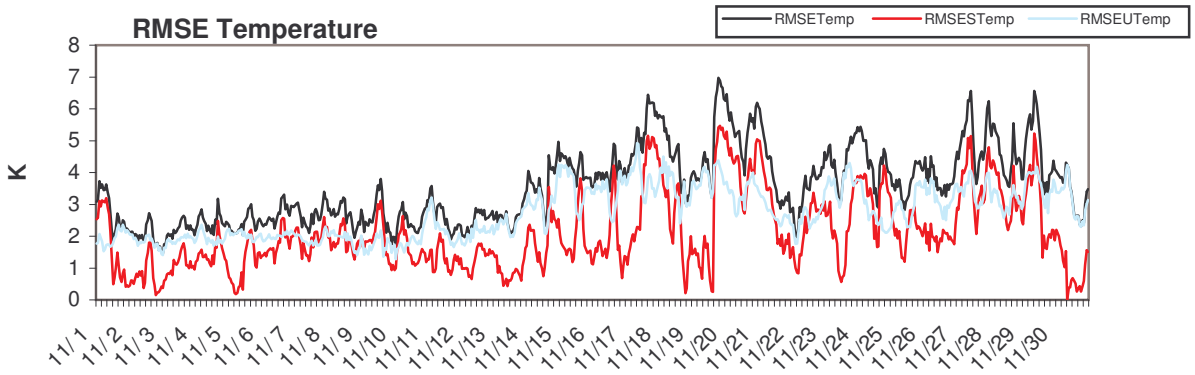

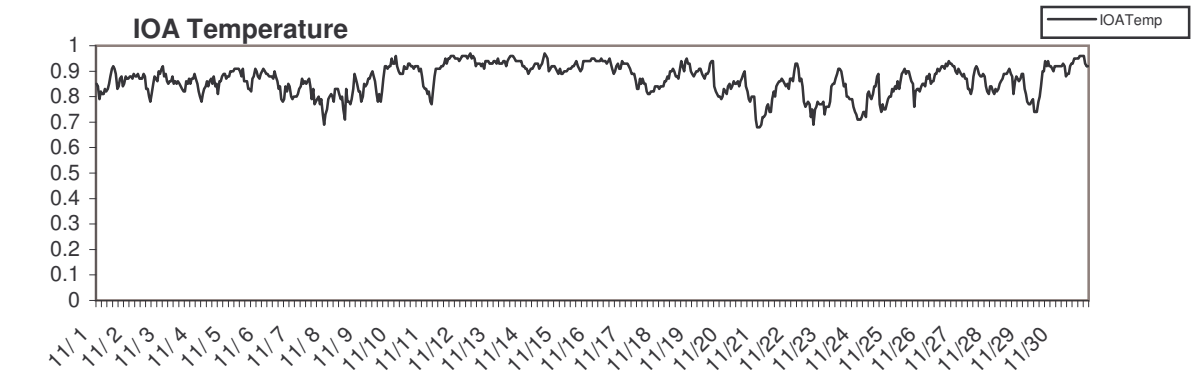

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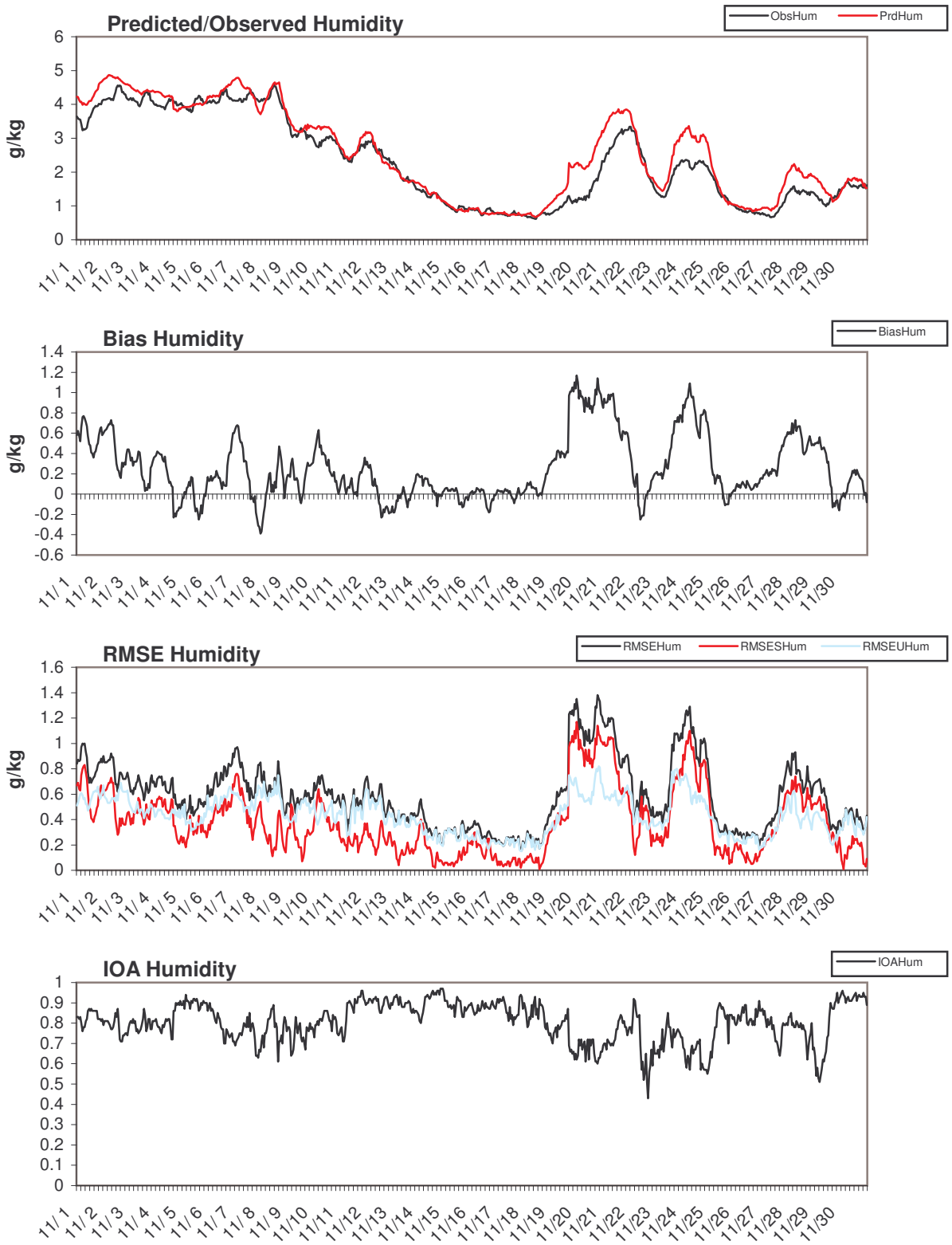

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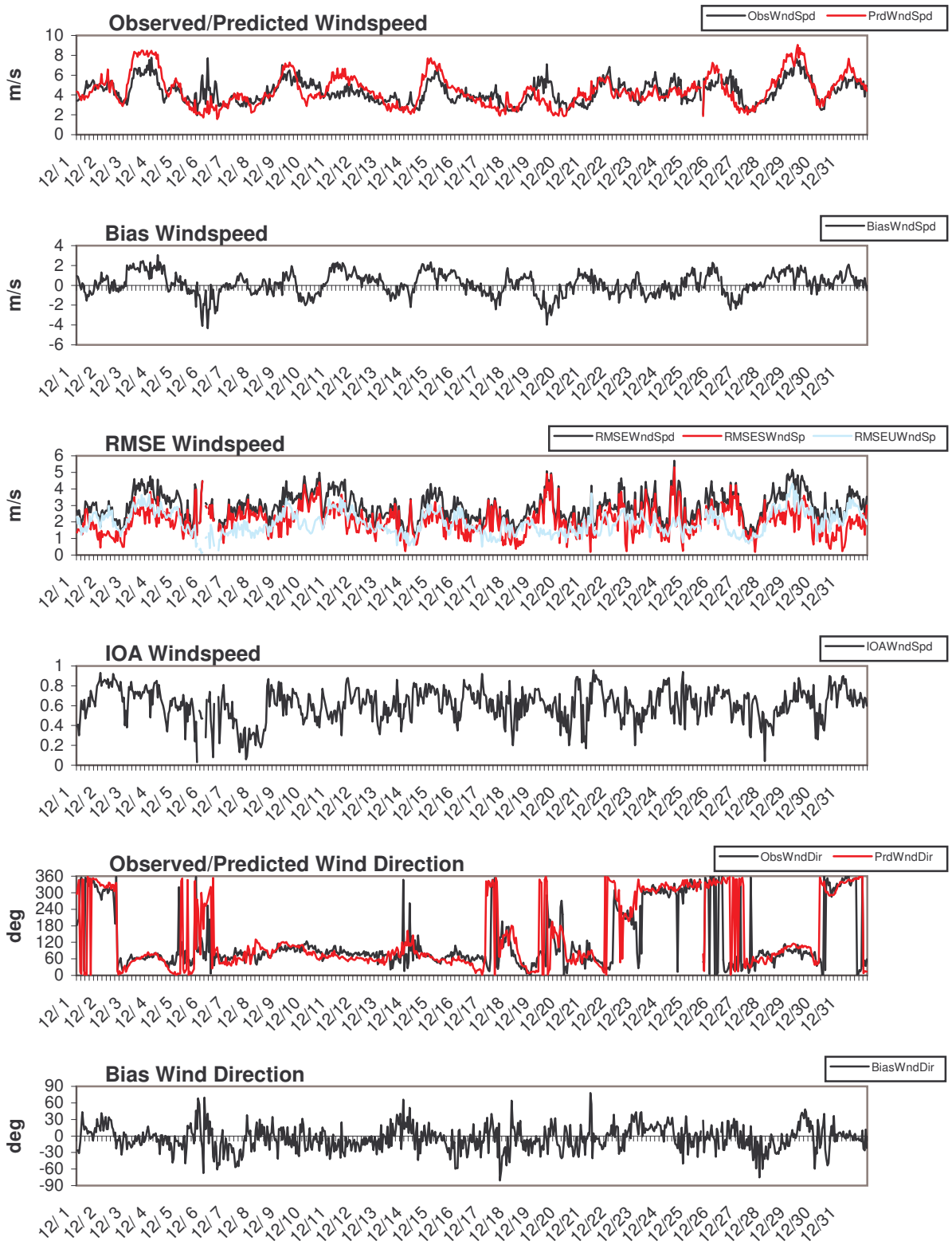

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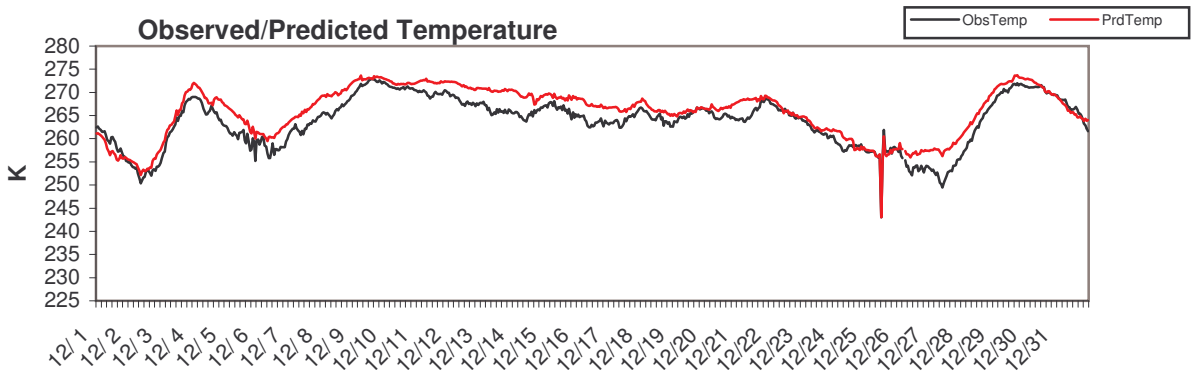

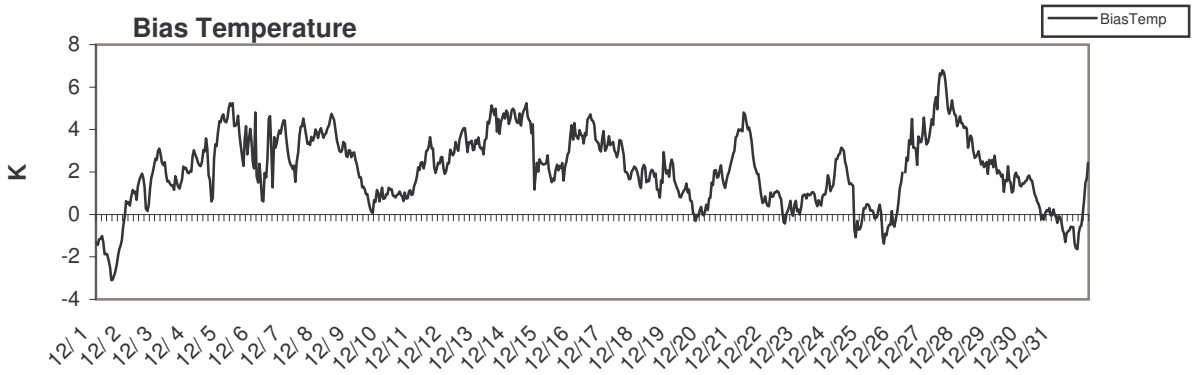

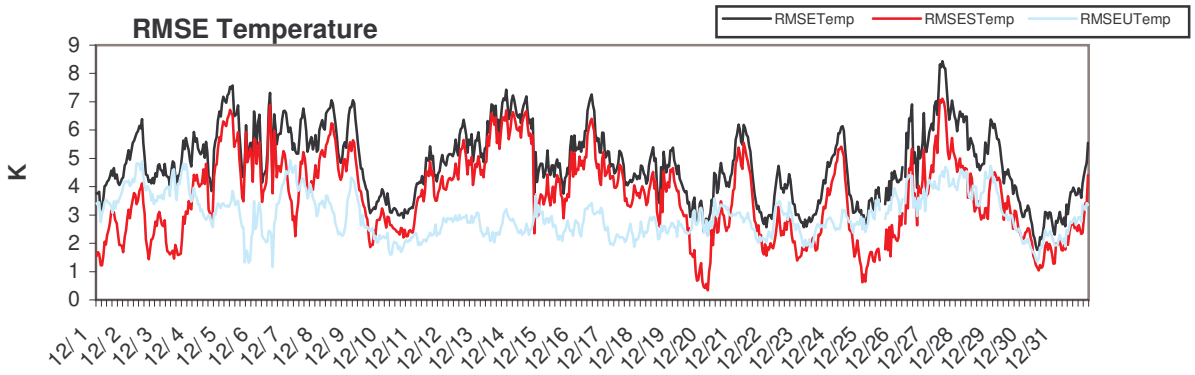

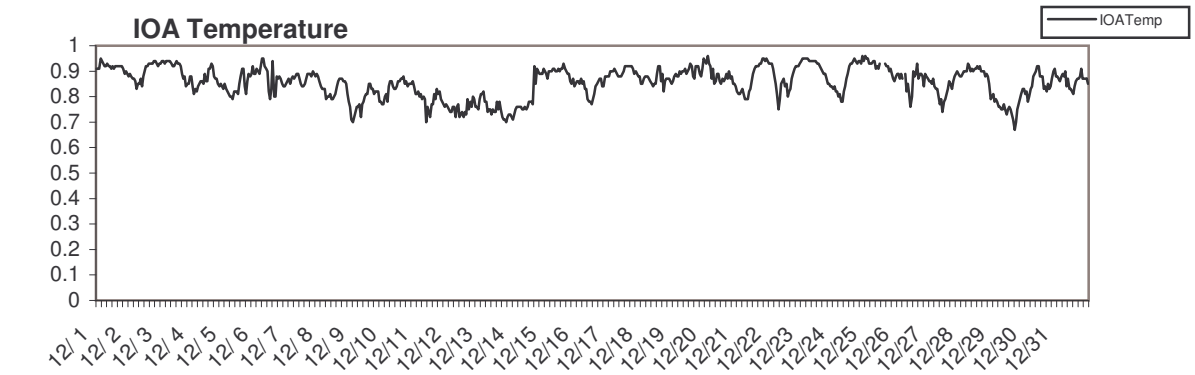

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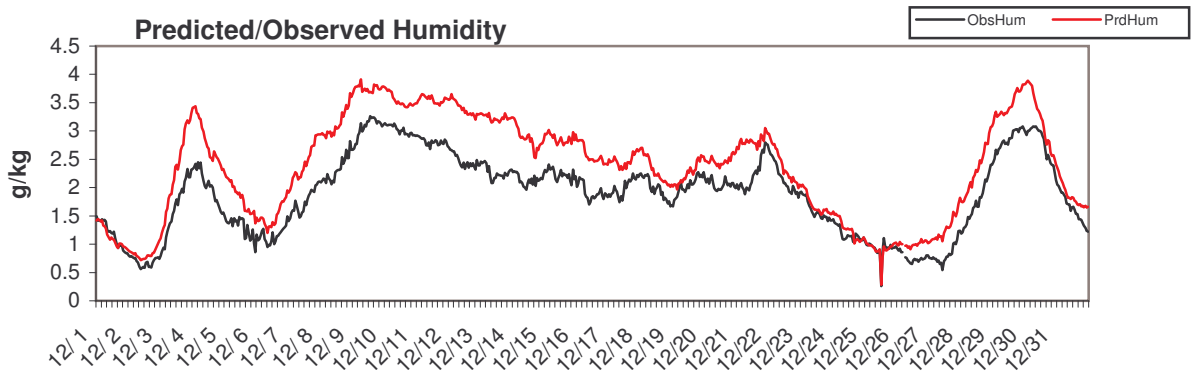
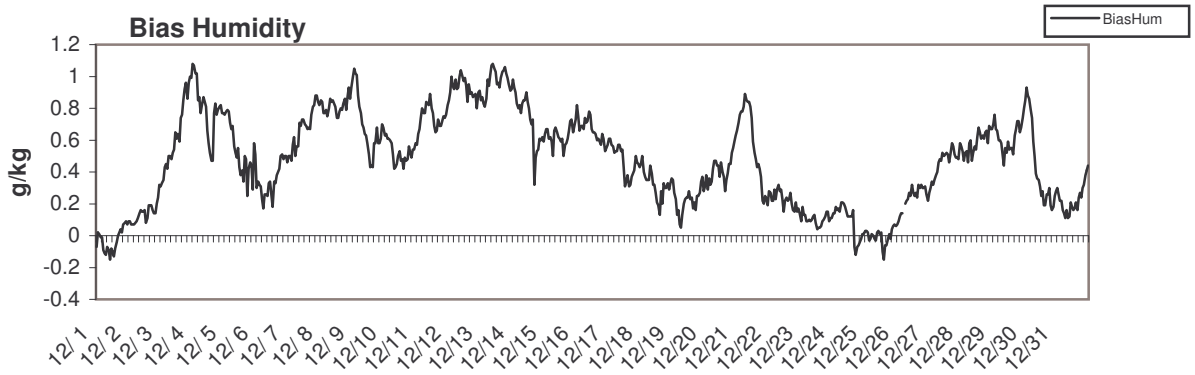
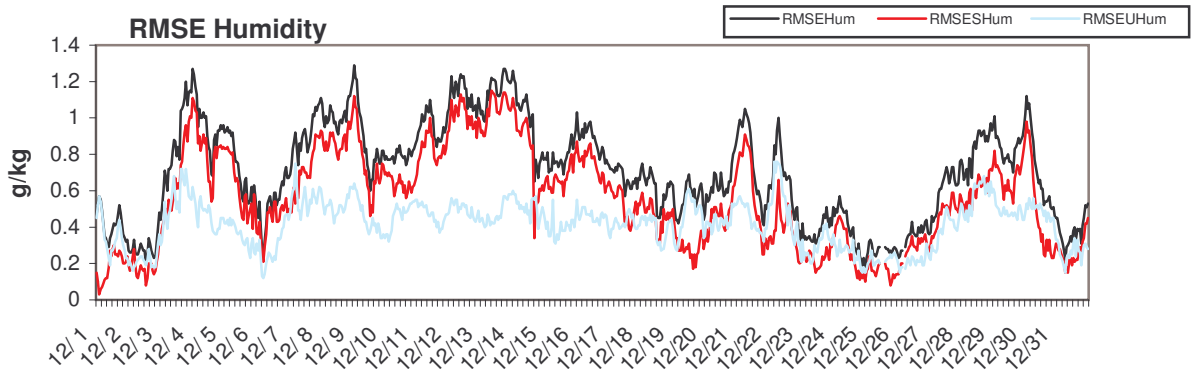
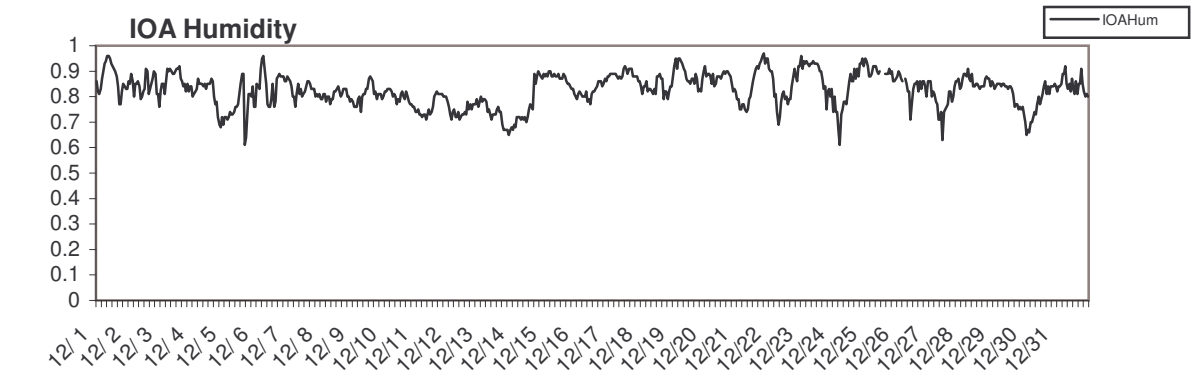
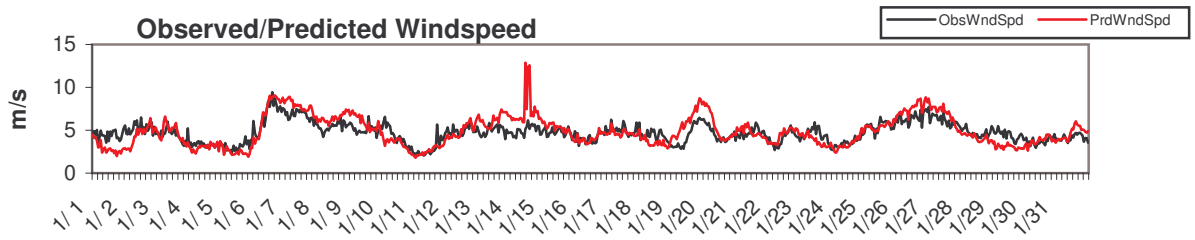


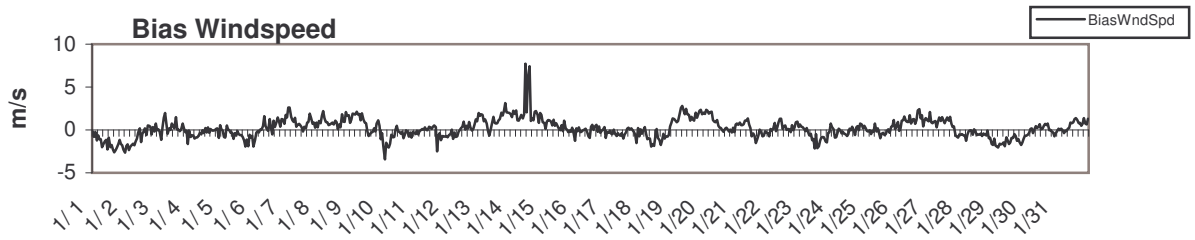


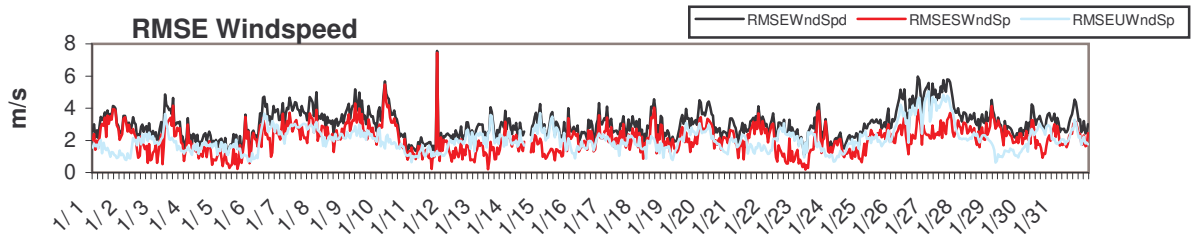


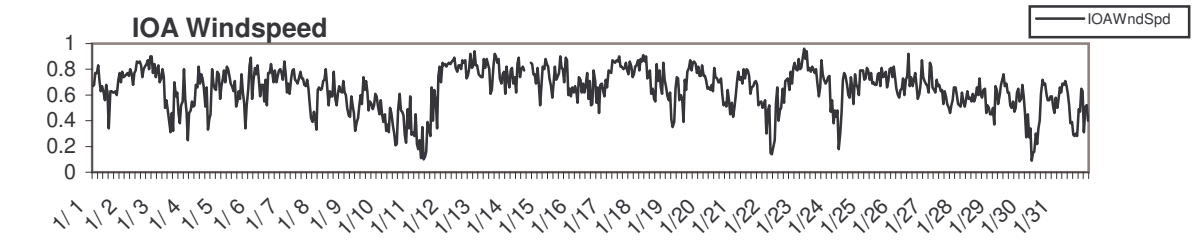


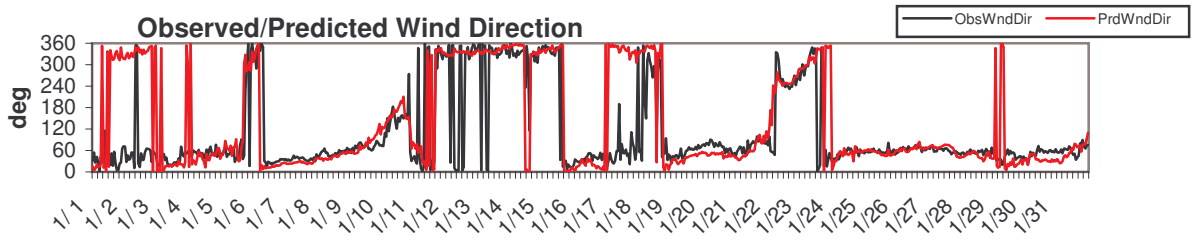
Alaska 5km 2004-01

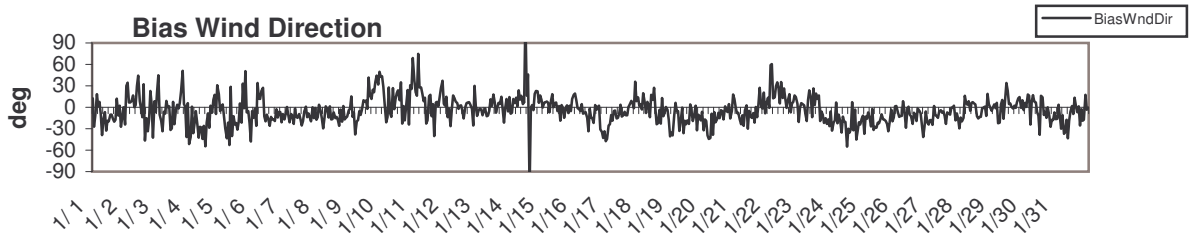




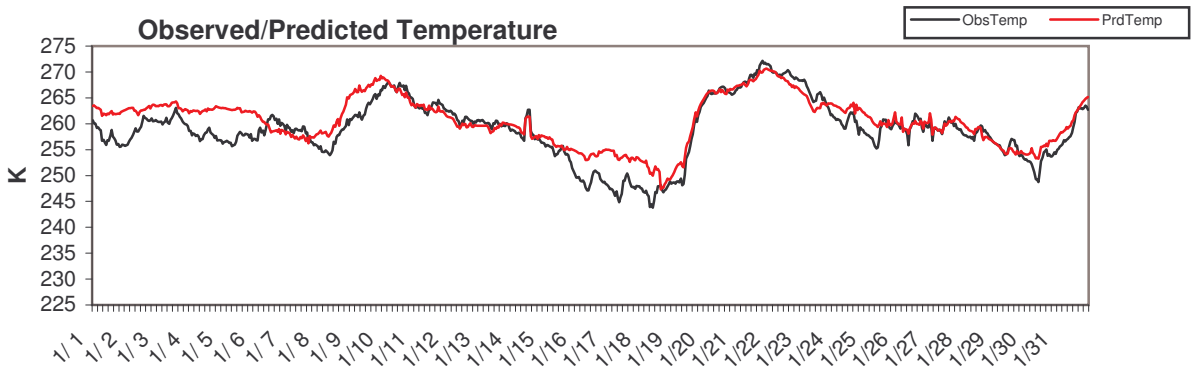


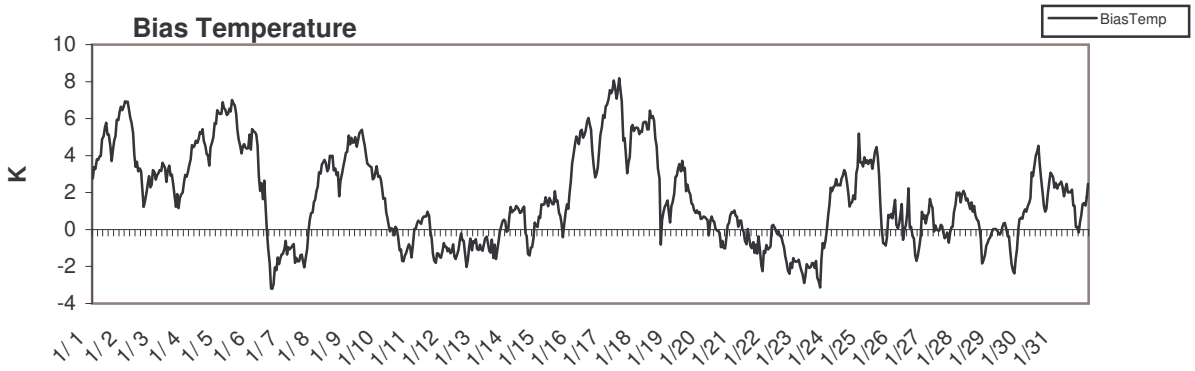


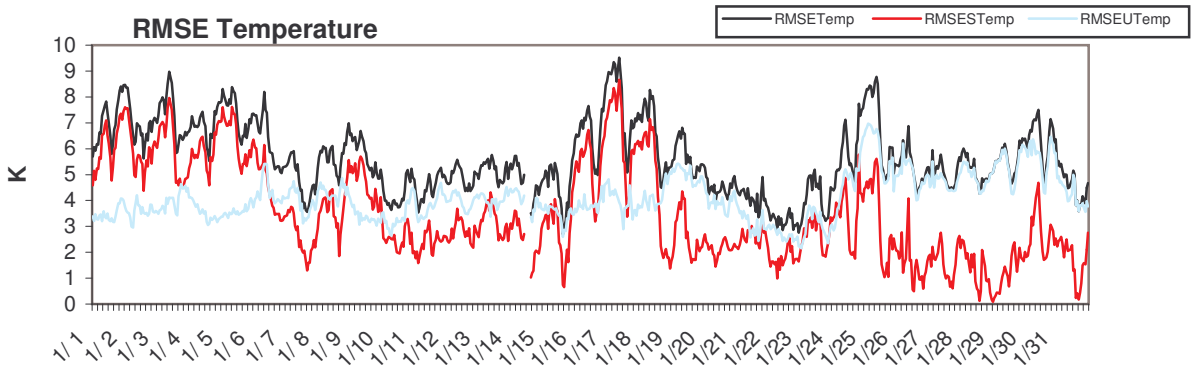


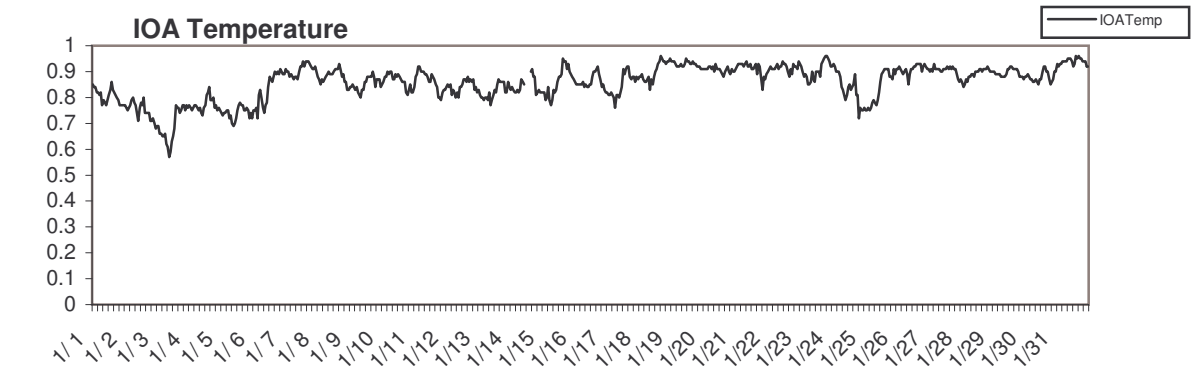


Alaska 5km 2004-01

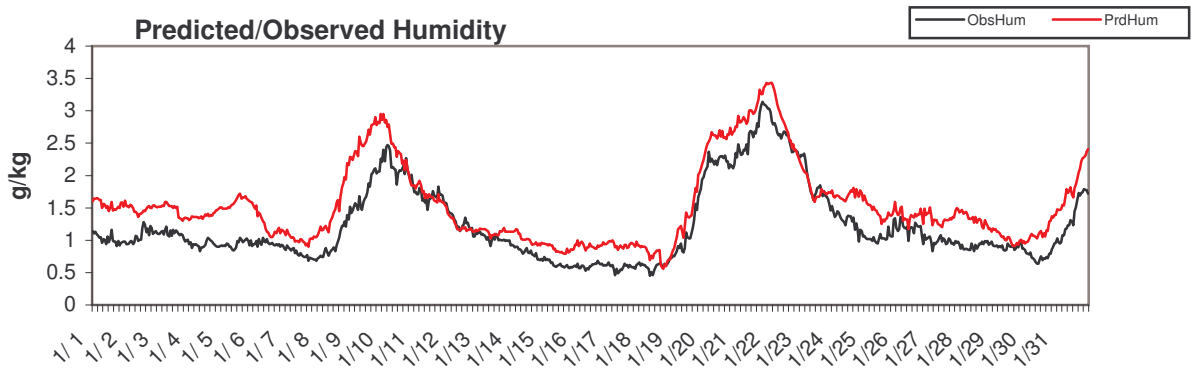


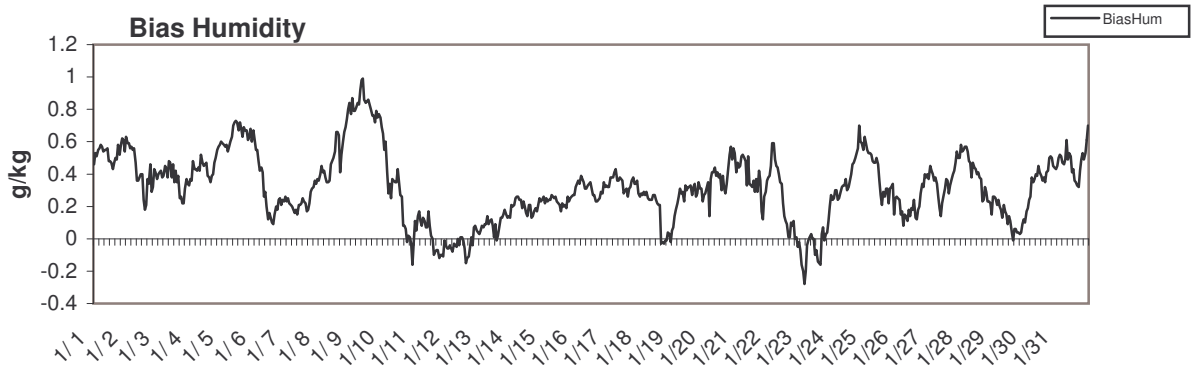


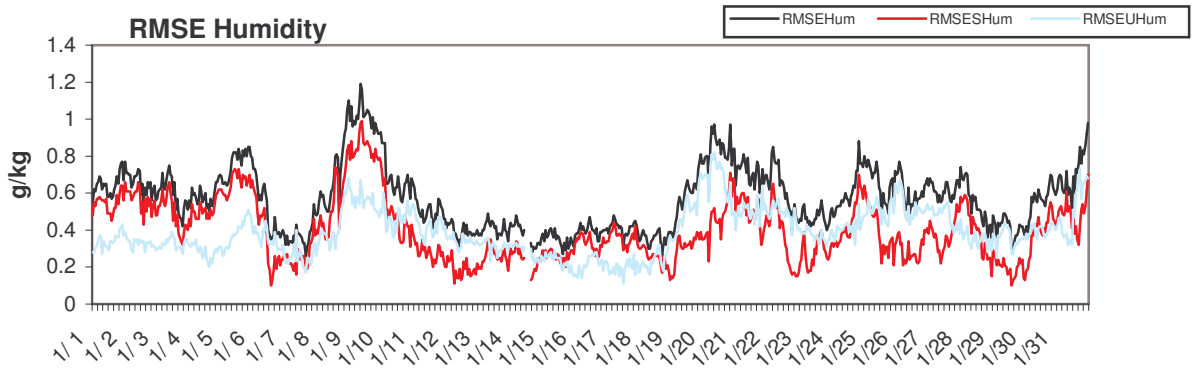


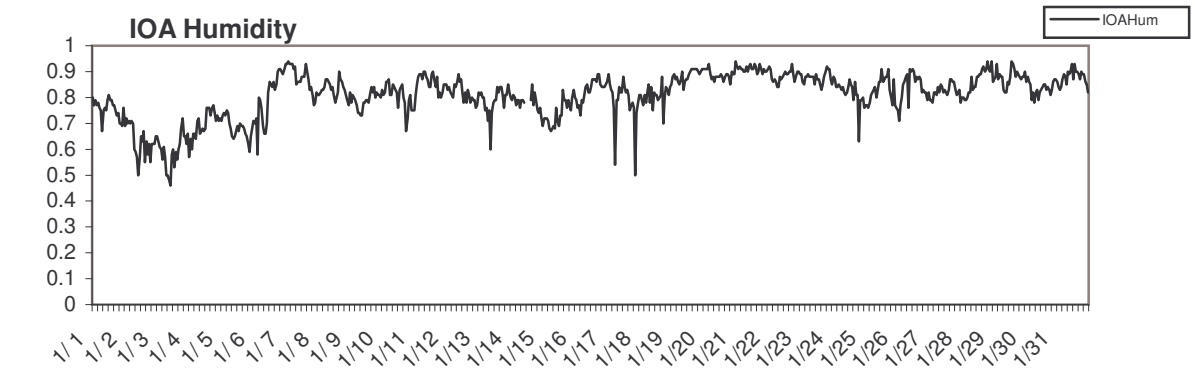


Alaska 5km 2004-01

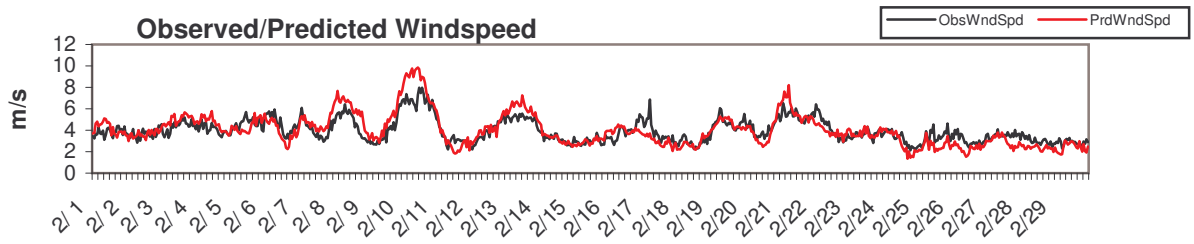


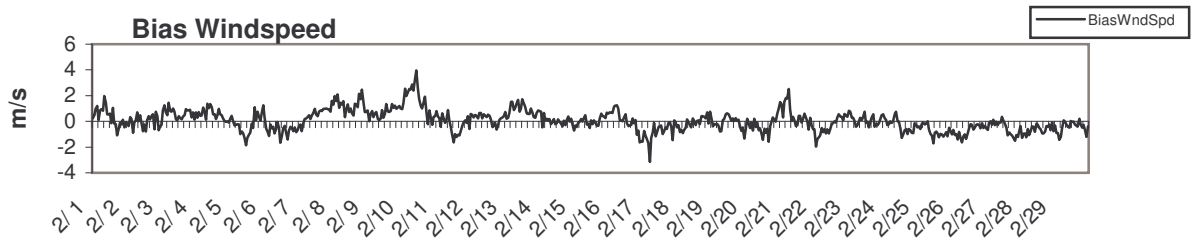


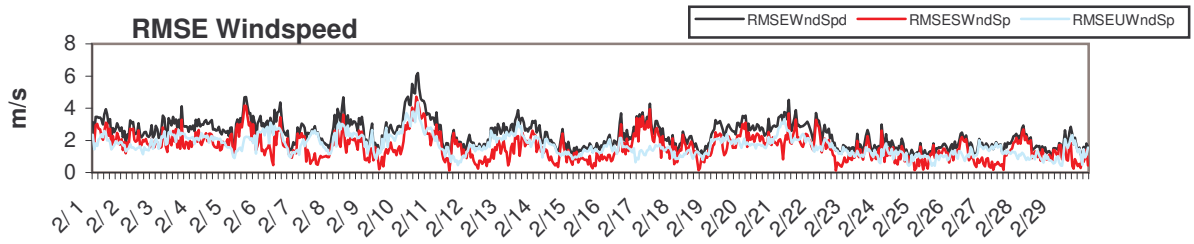


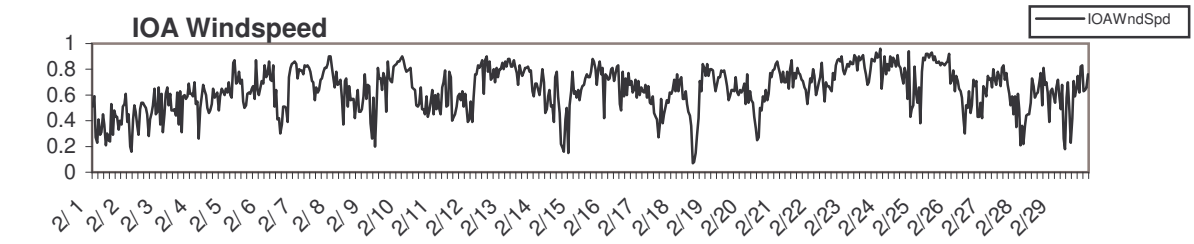


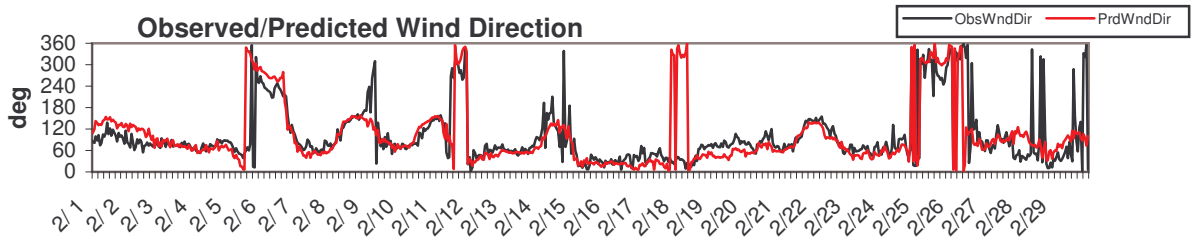
Alaska 5km 2004-02

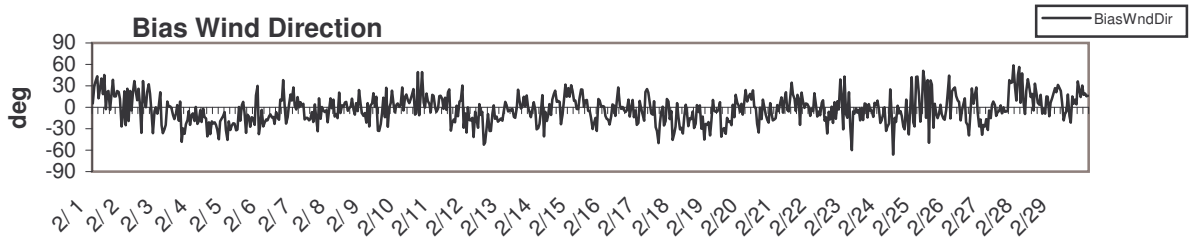




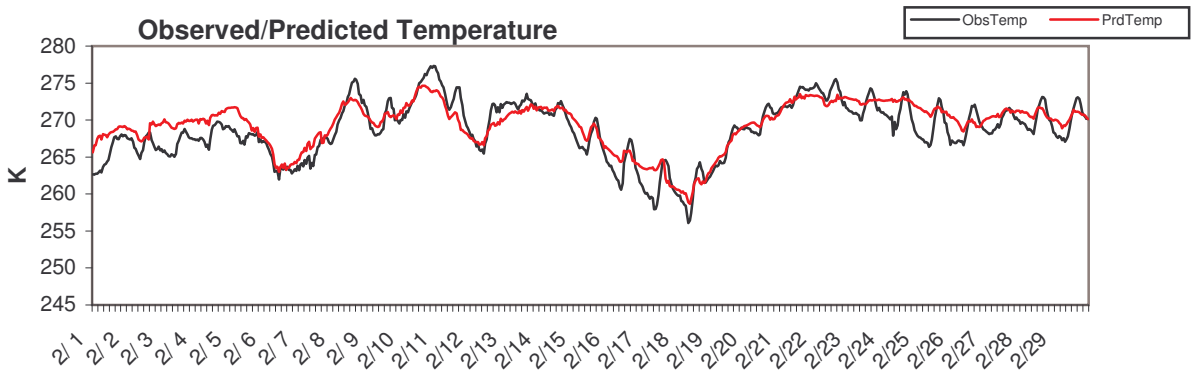


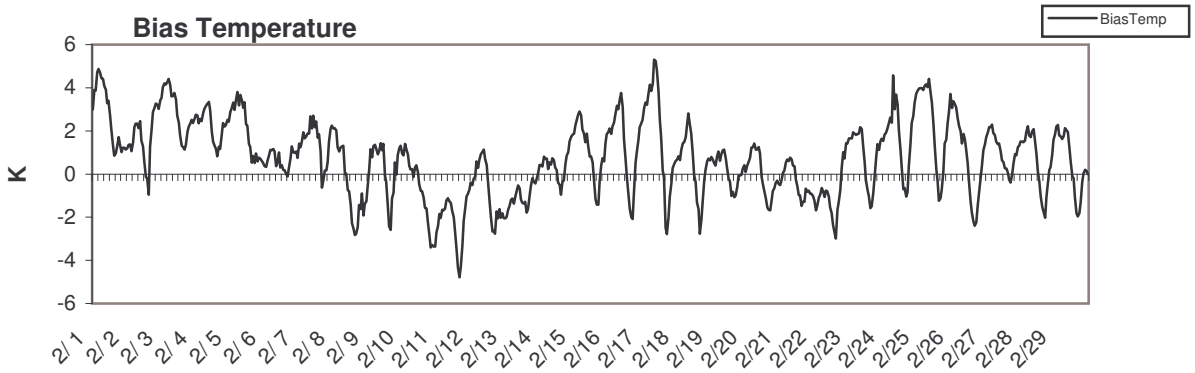


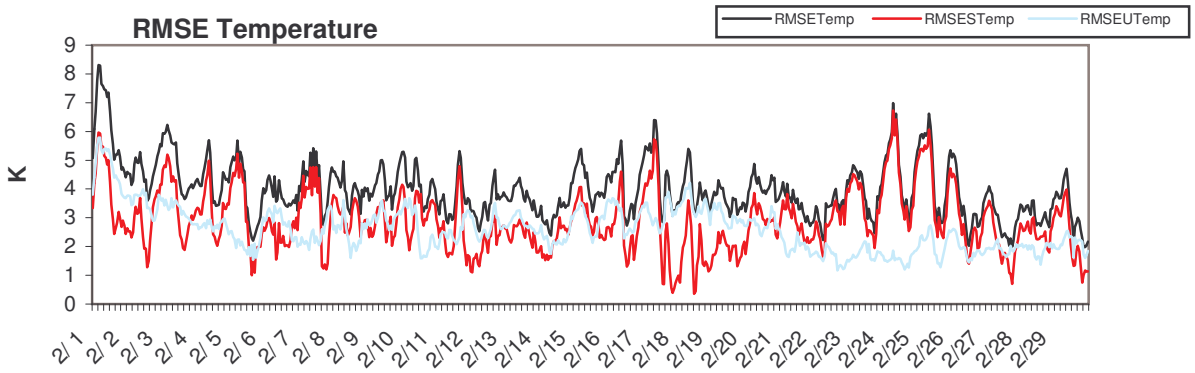


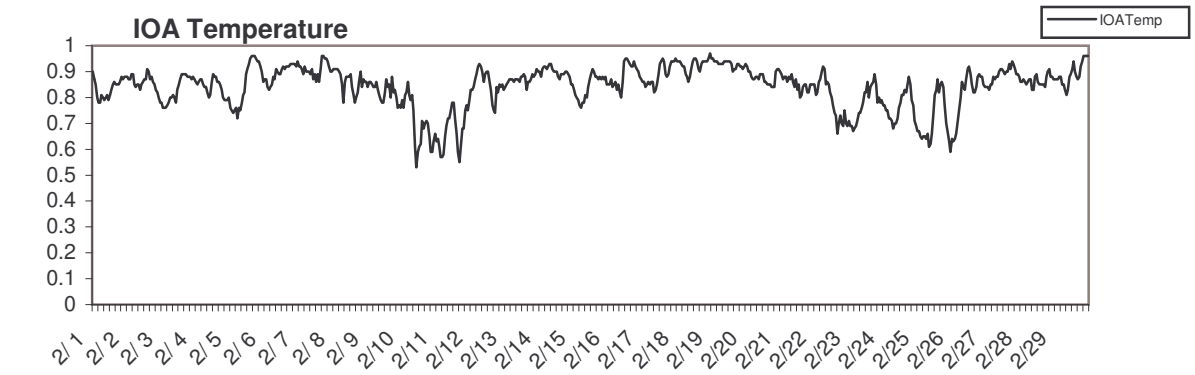


Alaska 5km 2004-02

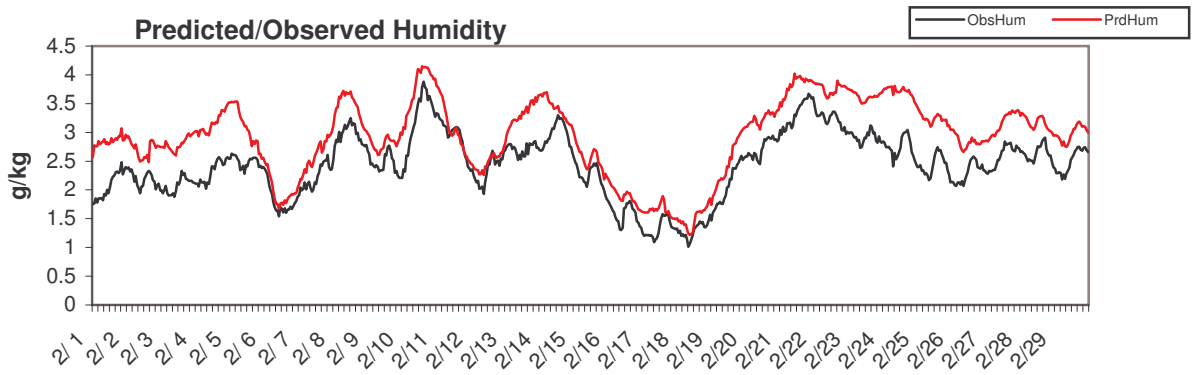


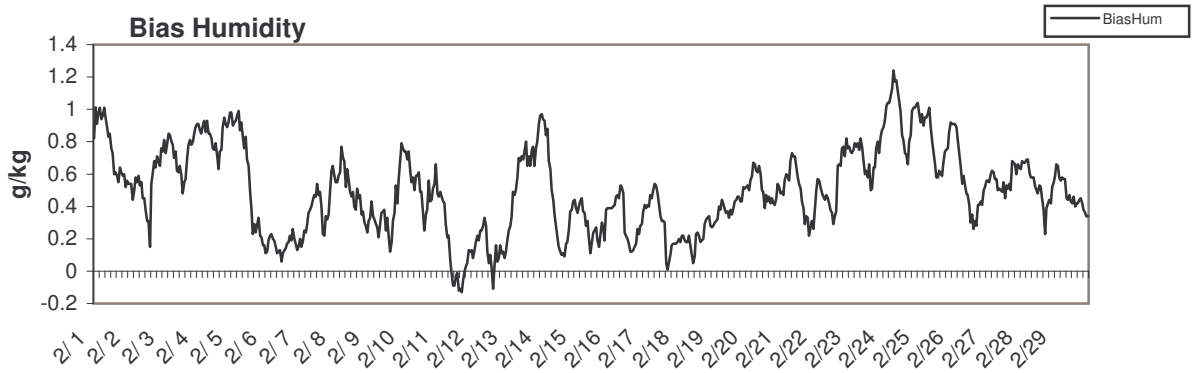


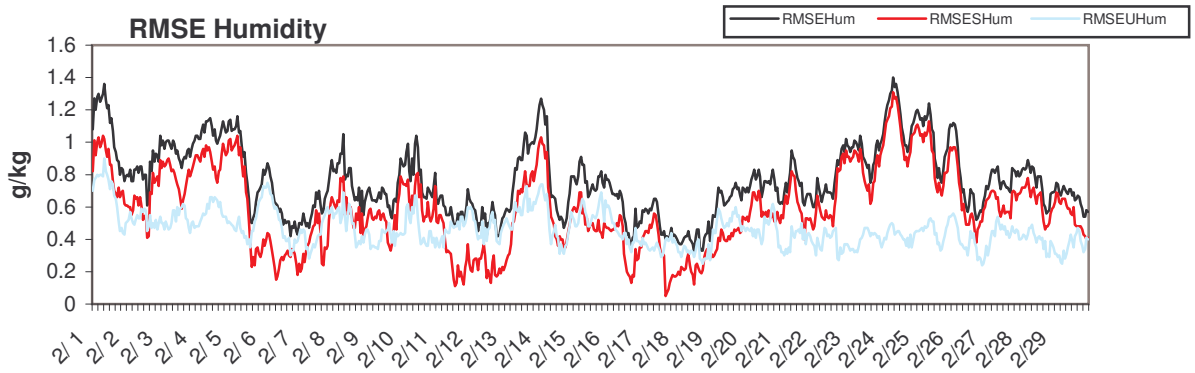


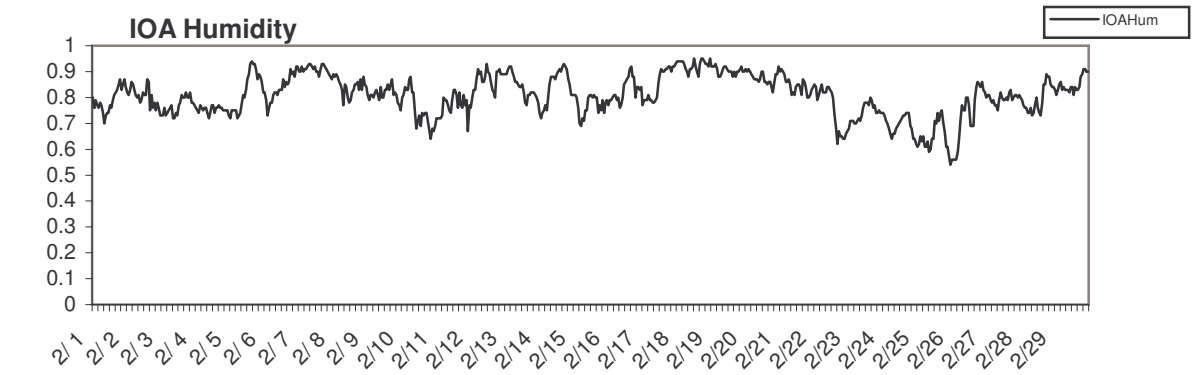


Alaska 5km 2004-02

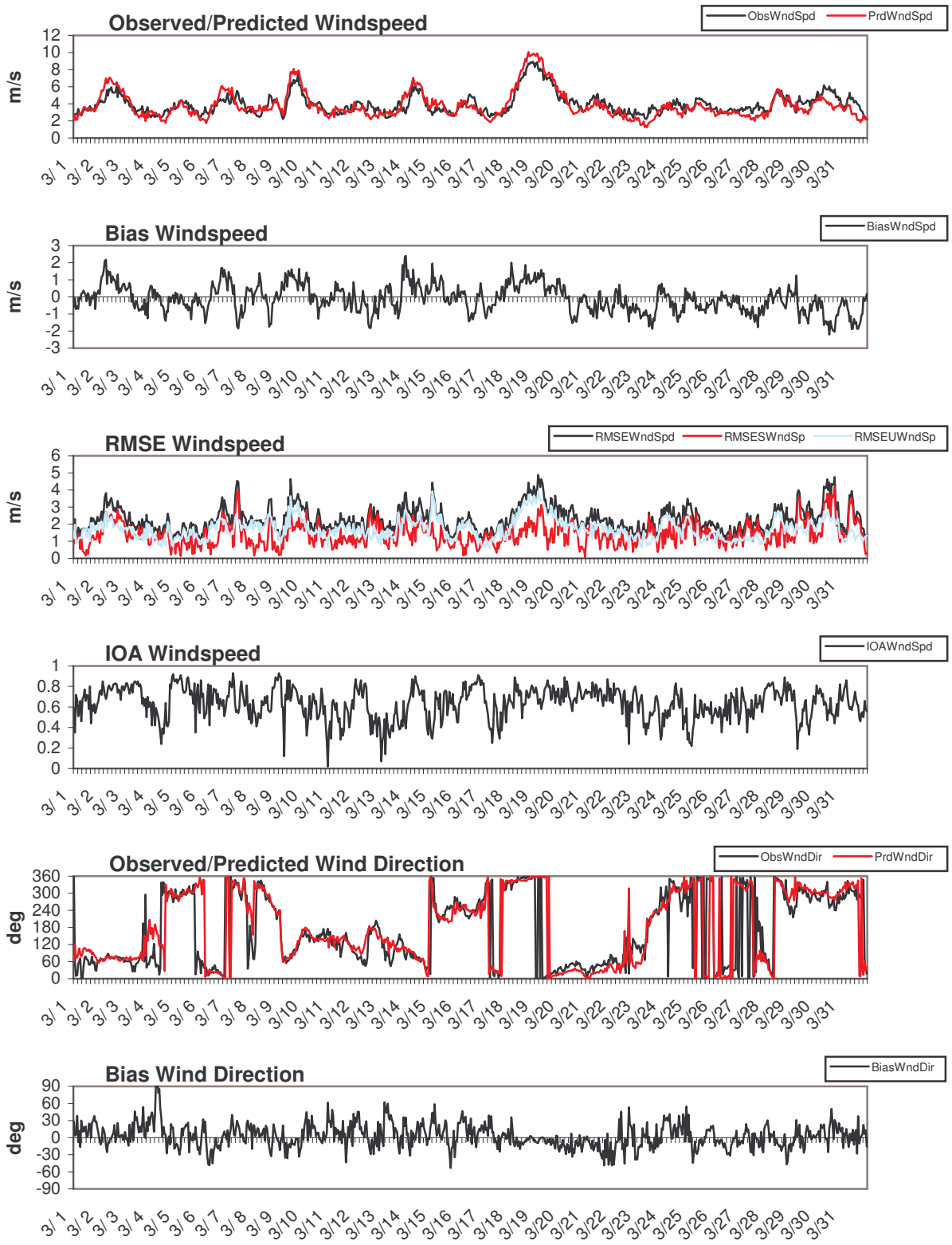




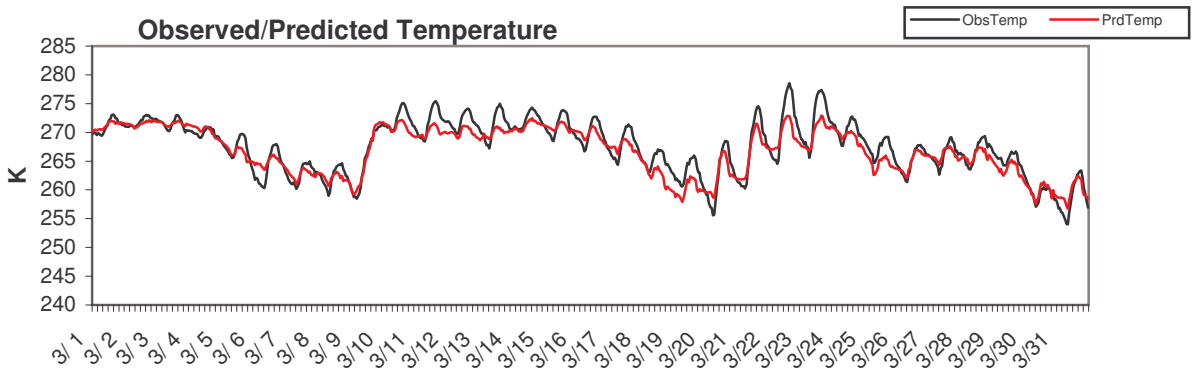


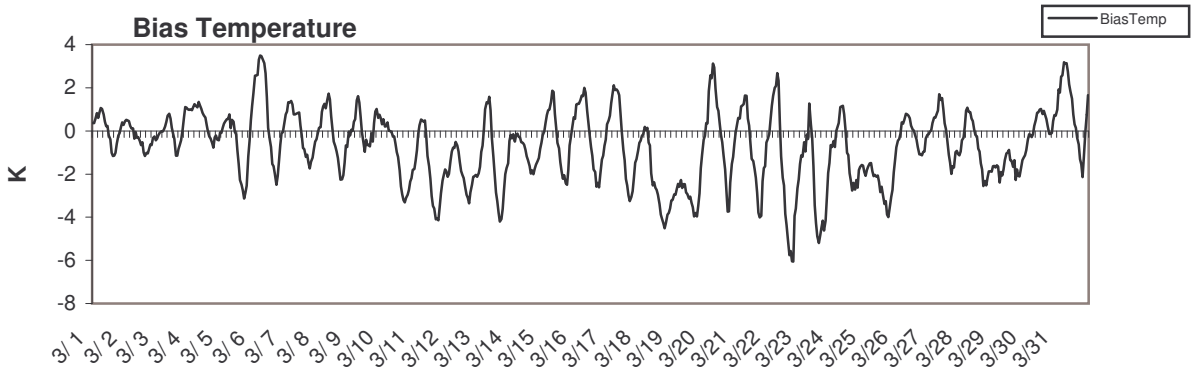


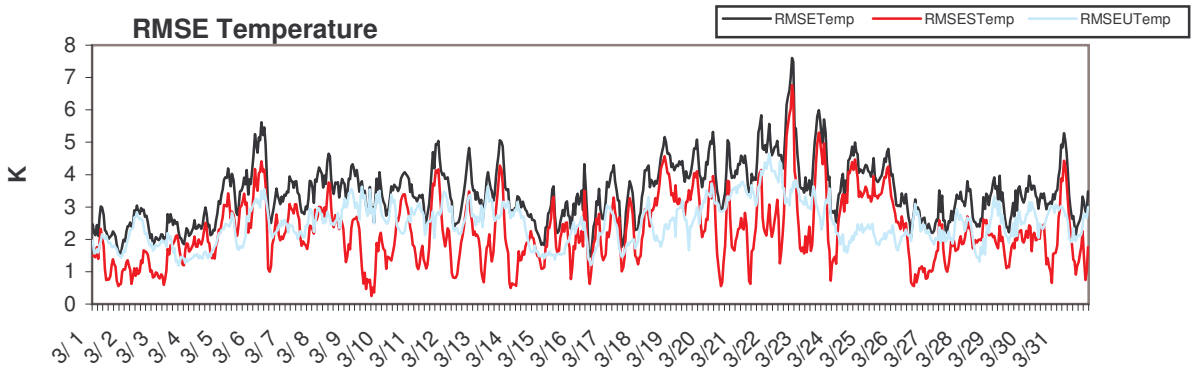
Alaska 5km 2004-03

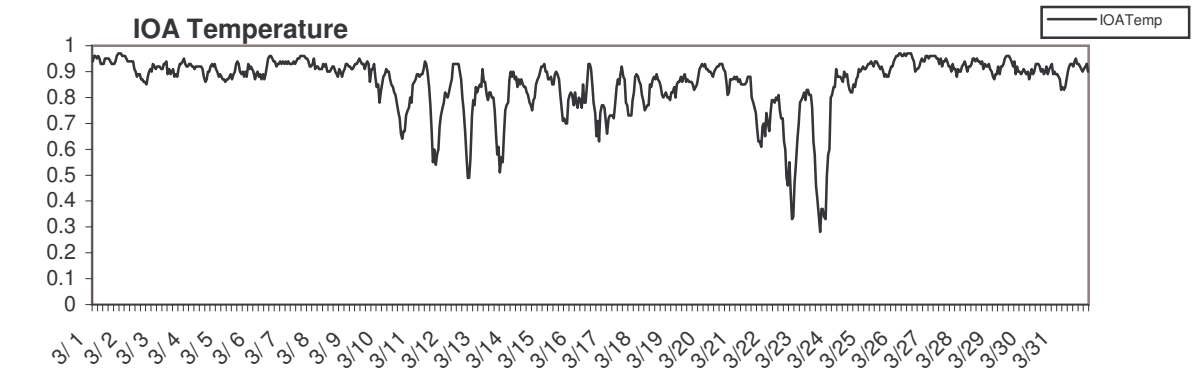


Alaska 5km 2004-03

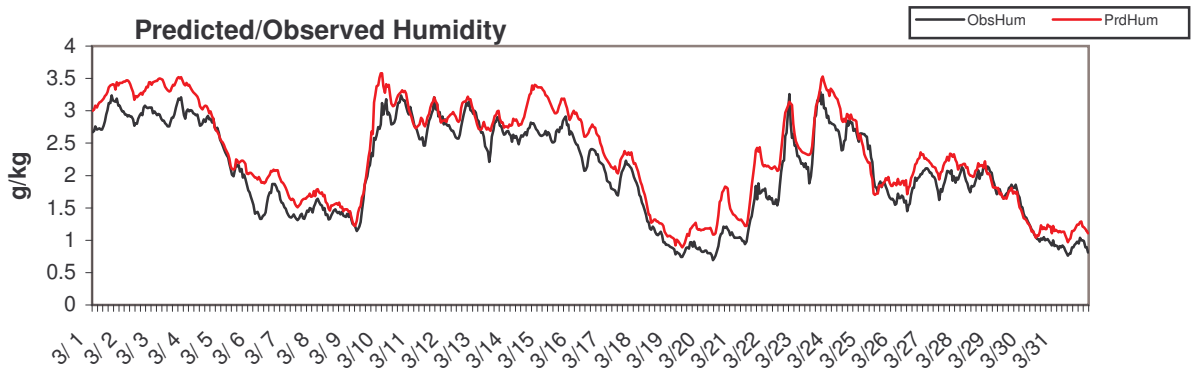


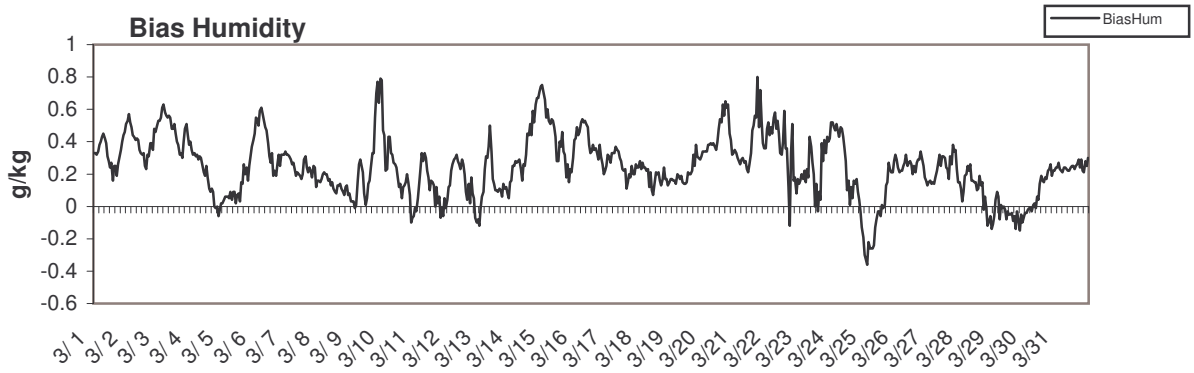


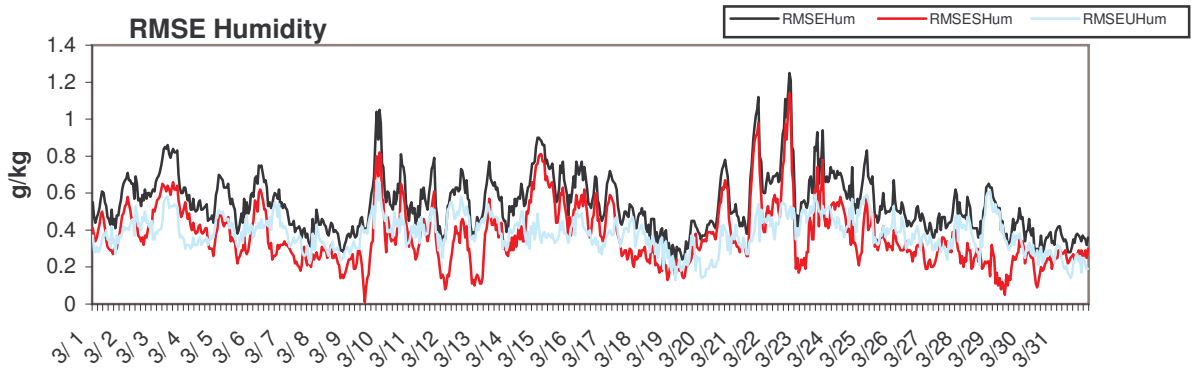


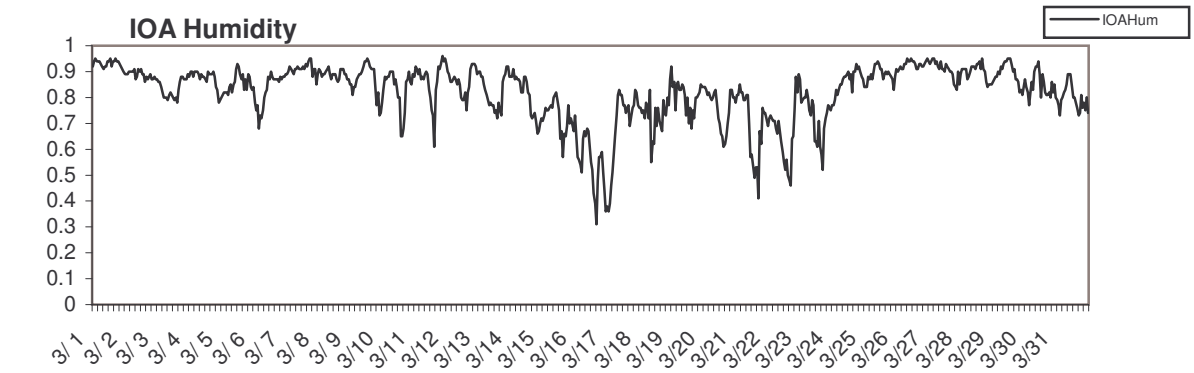


Alaska 5km 2004-03

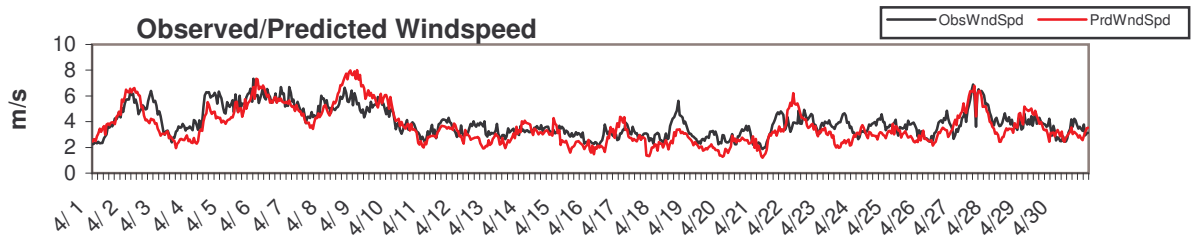


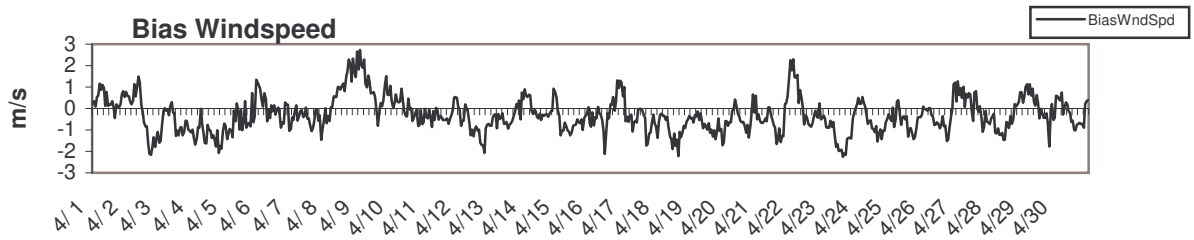


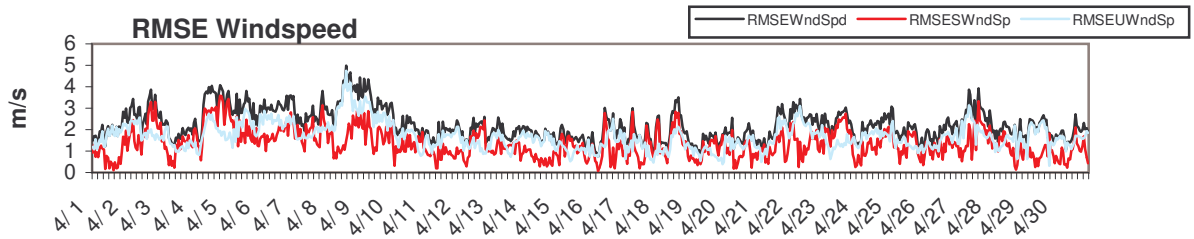


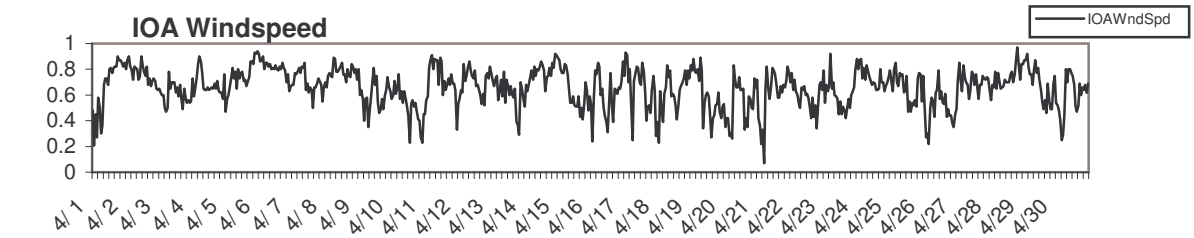


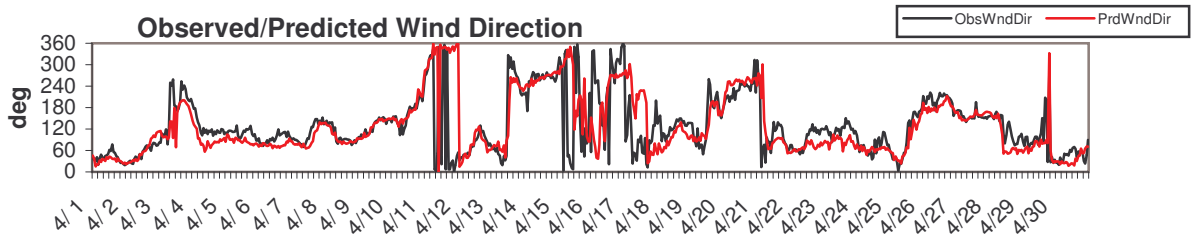
Alaska 5km 2004-04

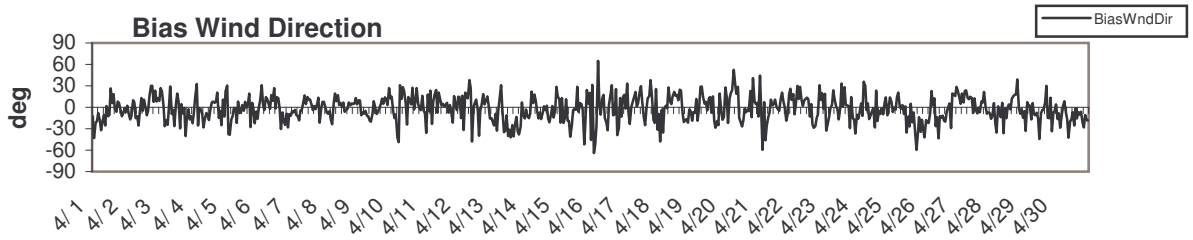




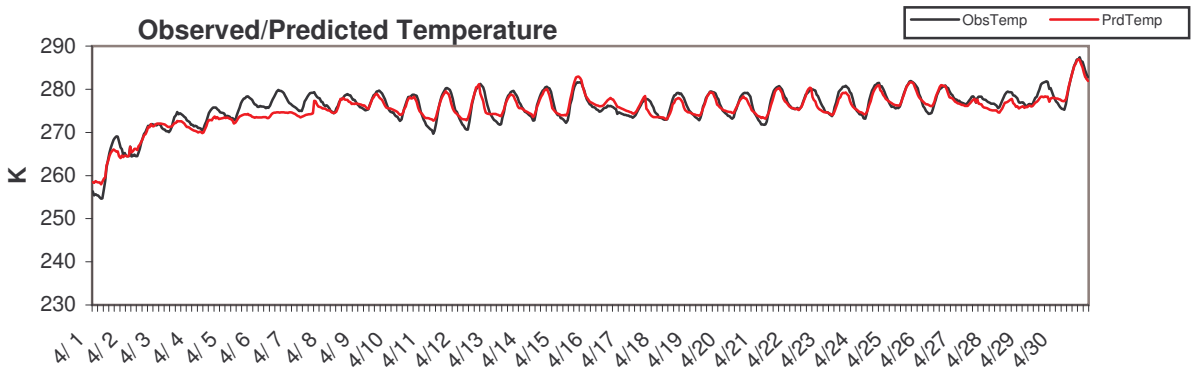


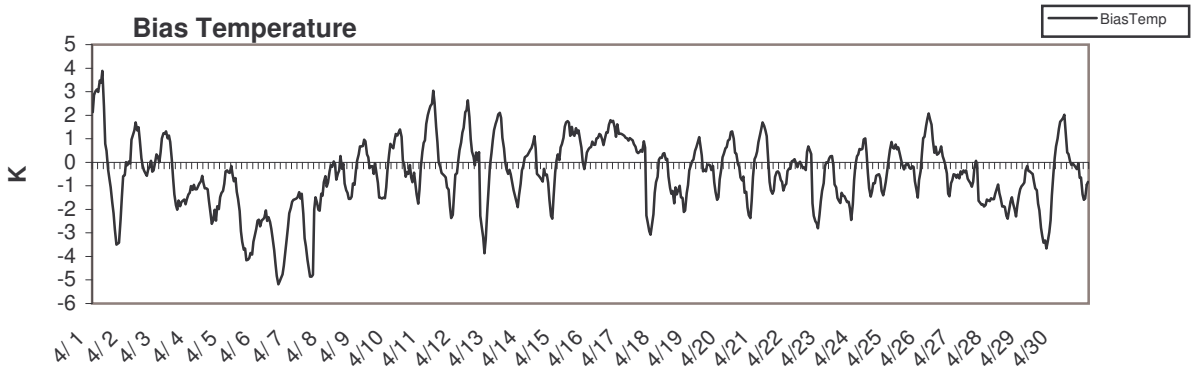


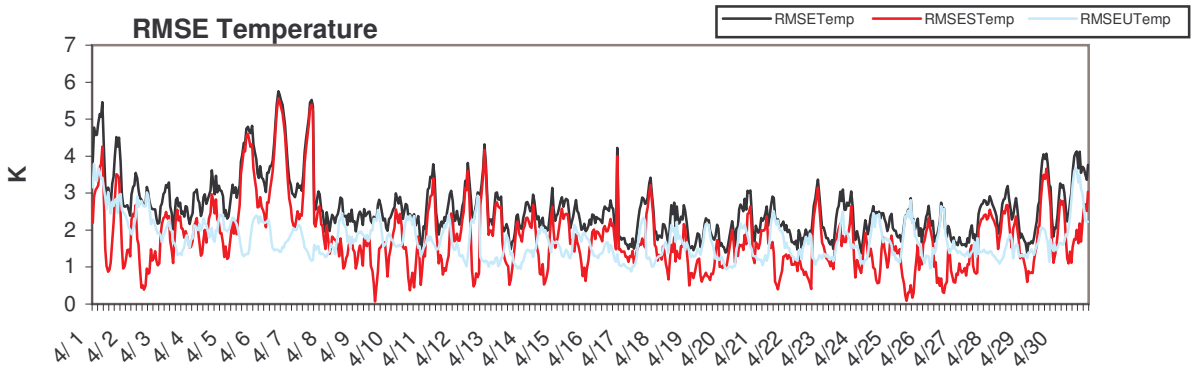


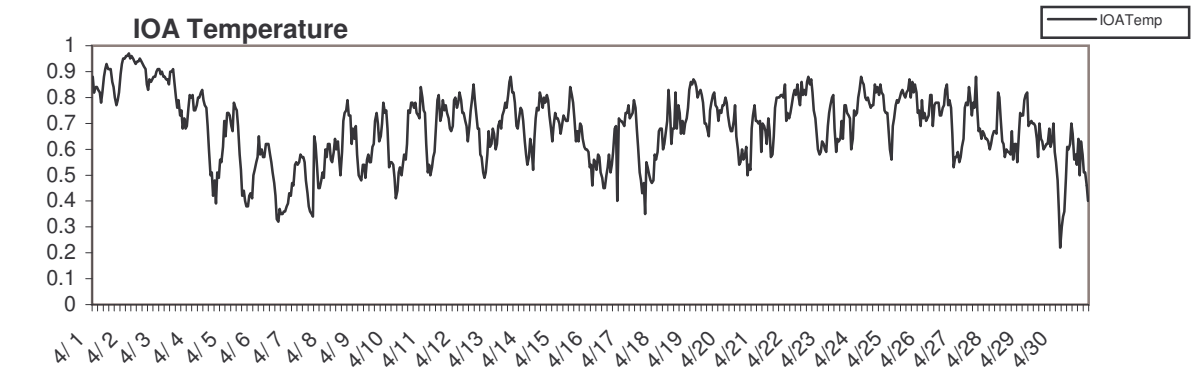


Alaska 5km 2004-04









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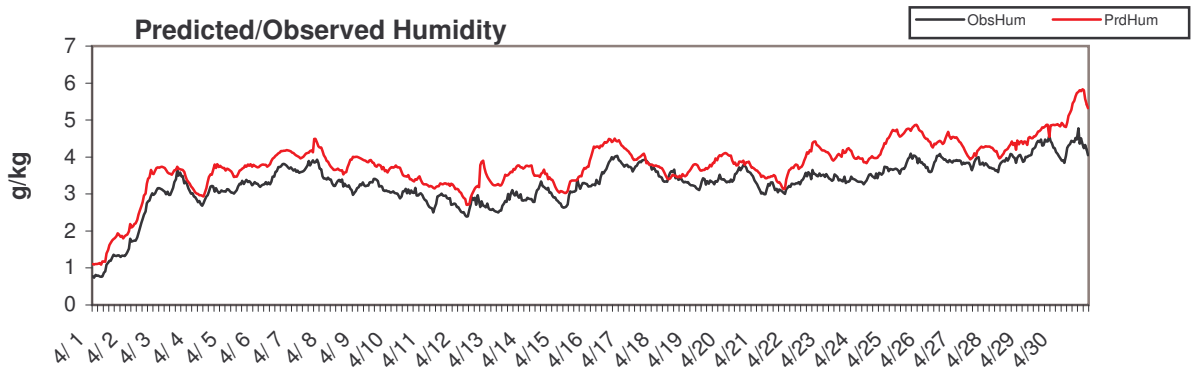
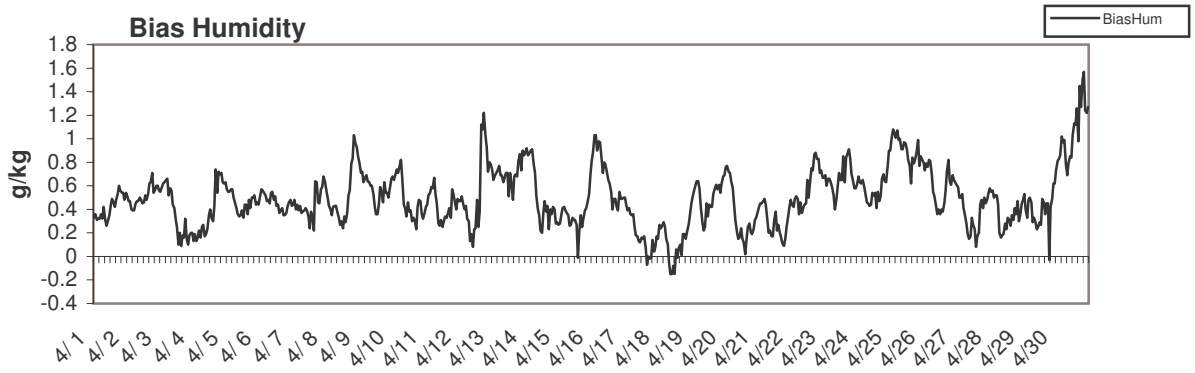
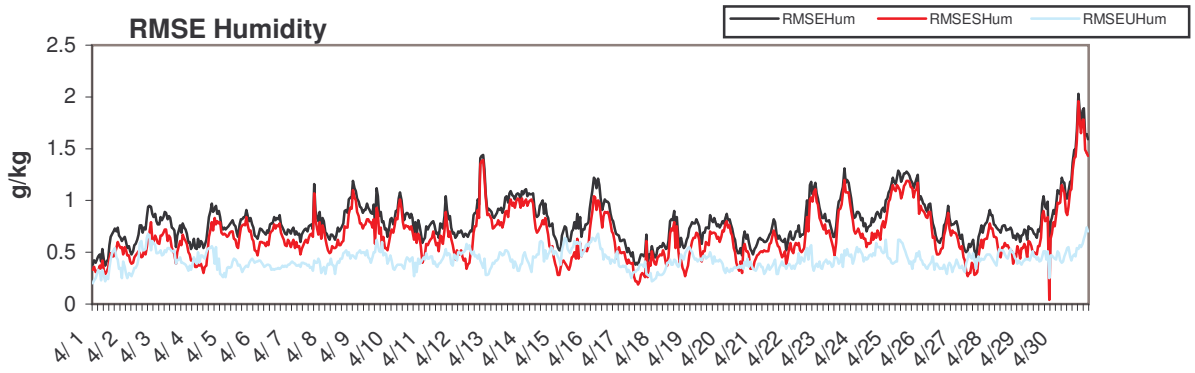
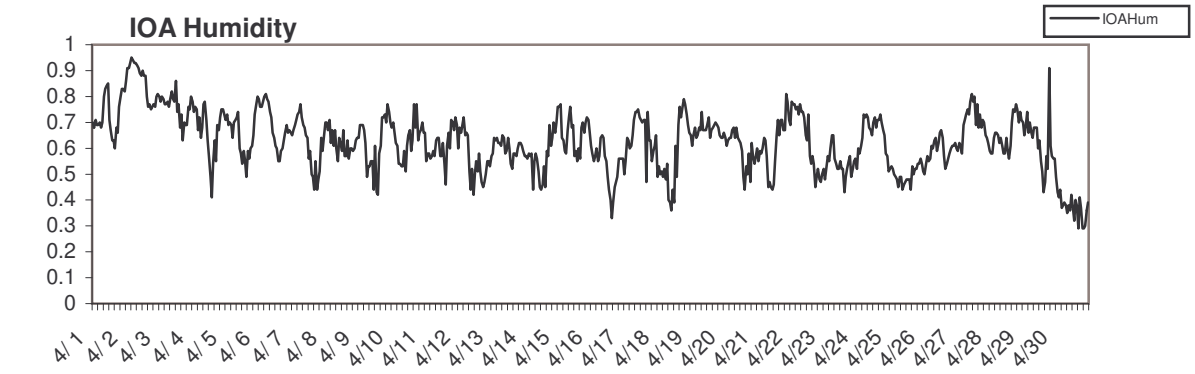
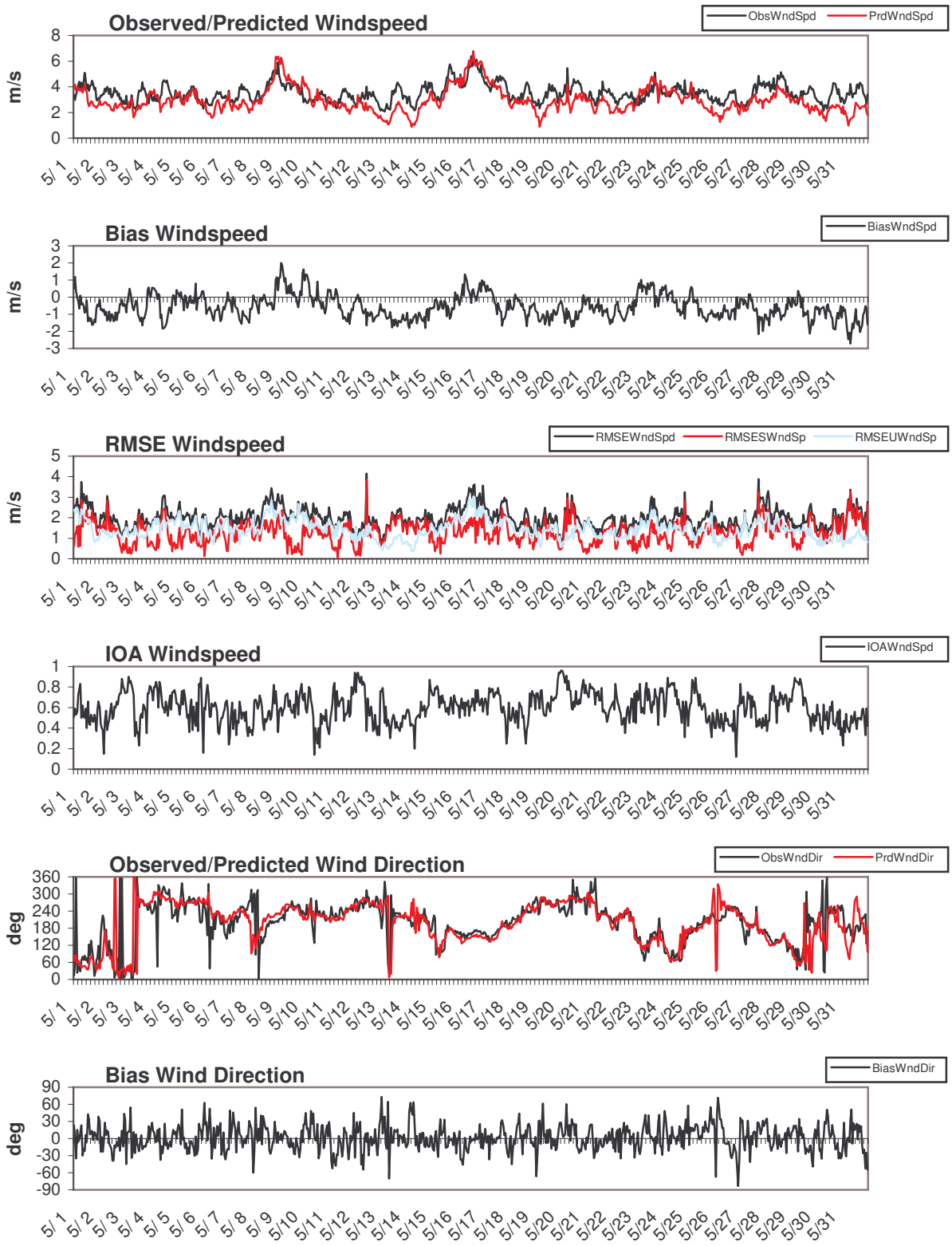




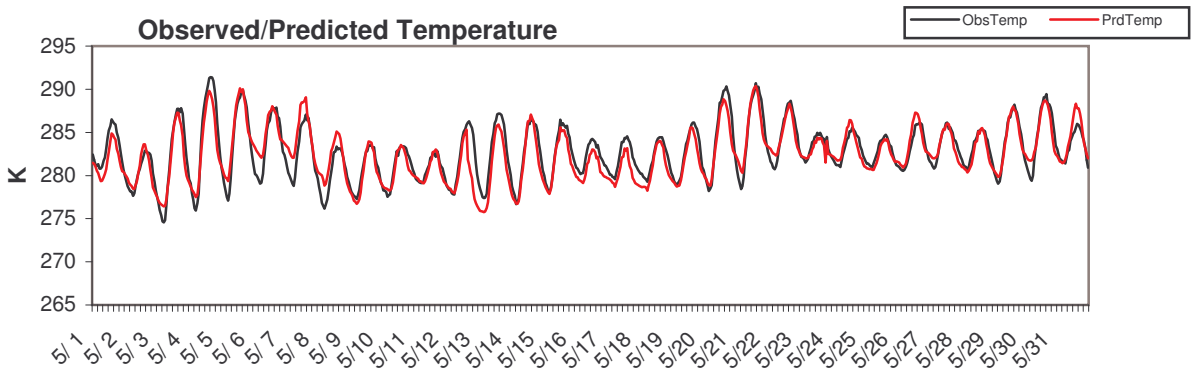


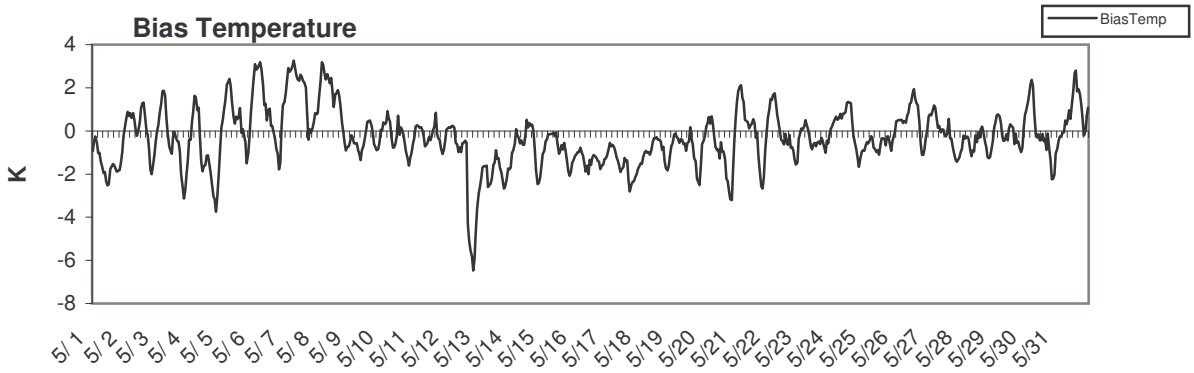


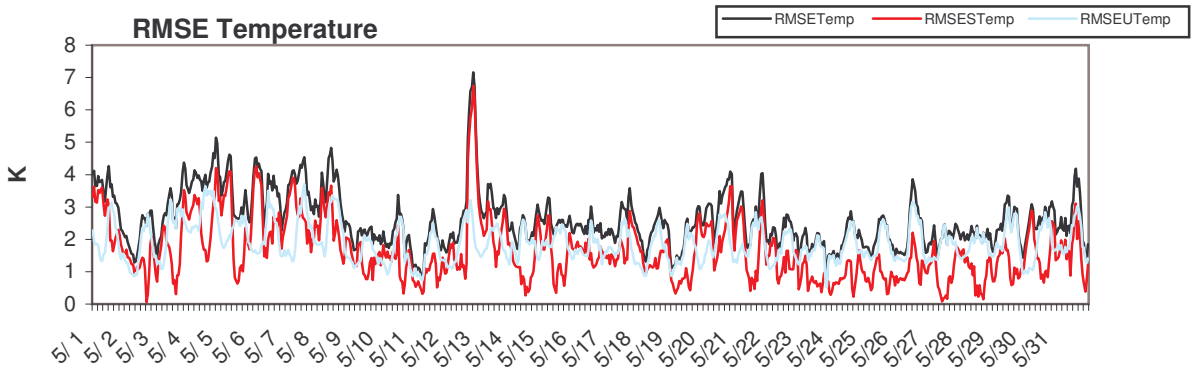
Alaska 5km 2004-05

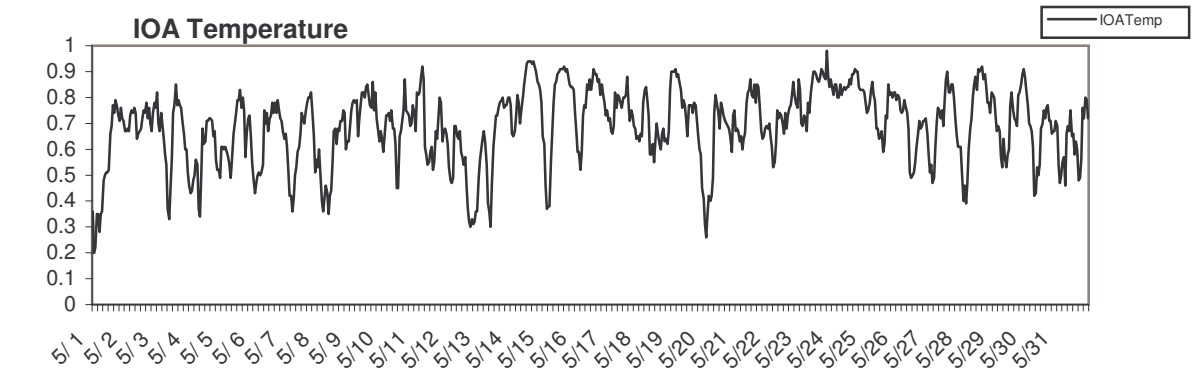


Alaska 5km 2004-05









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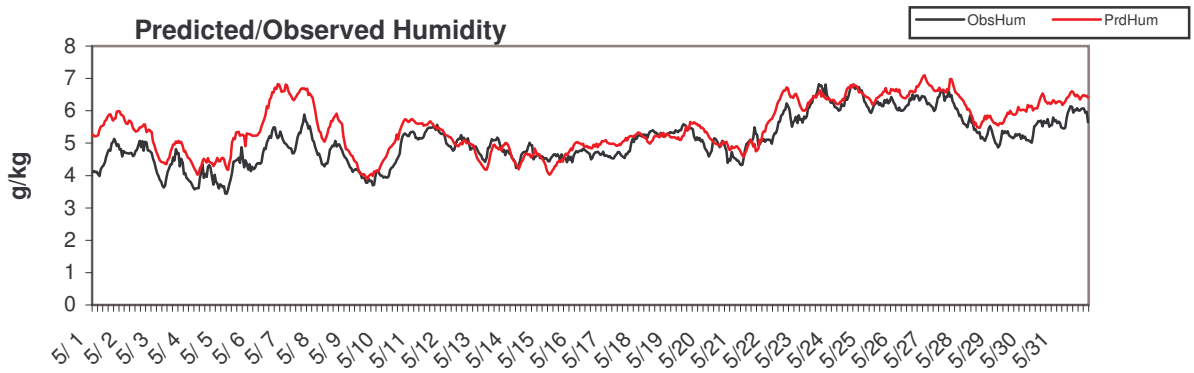
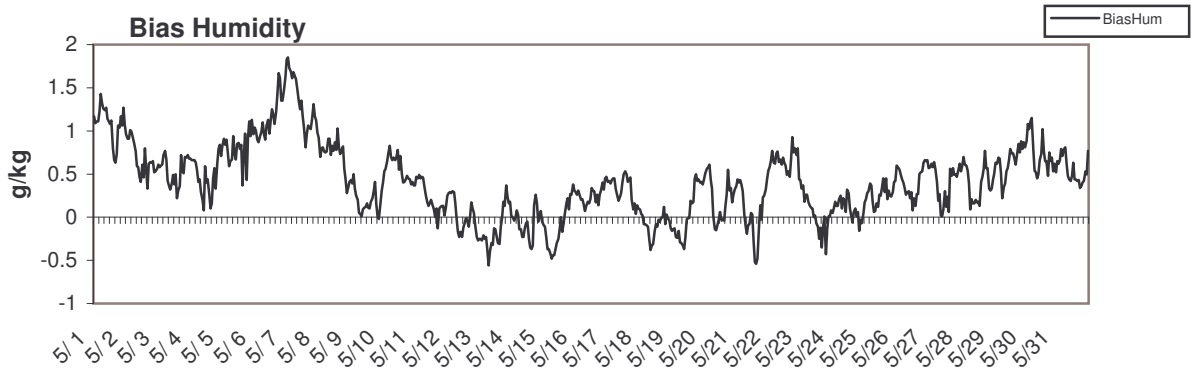
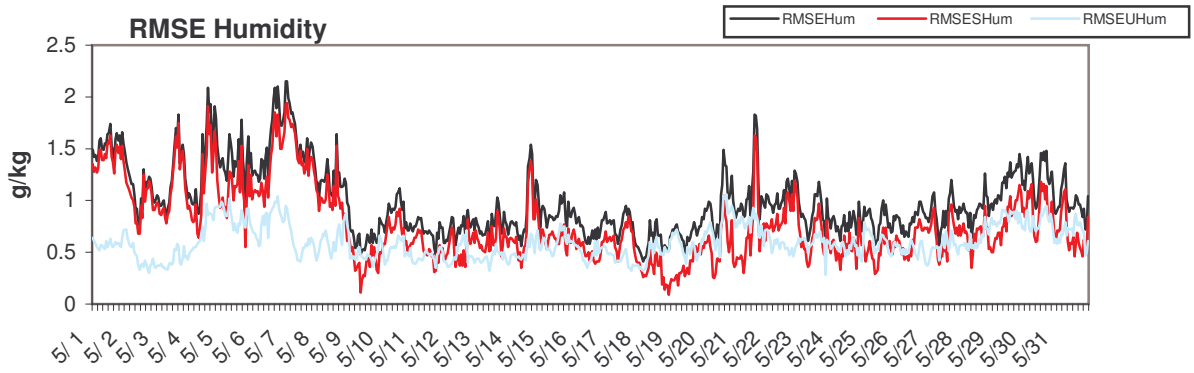
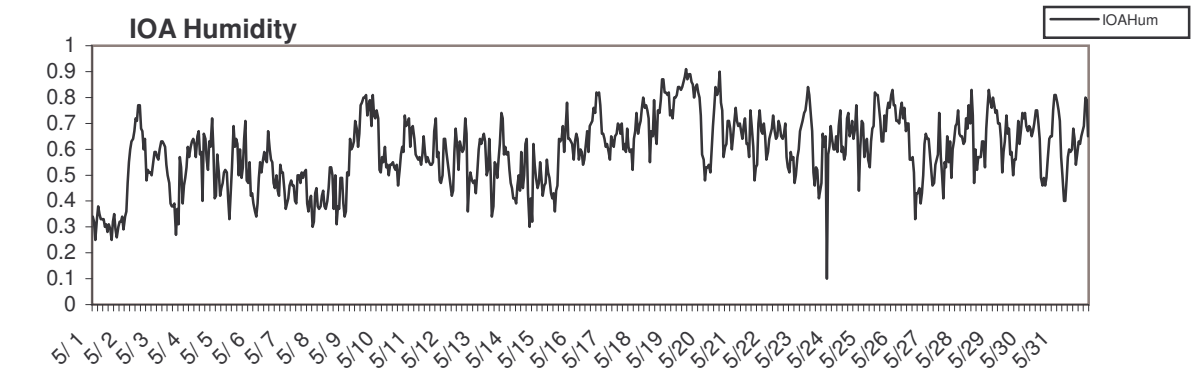
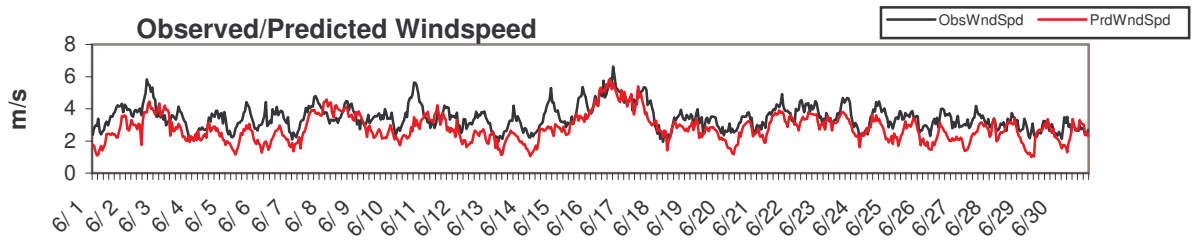


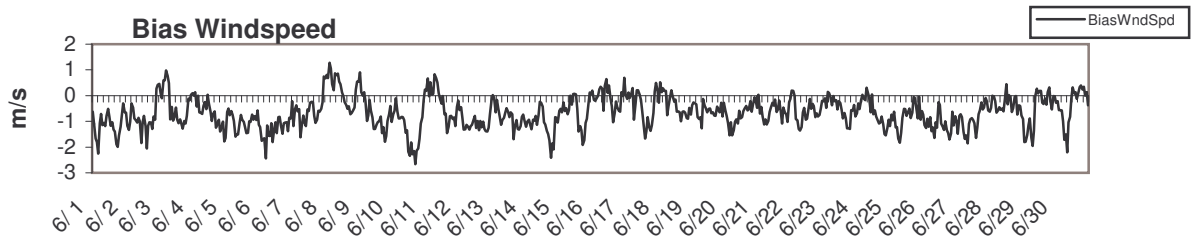


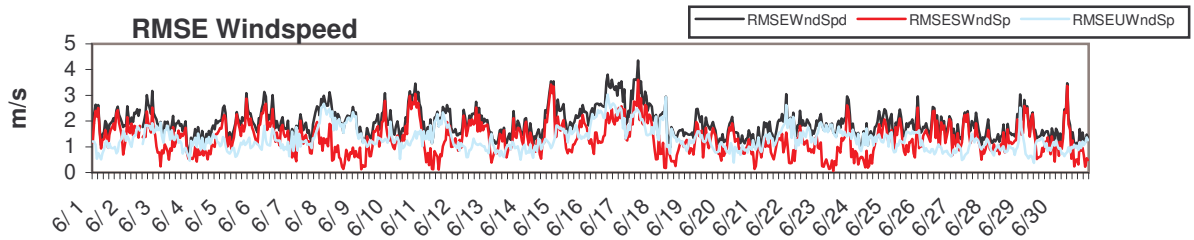


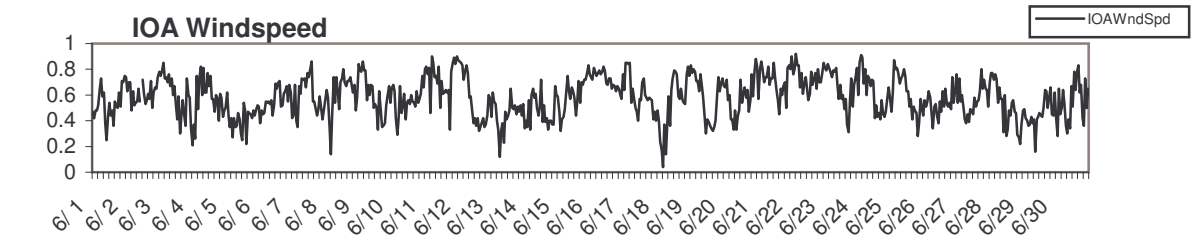


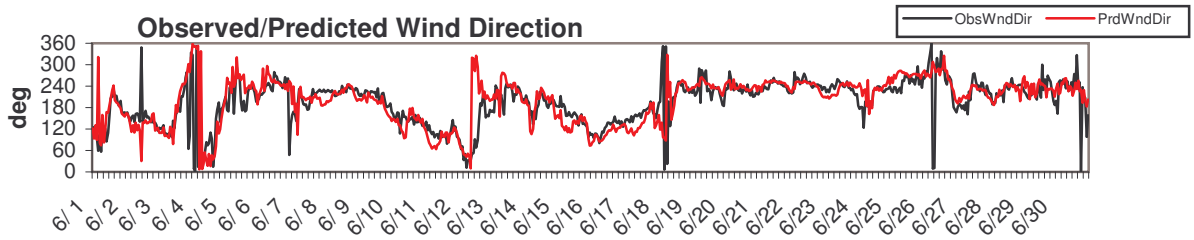
Alaska 5km 2004-06

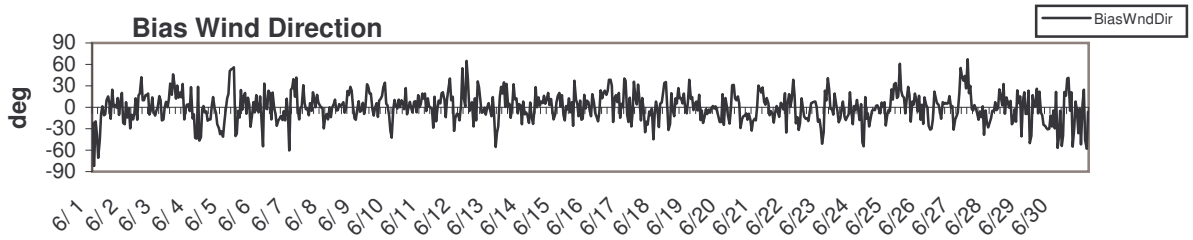




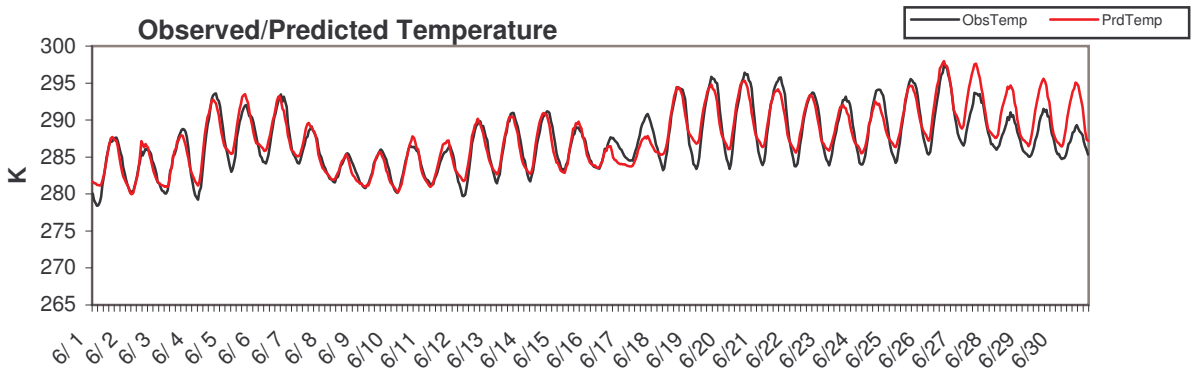


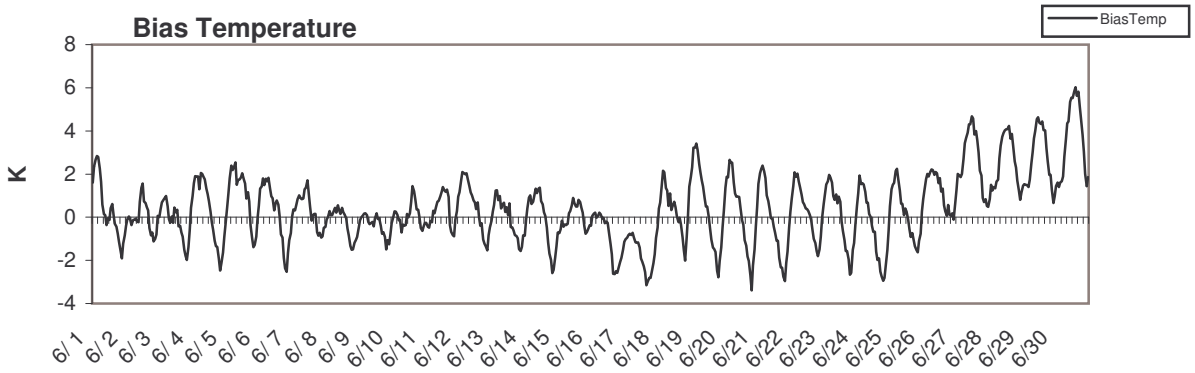


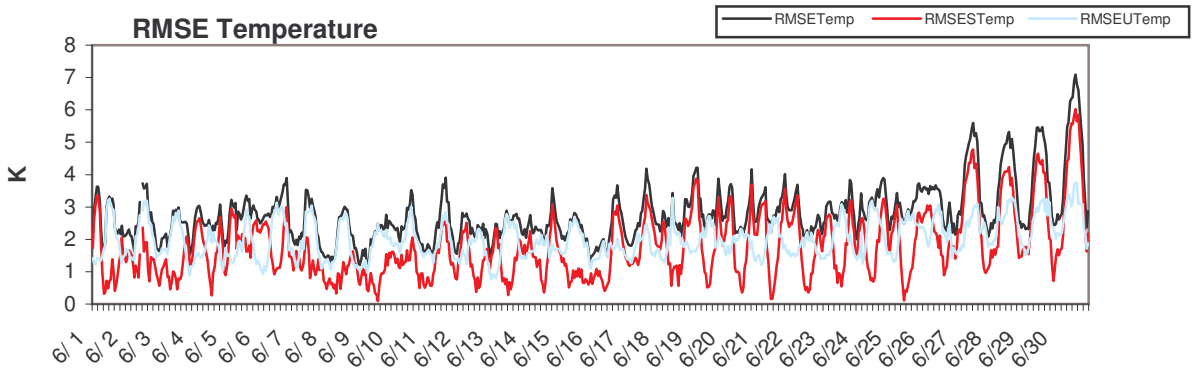


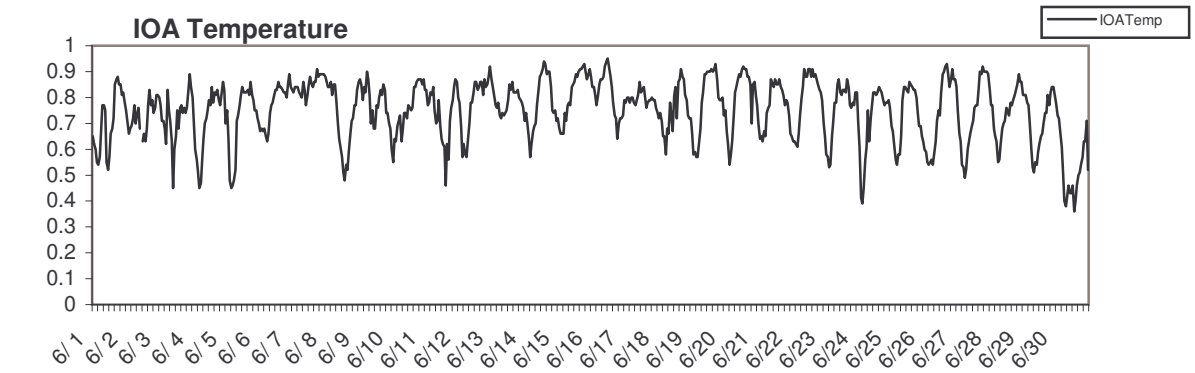


Alaska 5km 2004-06

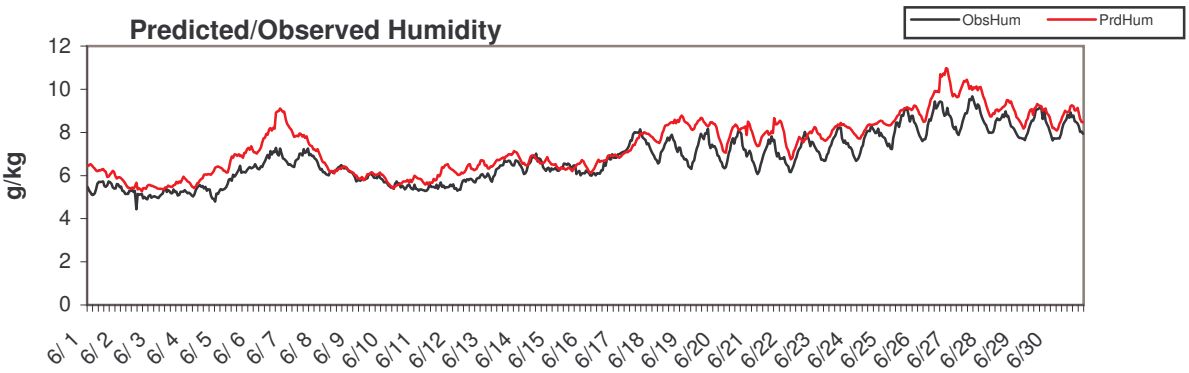


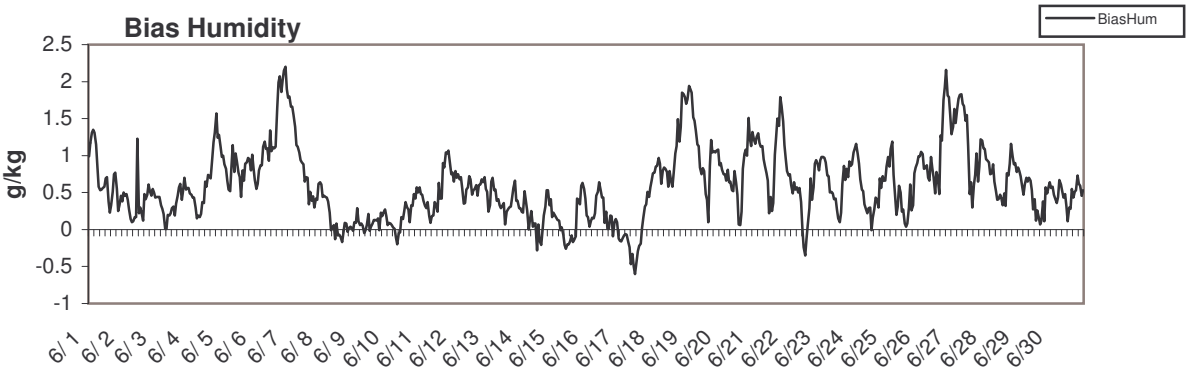


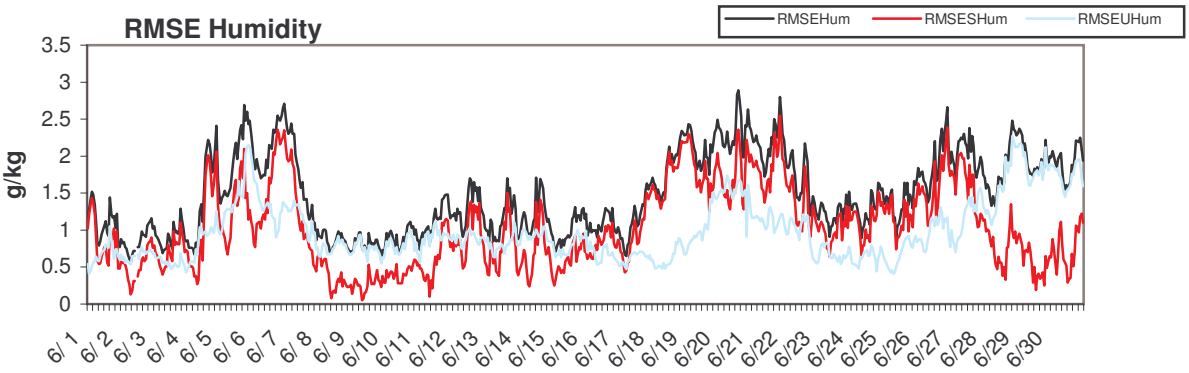


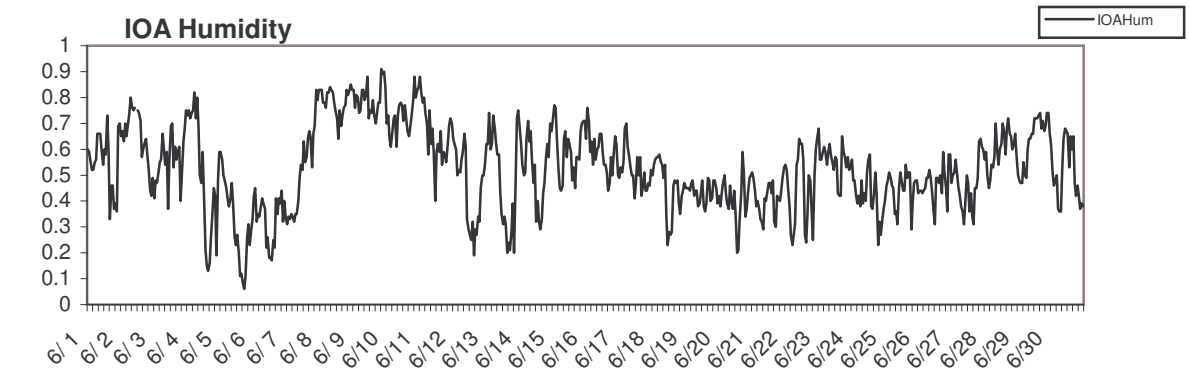


Alaska 5km 2004-06

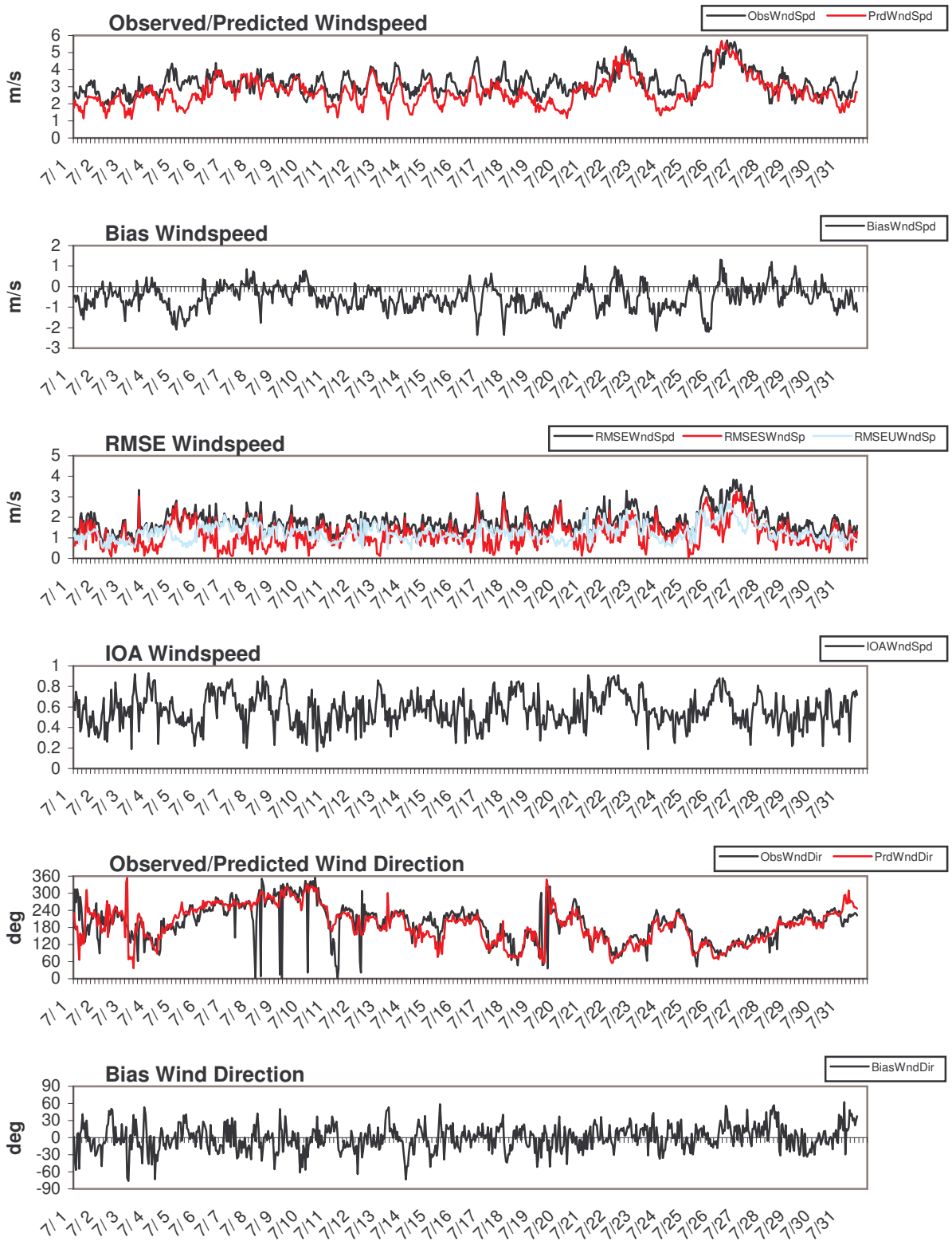




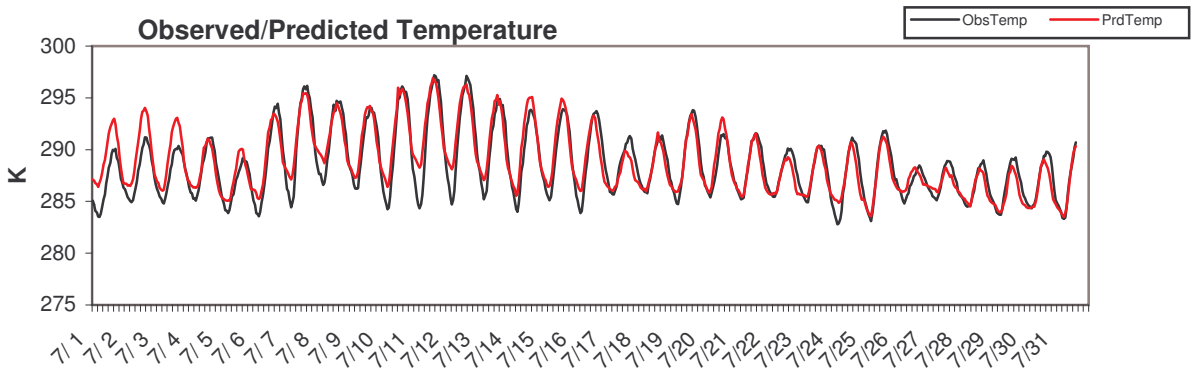


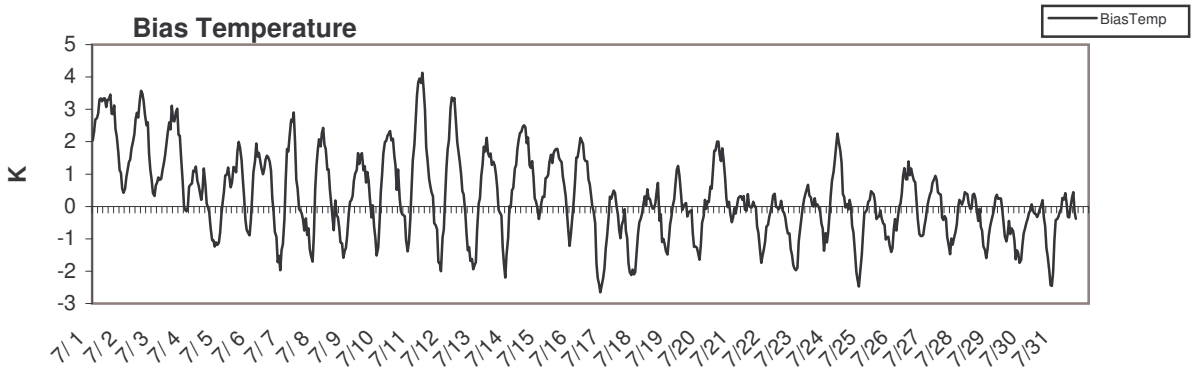


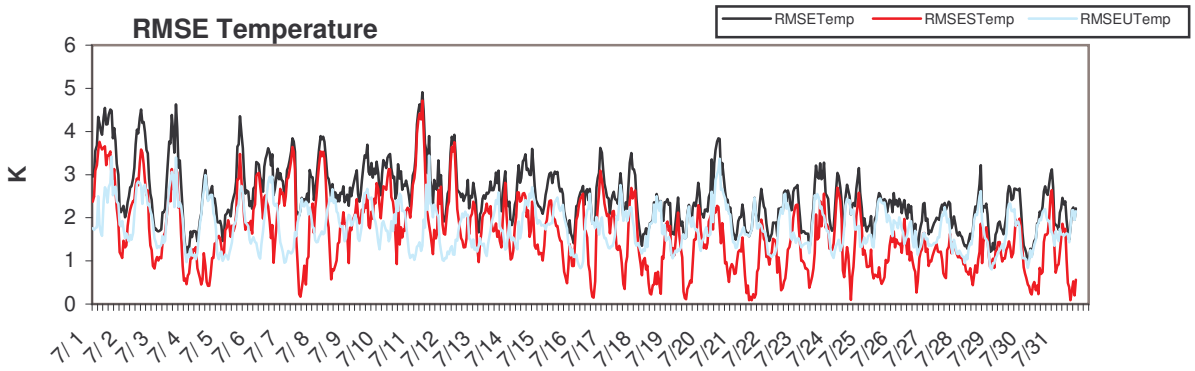
Alaska 5km 2004-07

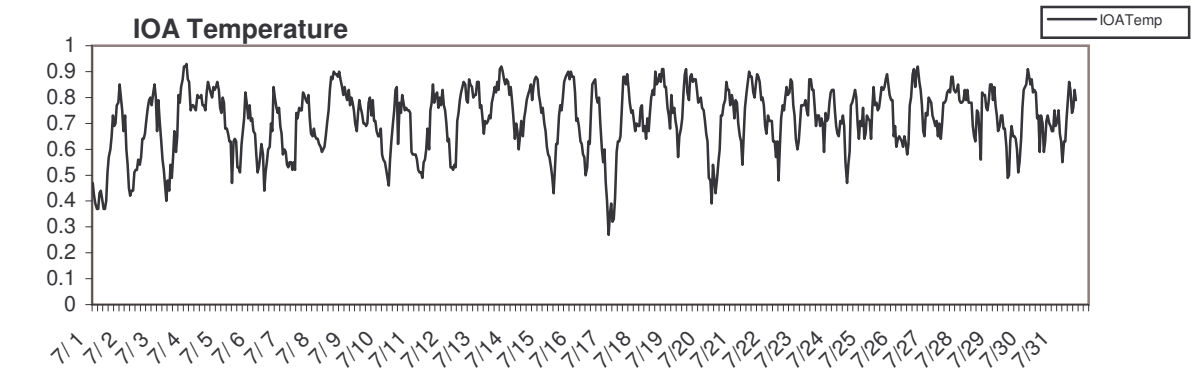


Alaska 5km 2004-07

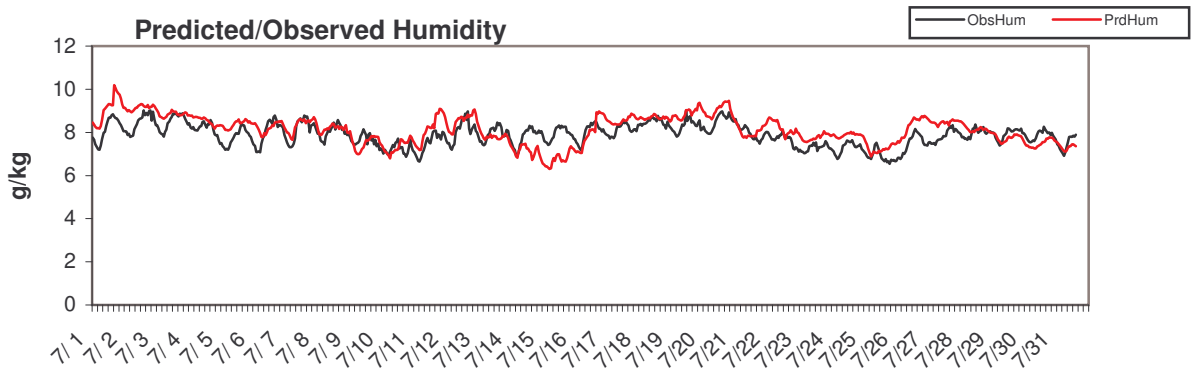


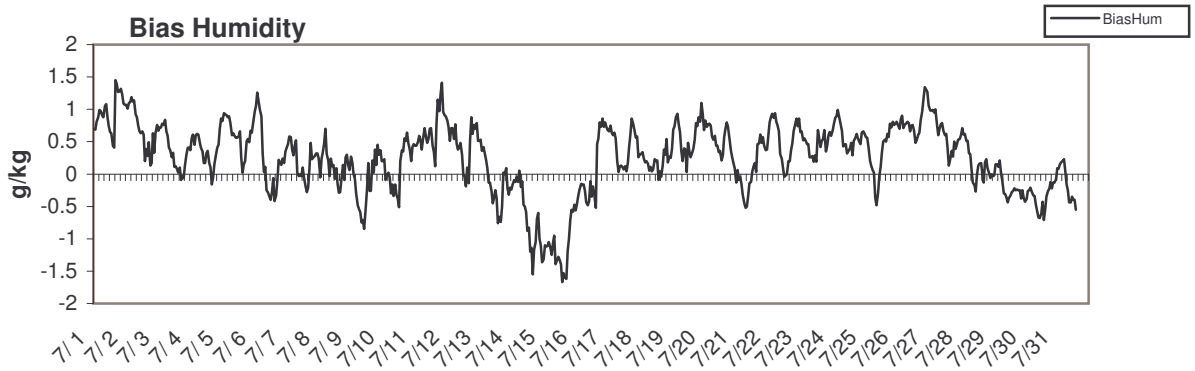


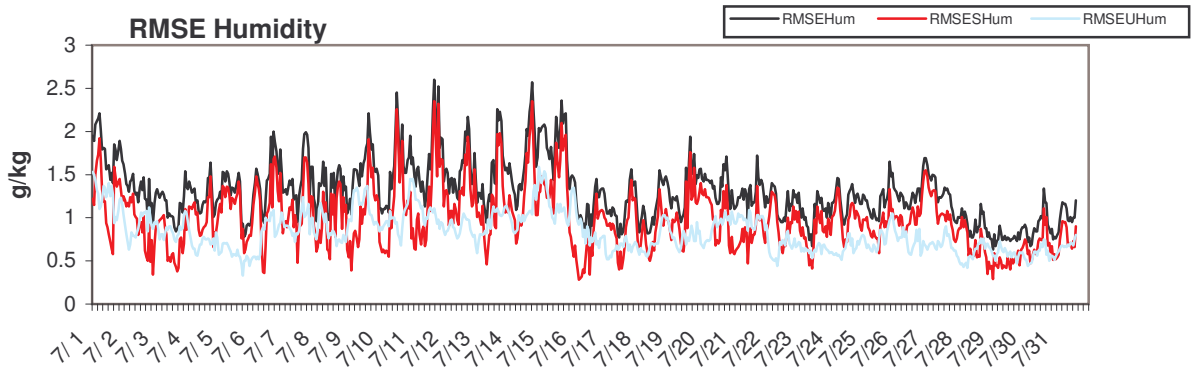


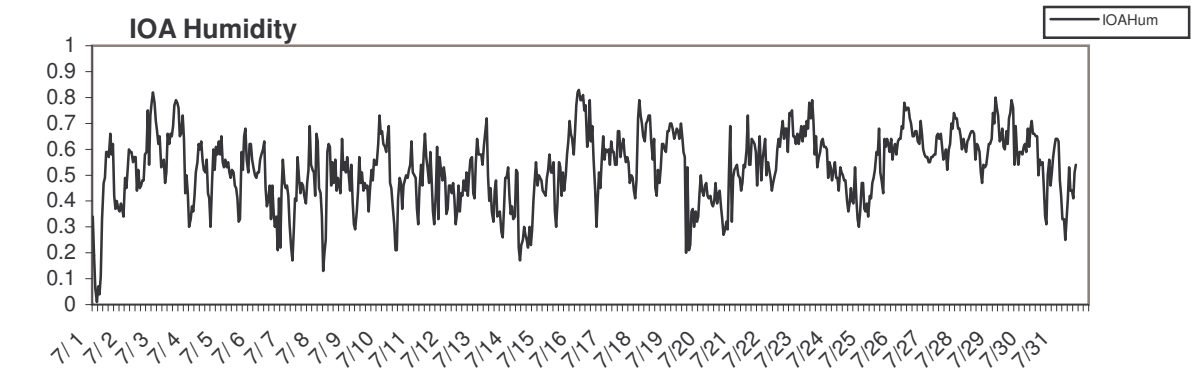


Alaska 5km 2004-07

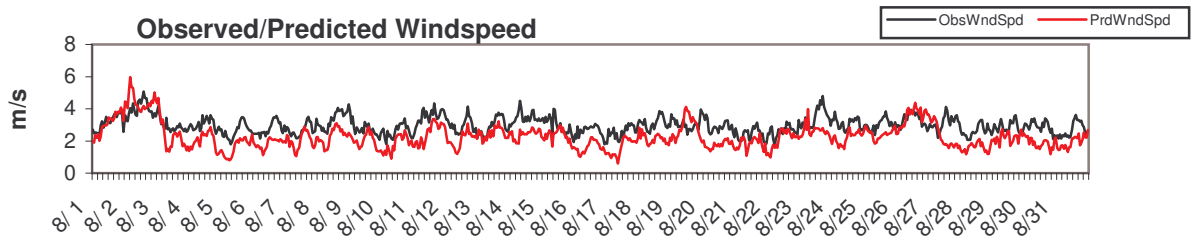


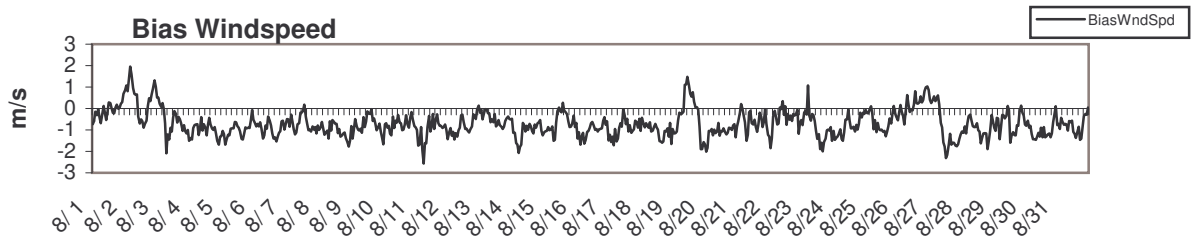


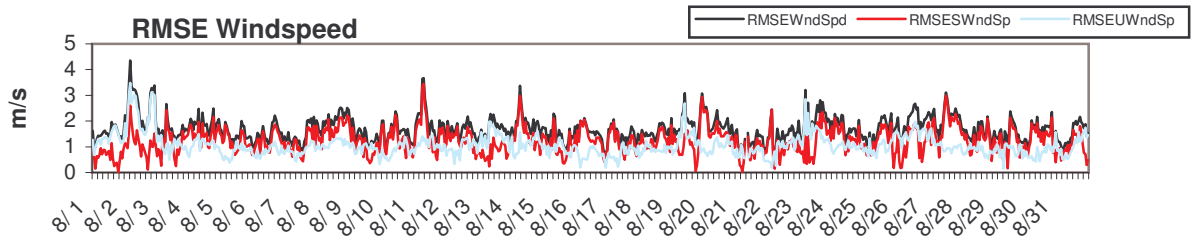


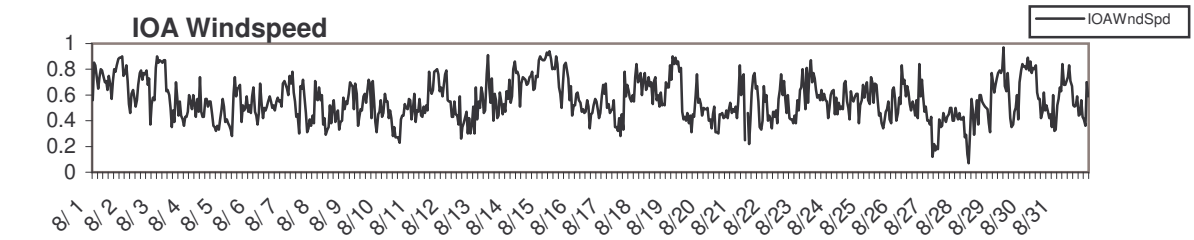


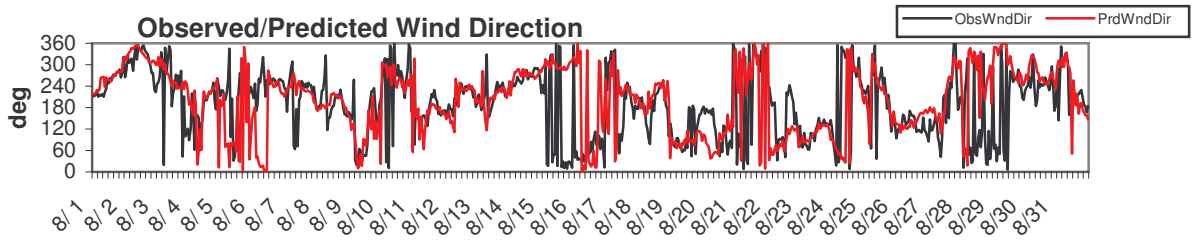
Alaska 5km 2004-08

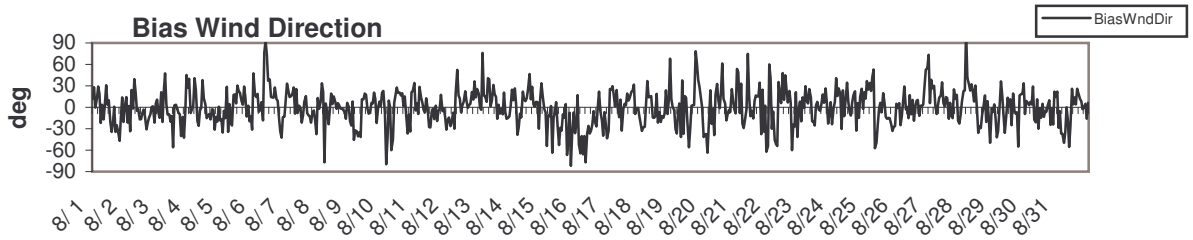




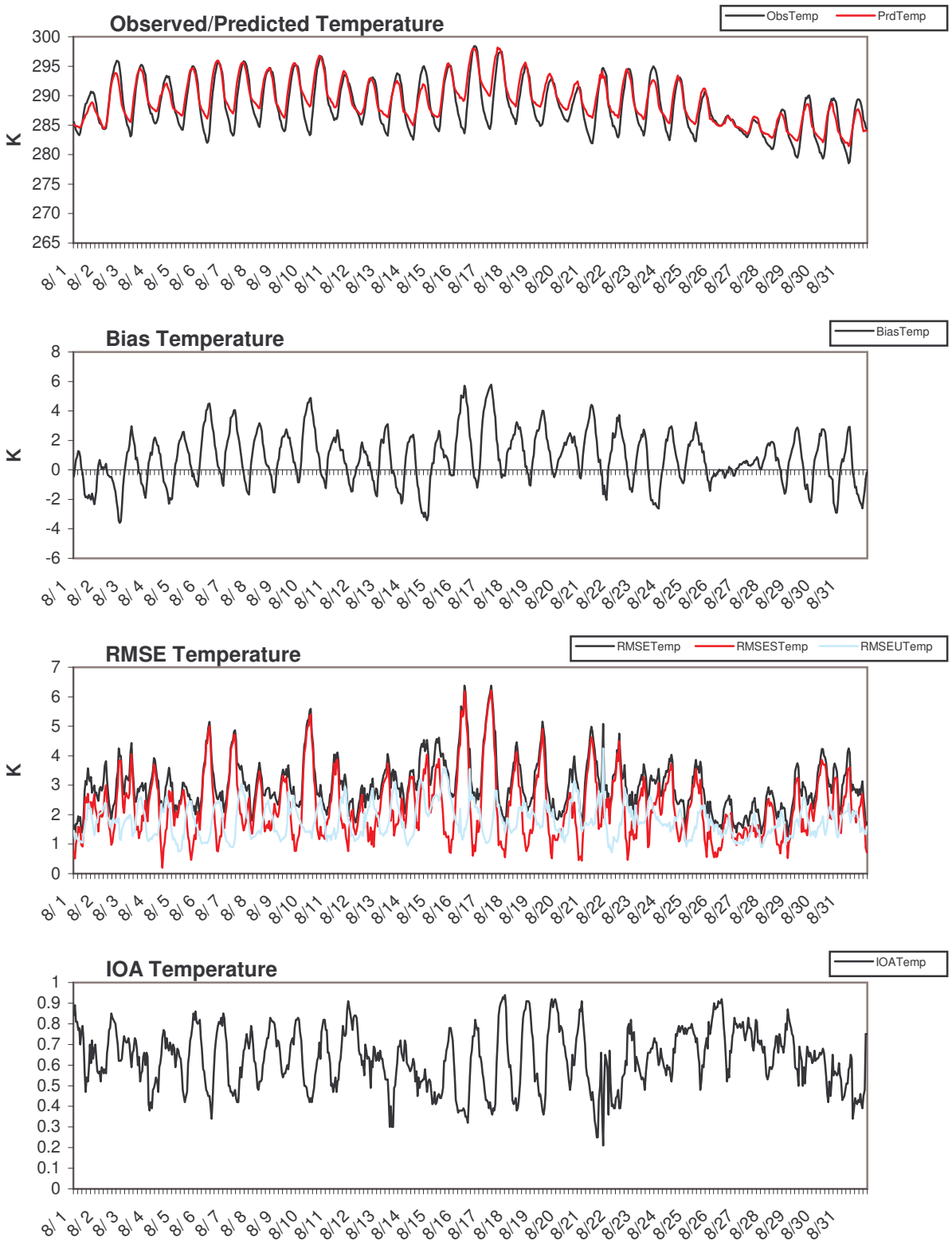




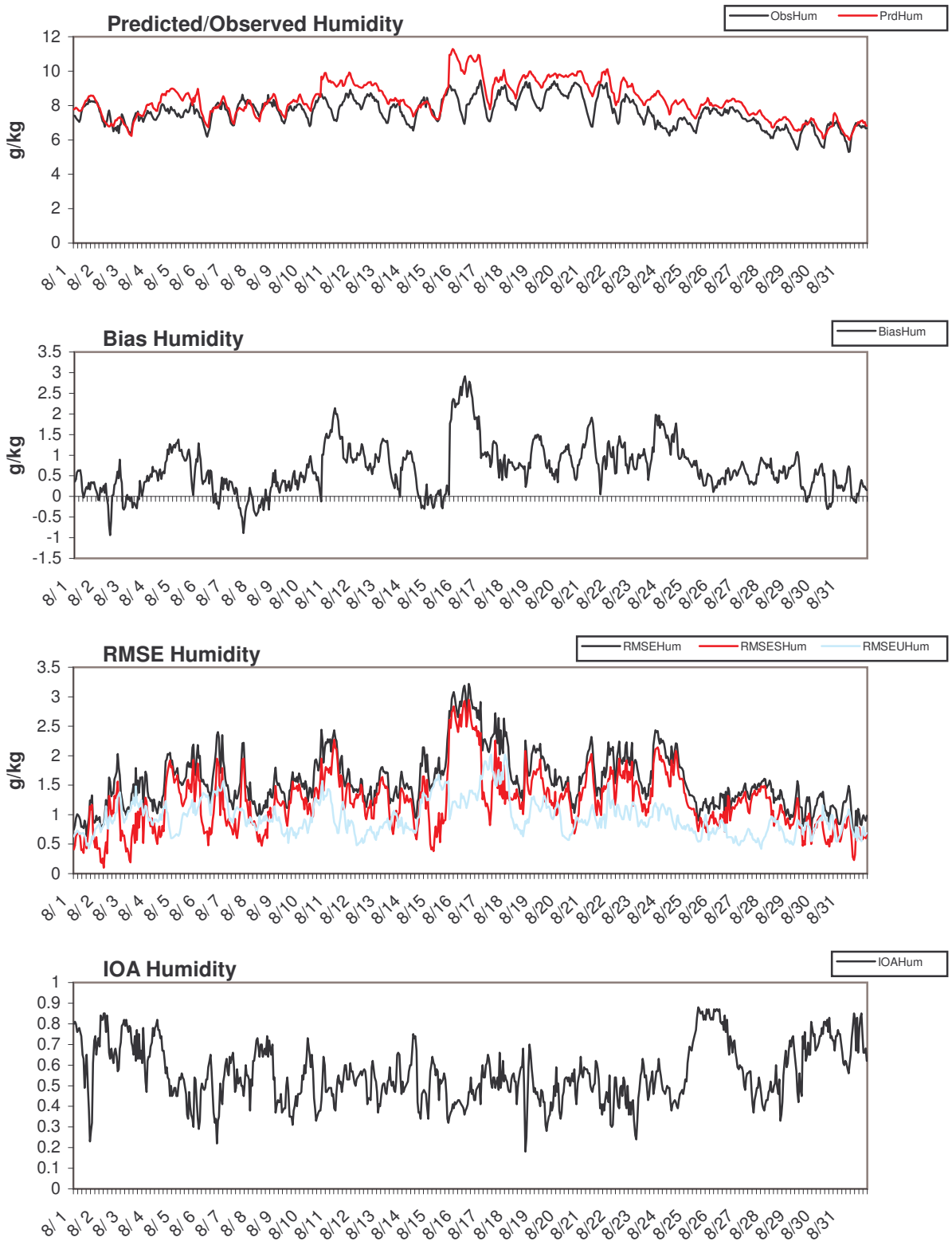




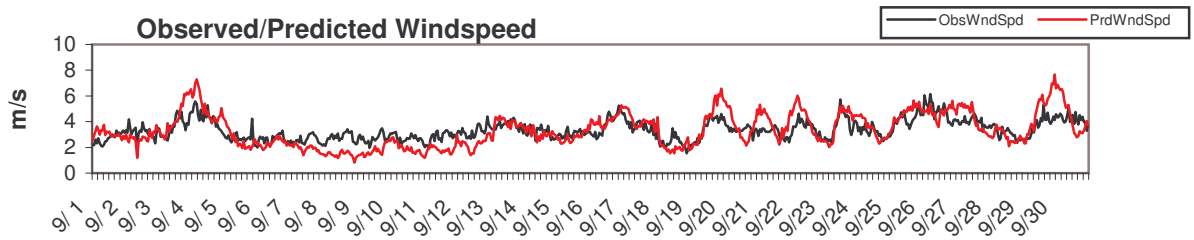
Alaska 5km 2004-08

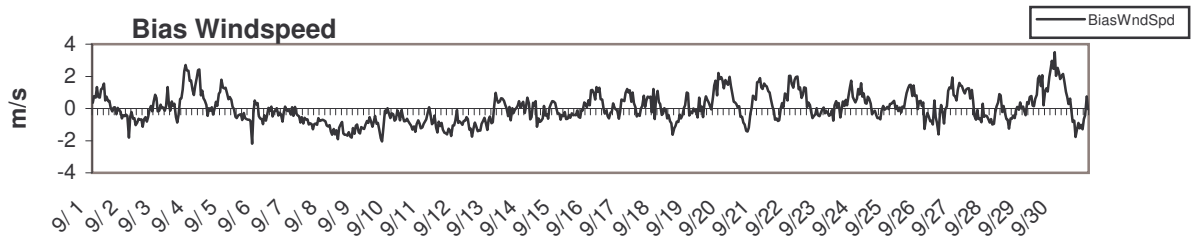


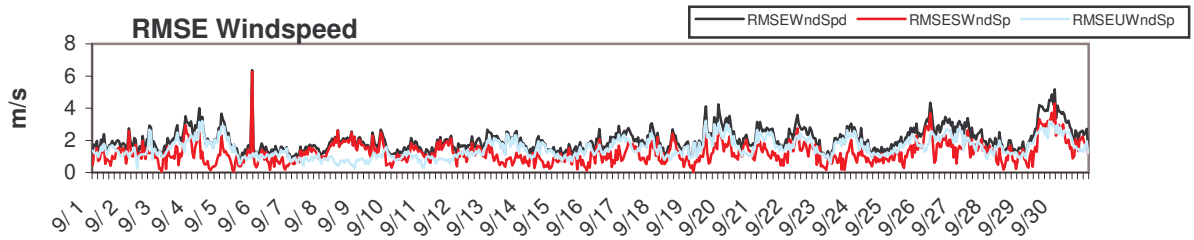
Alaska 5km 2004-08

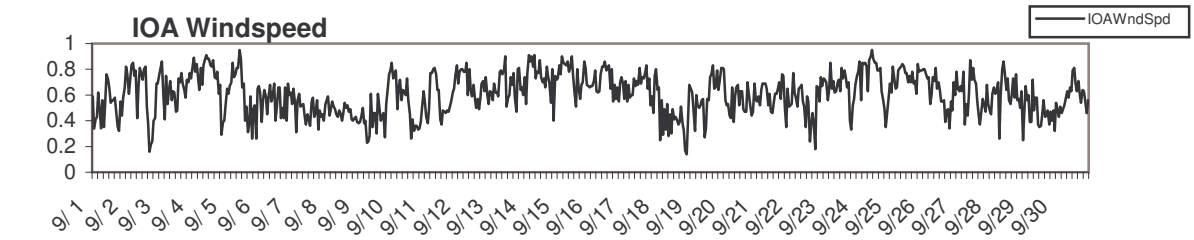


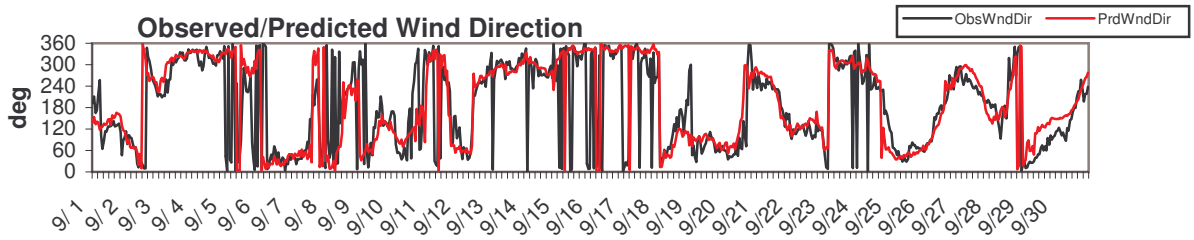
Alaska 5km 2004-09

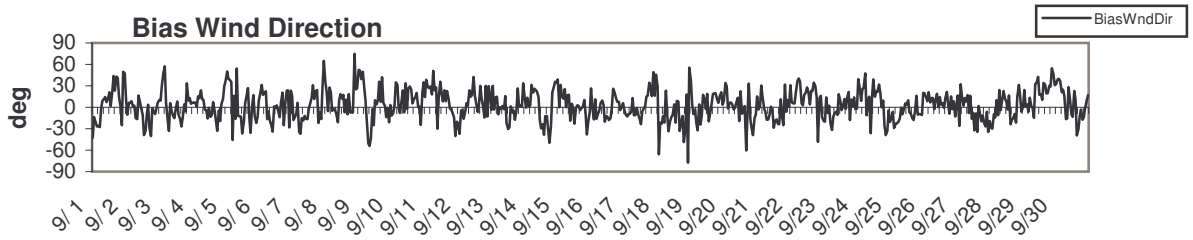




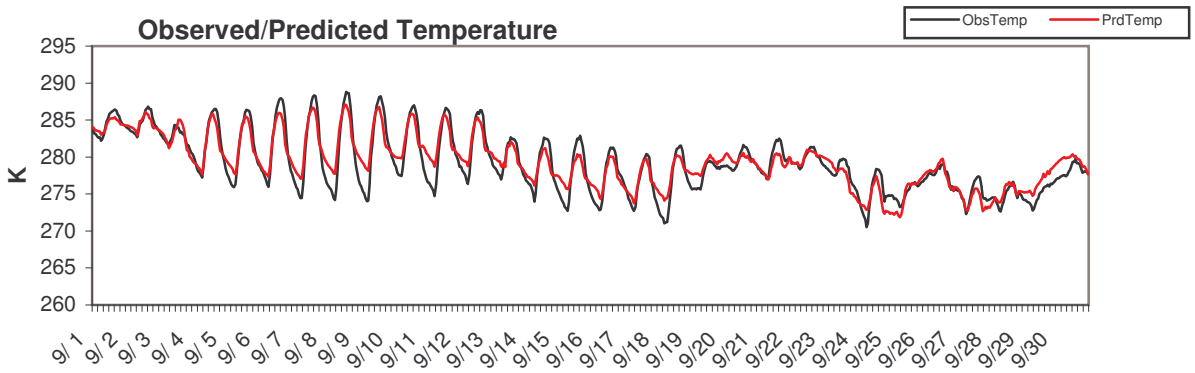


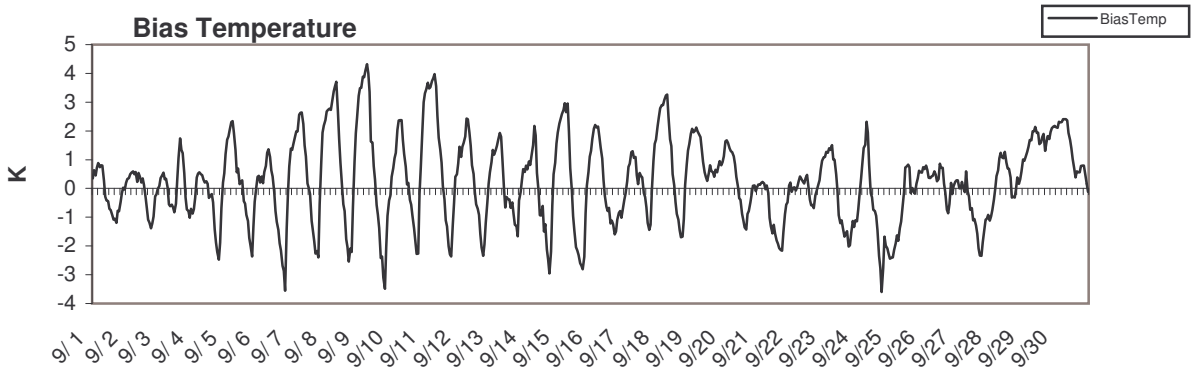


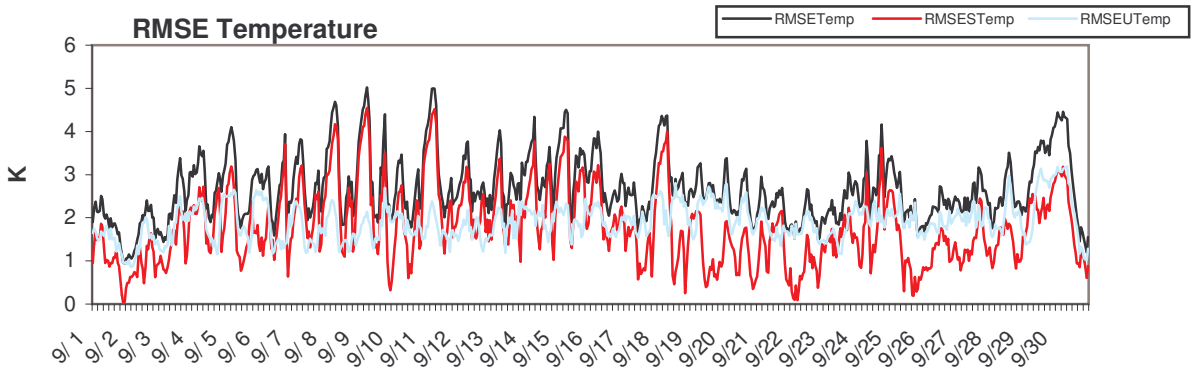


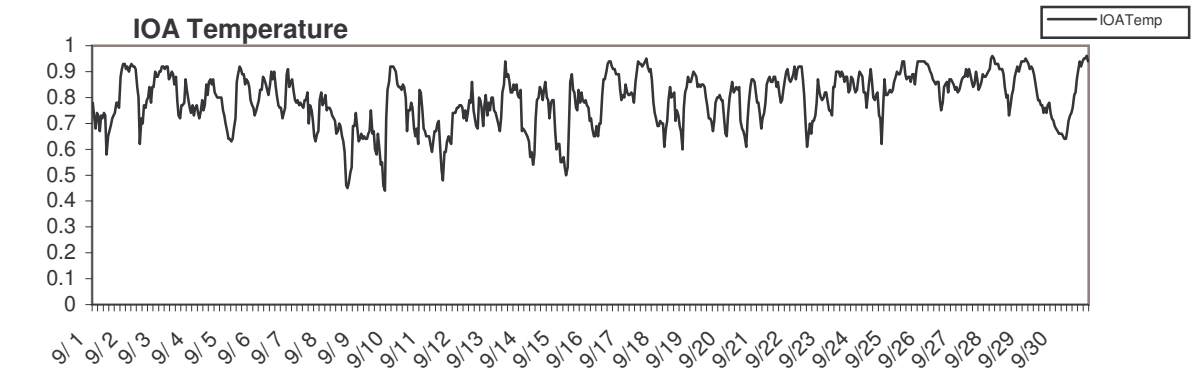


Alaska 5km 2004-09









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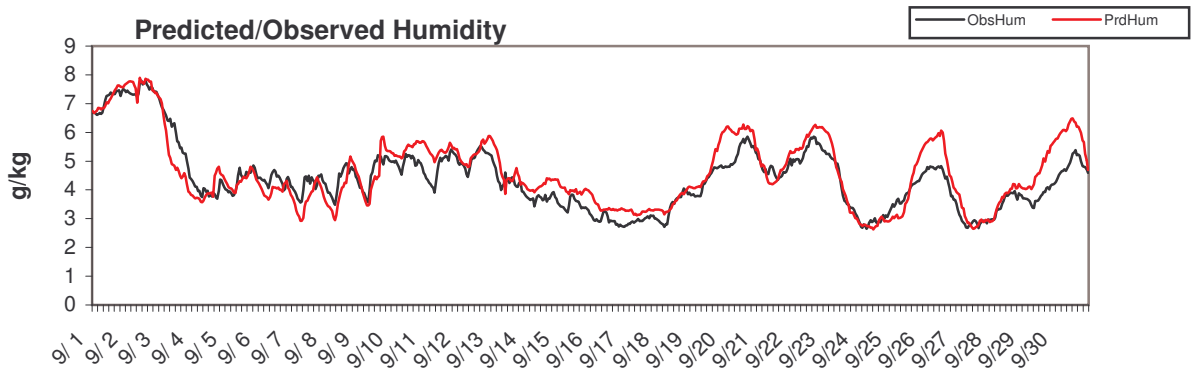
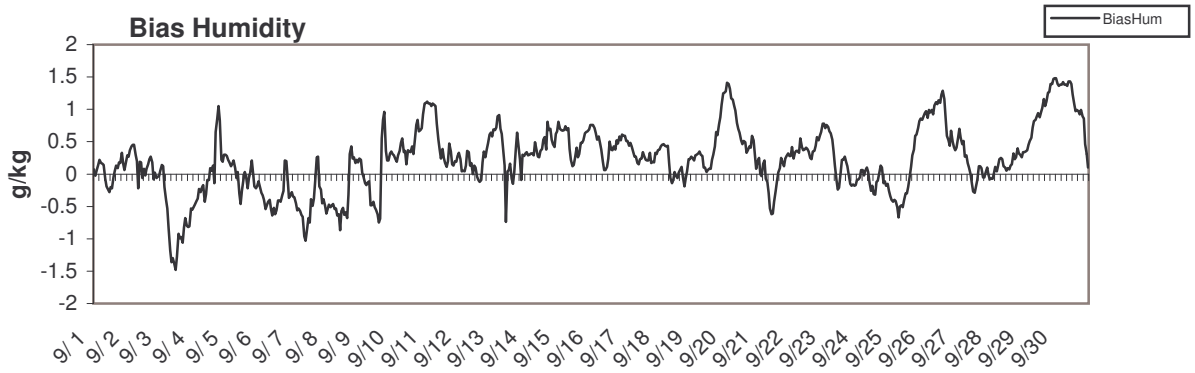
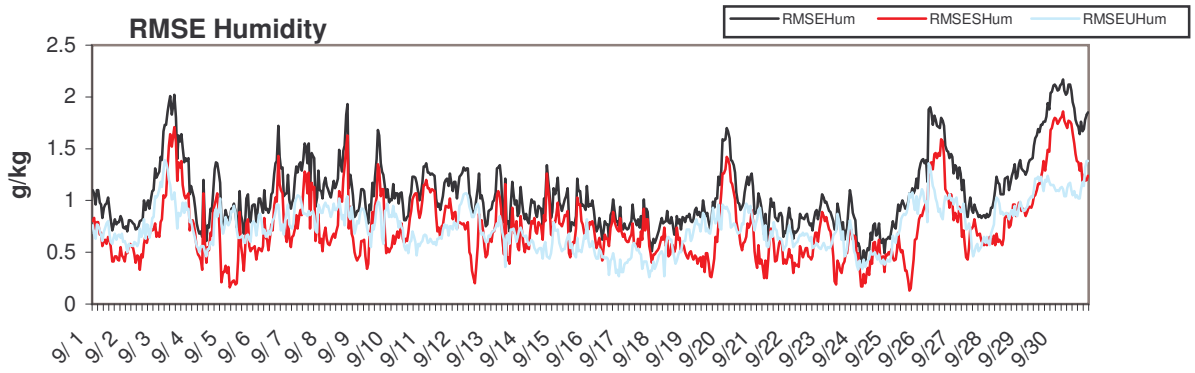
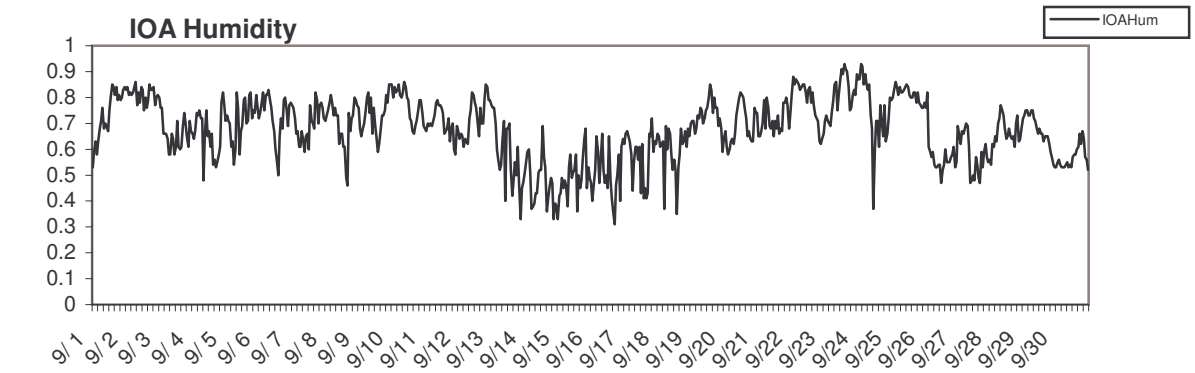
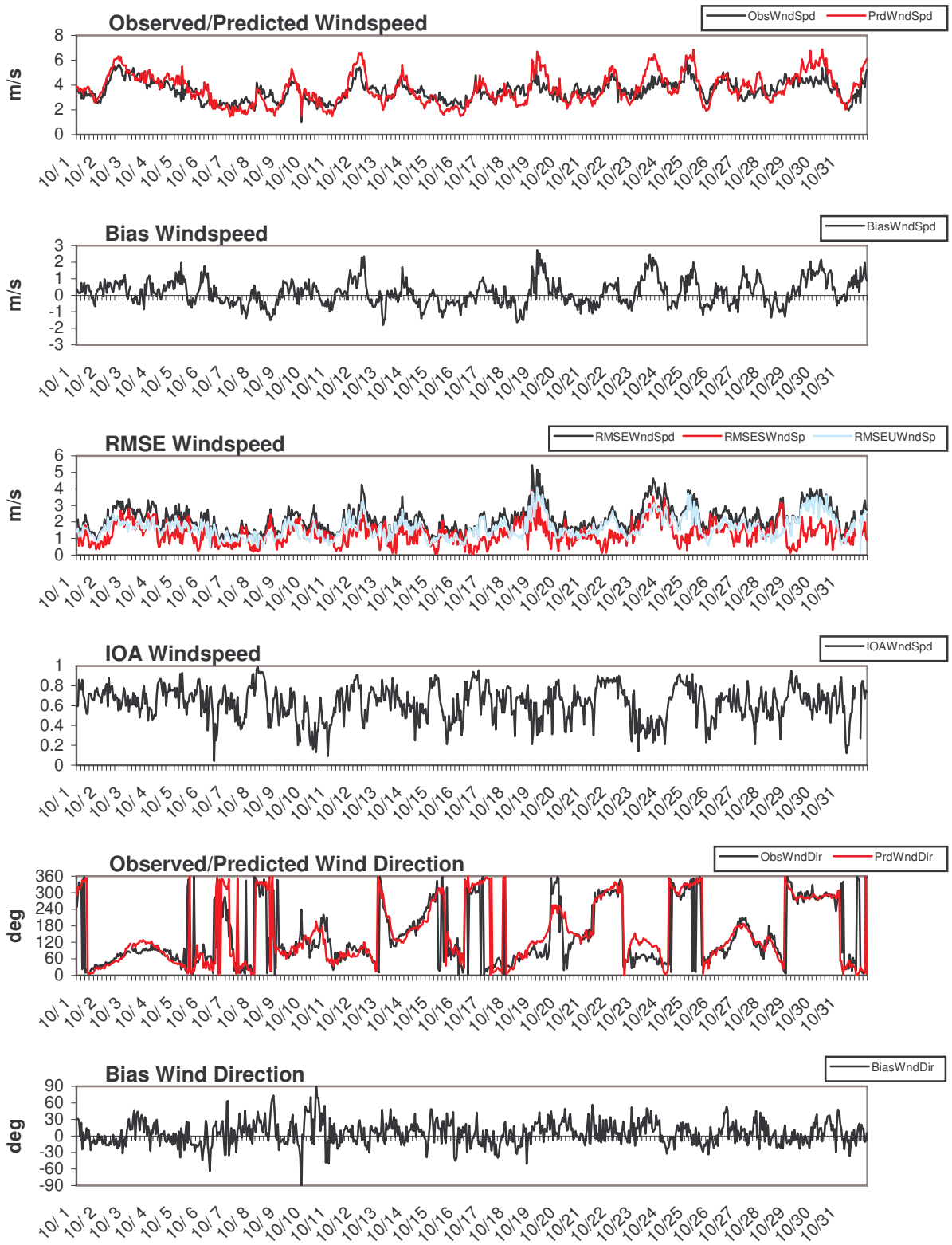




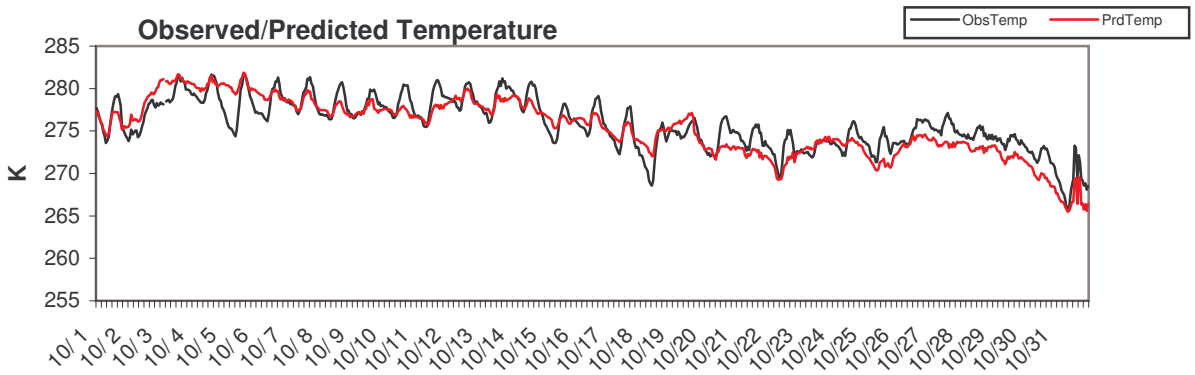


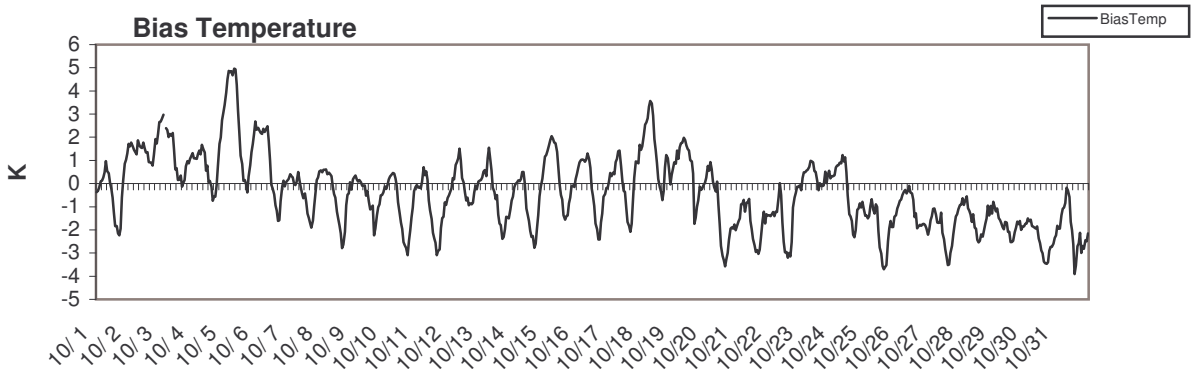


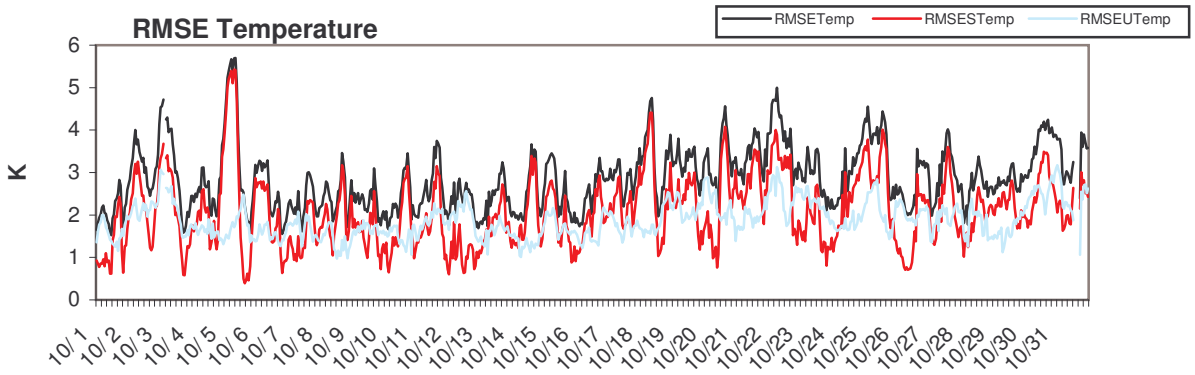
Alaska 5km 2004-10

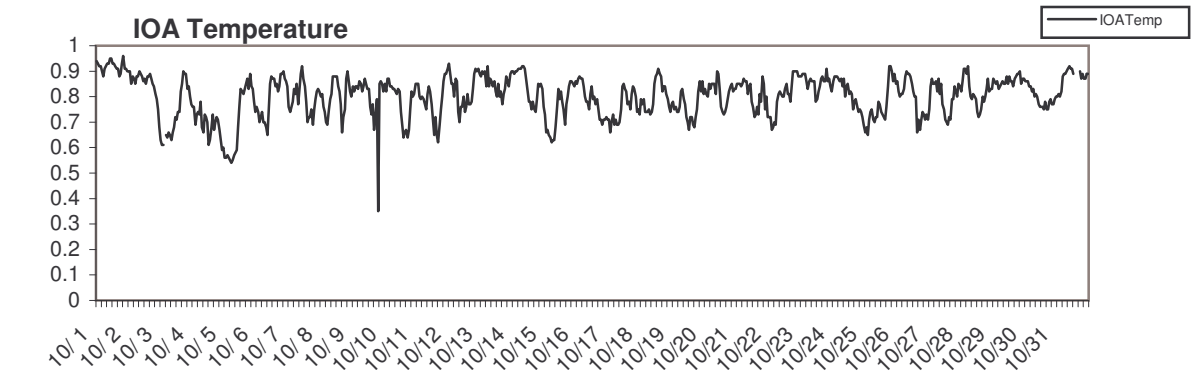


Alaska 5km 2004-10









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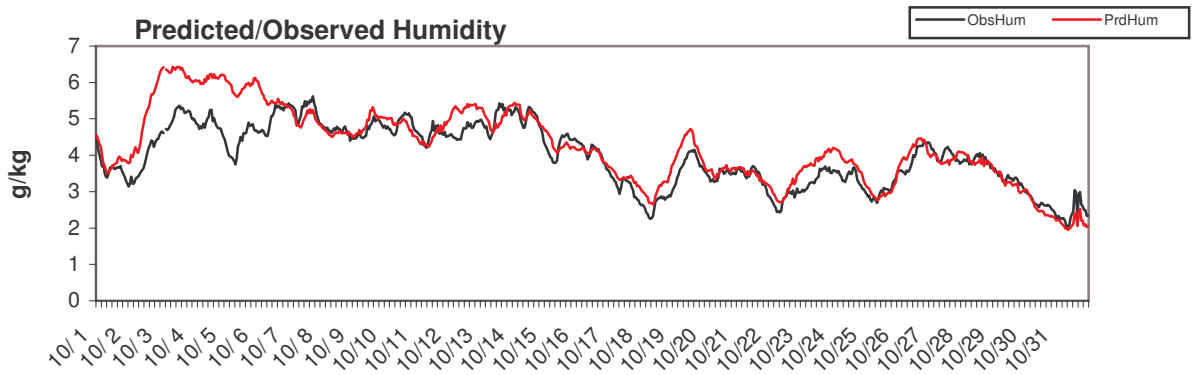
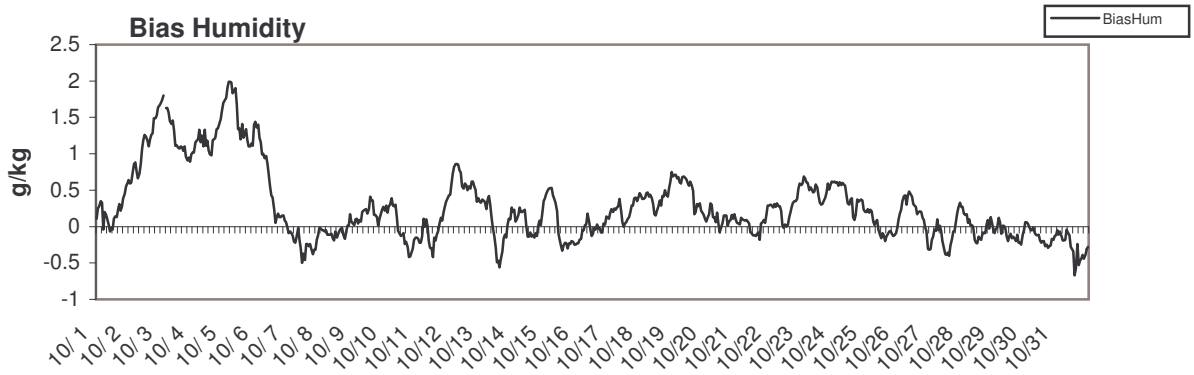
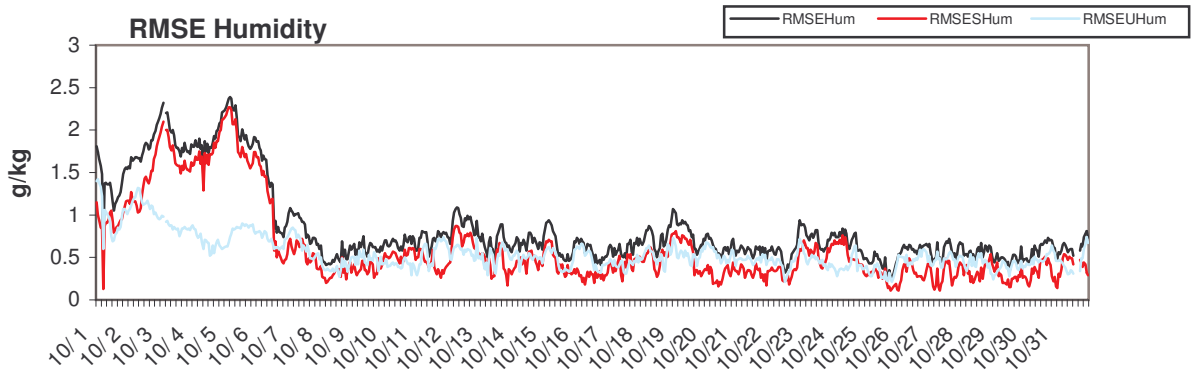
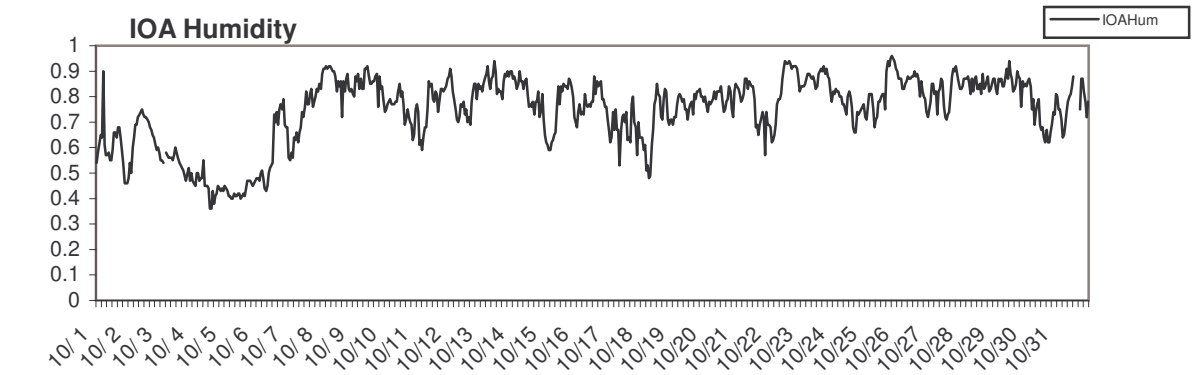
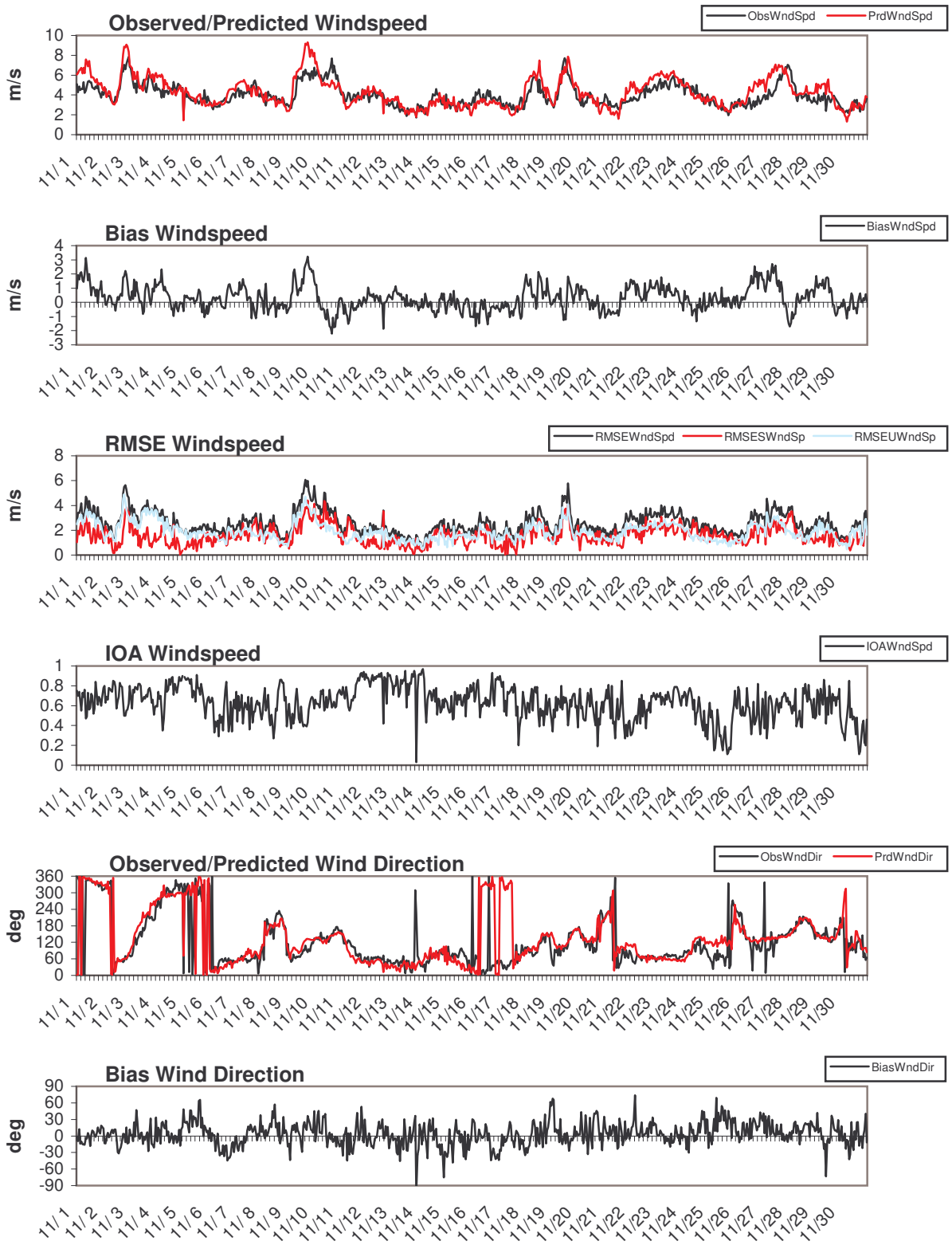




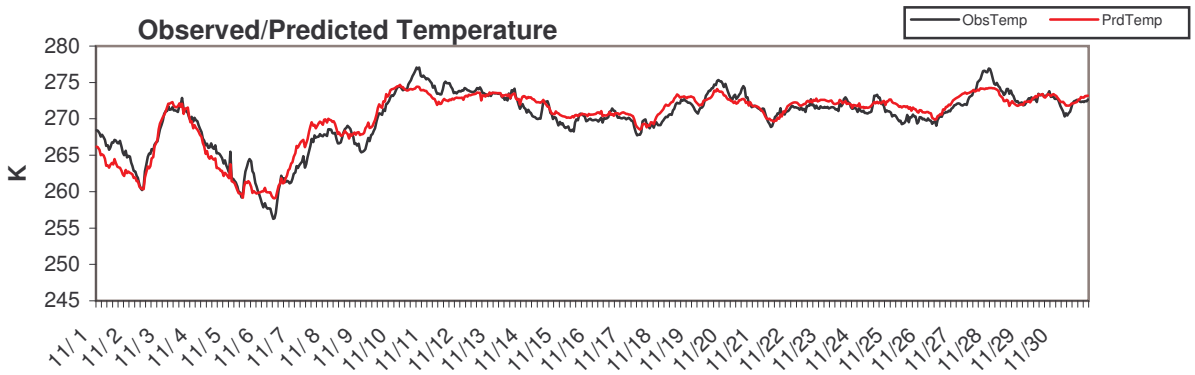


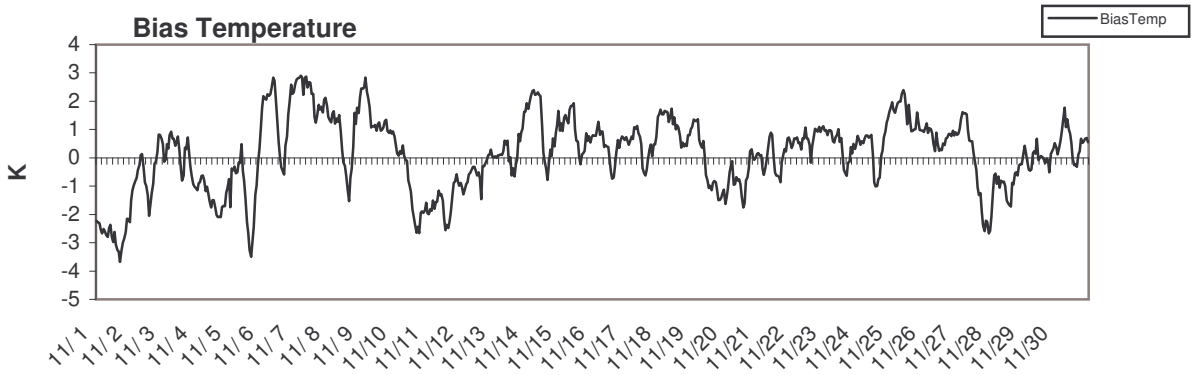


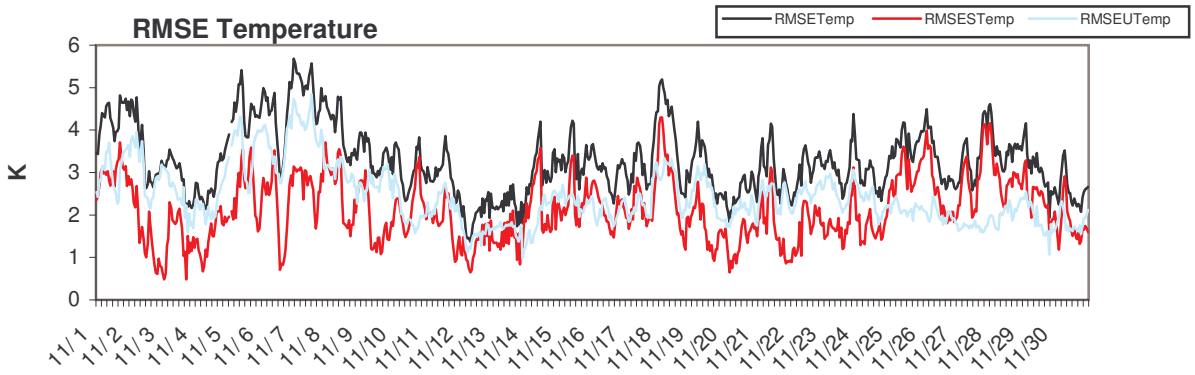
Alaska 5km 2004-11

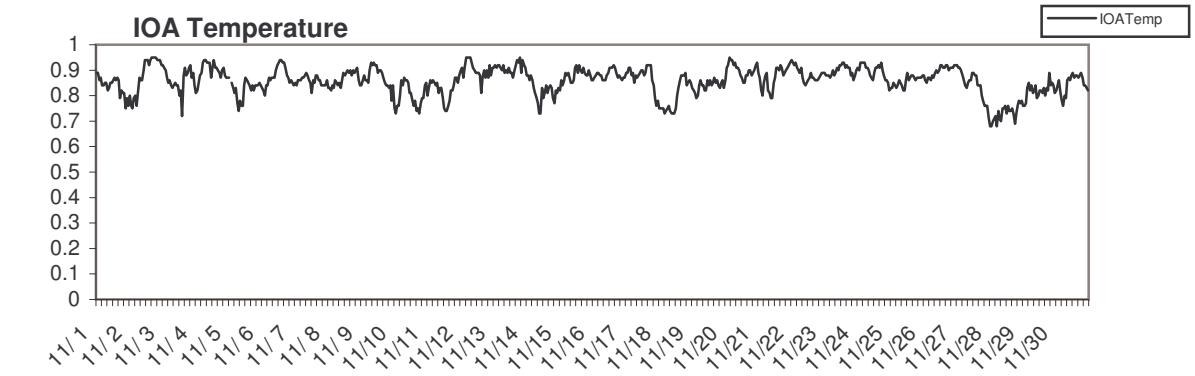


Alaska 5km 2004-11

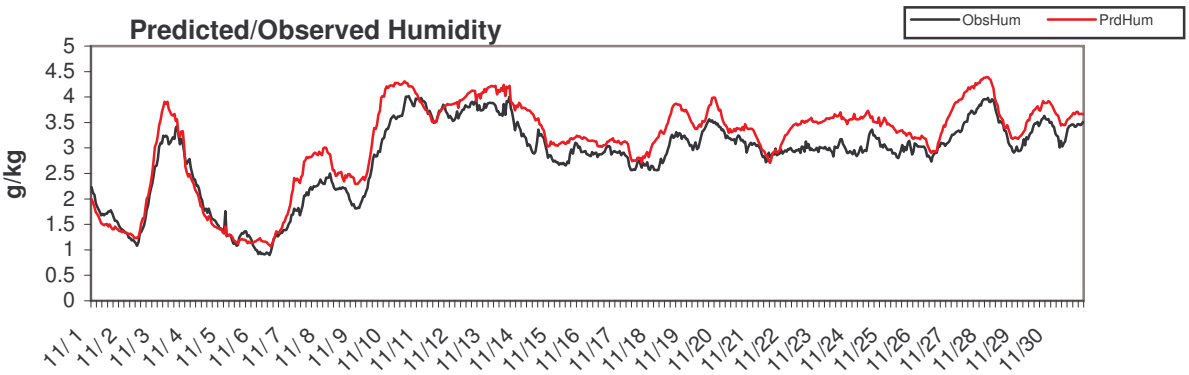


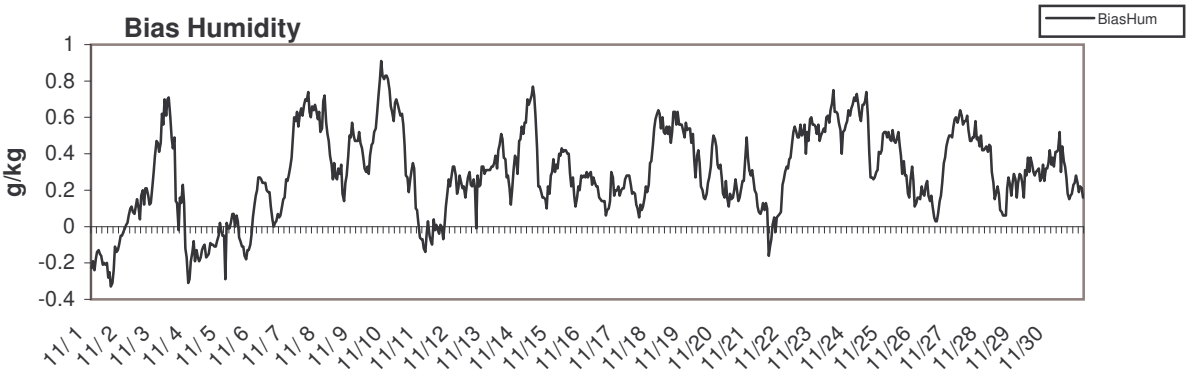


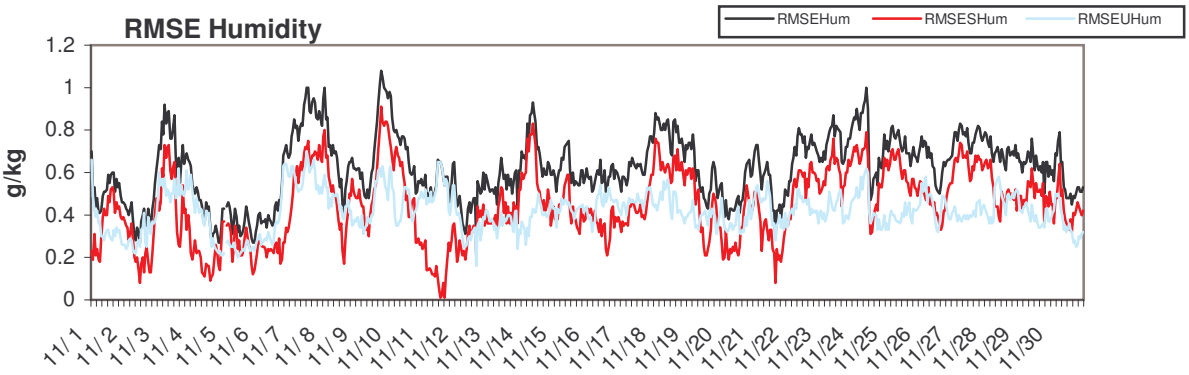


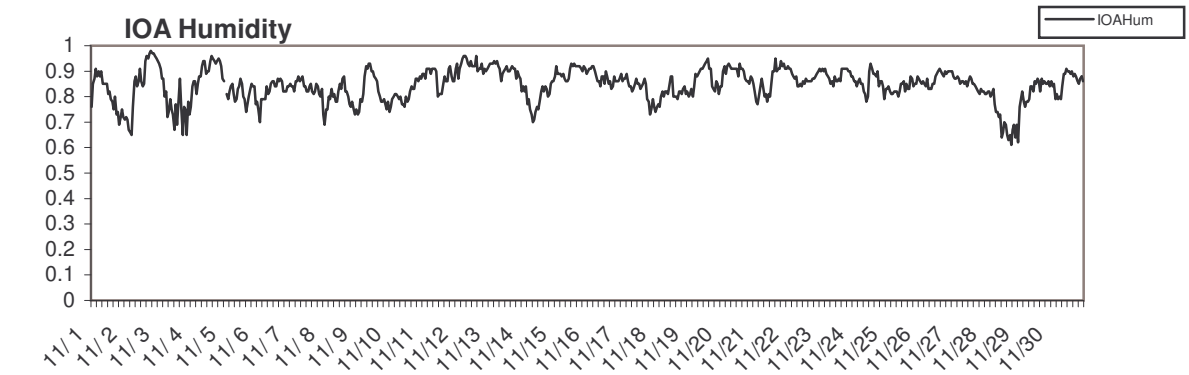


Alaska 5km 2004-11

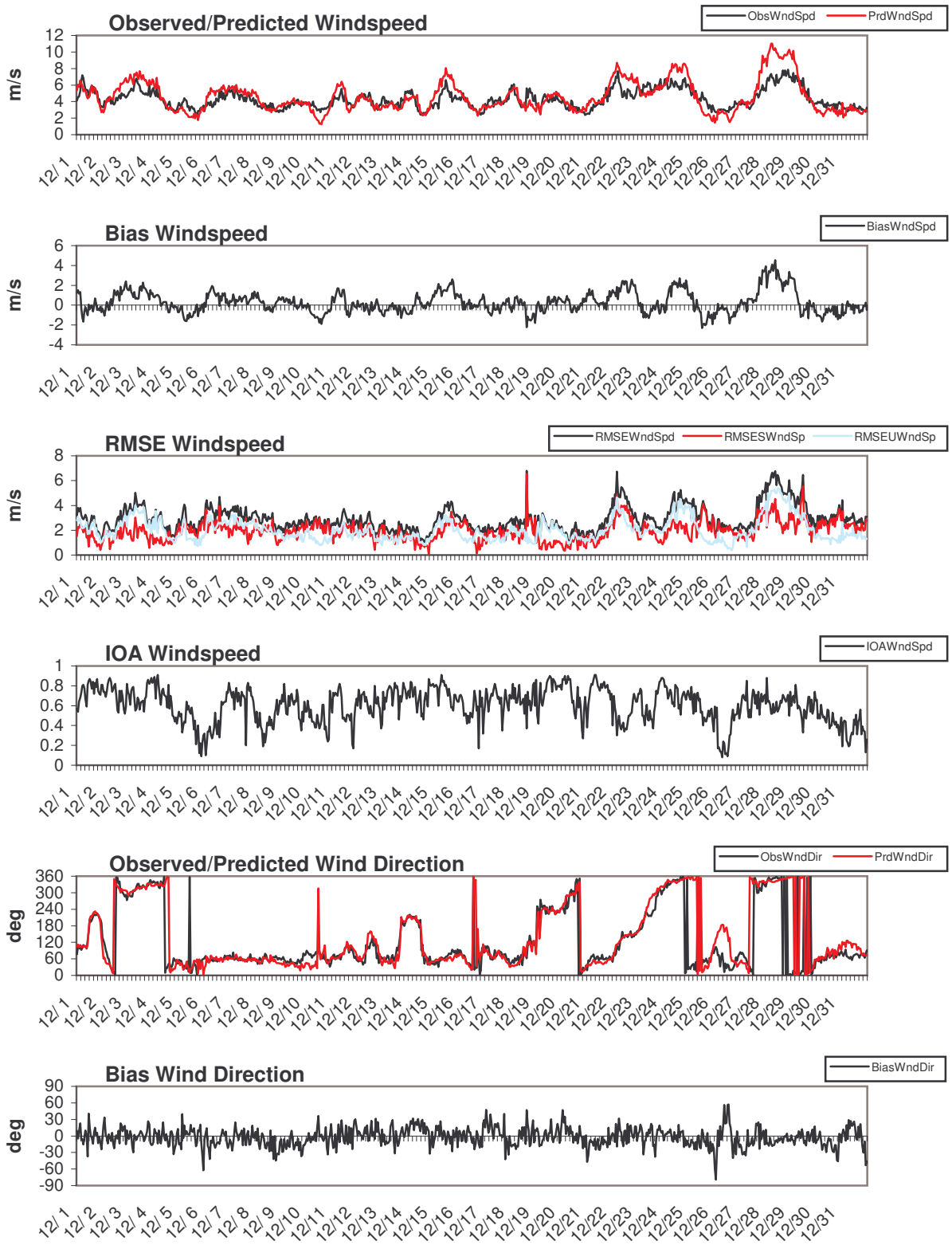




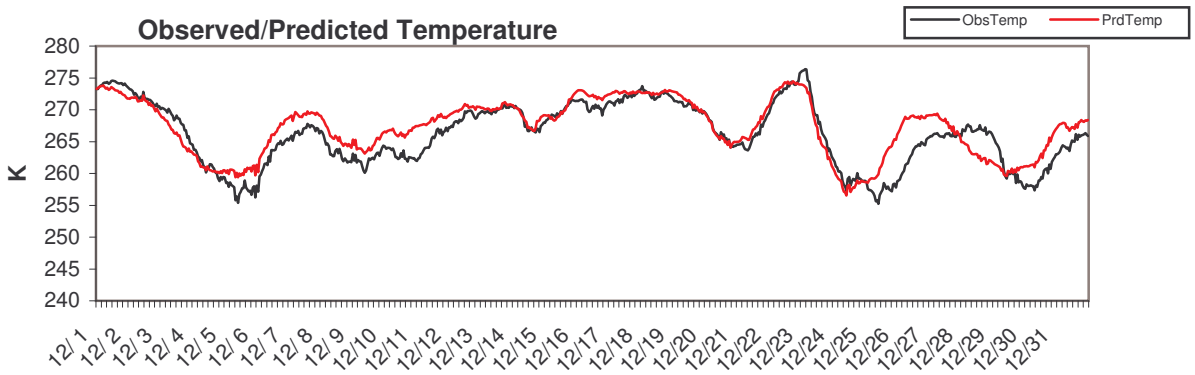


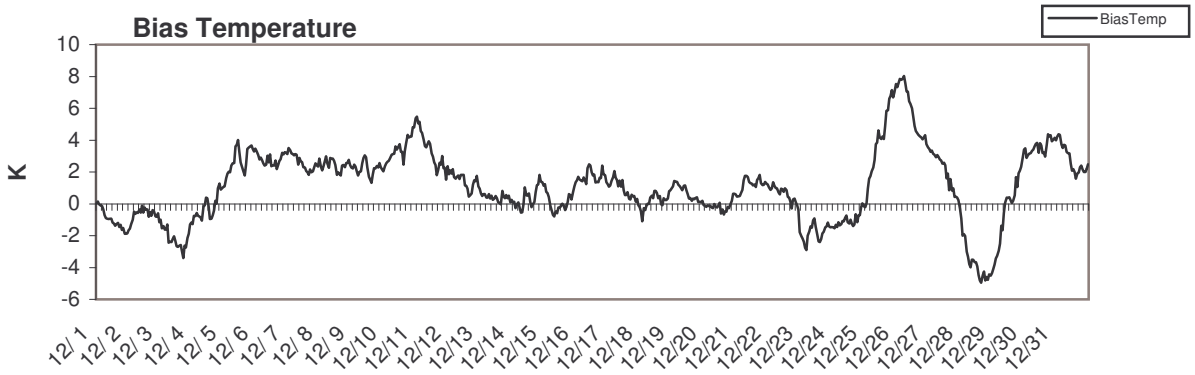


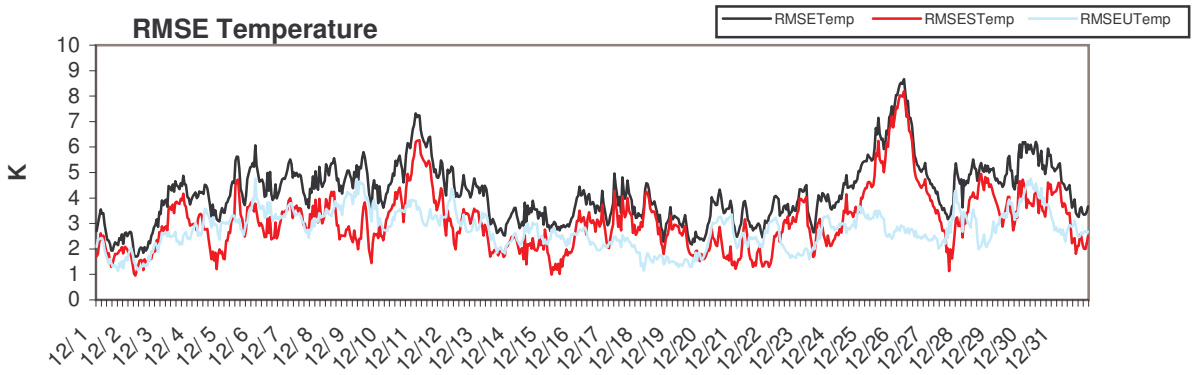
Alaska 5km 2004-12

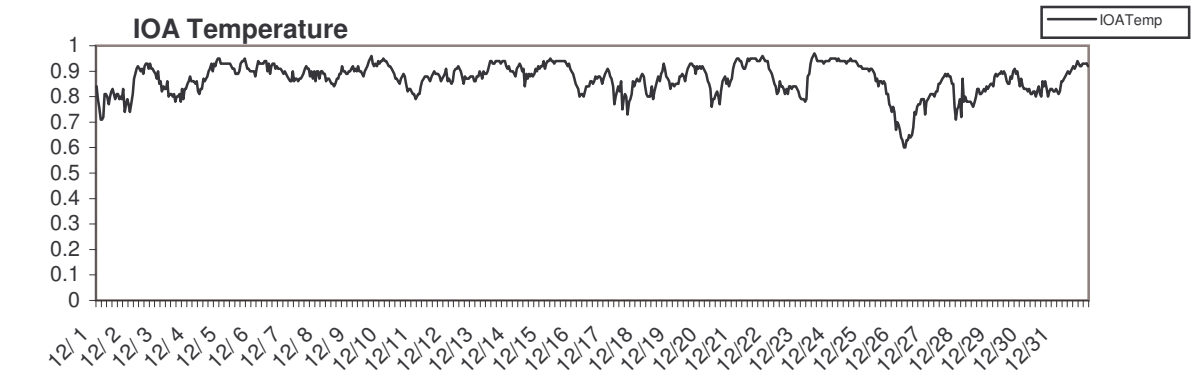
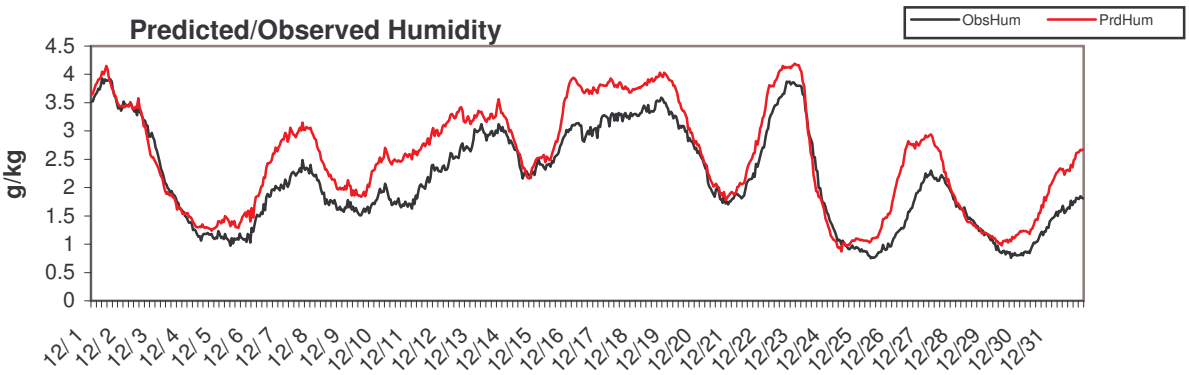
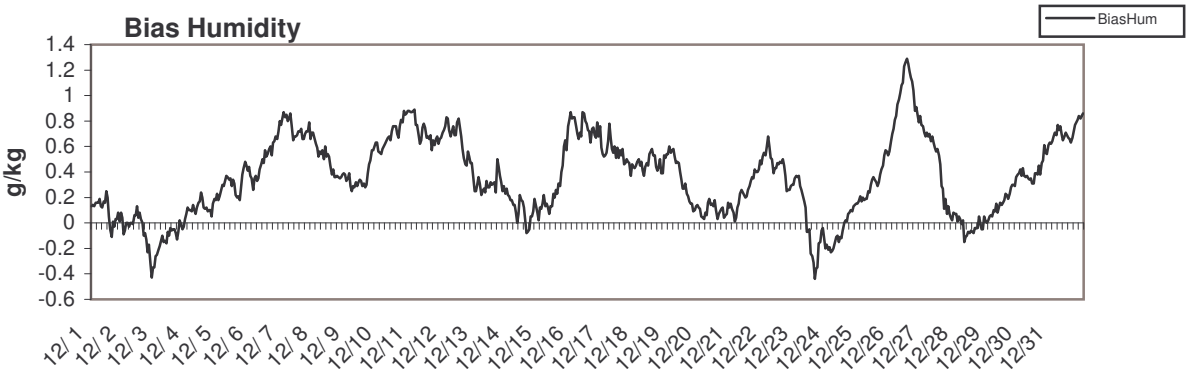
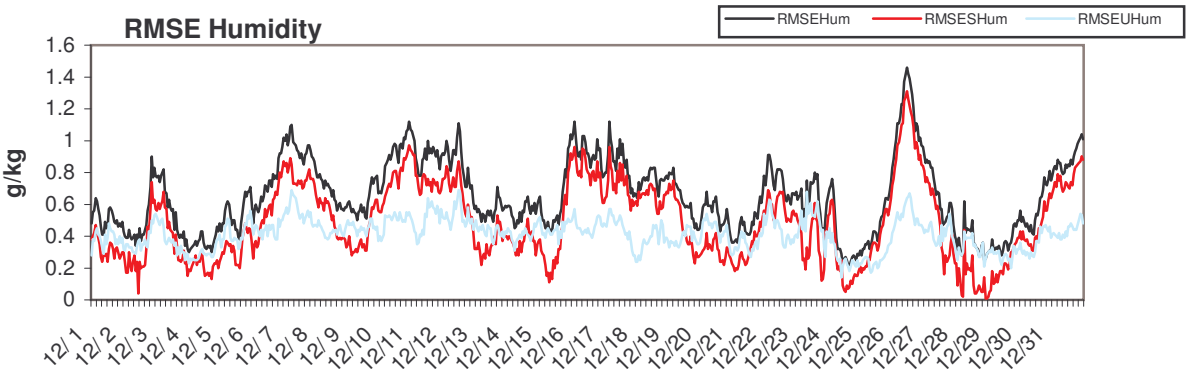
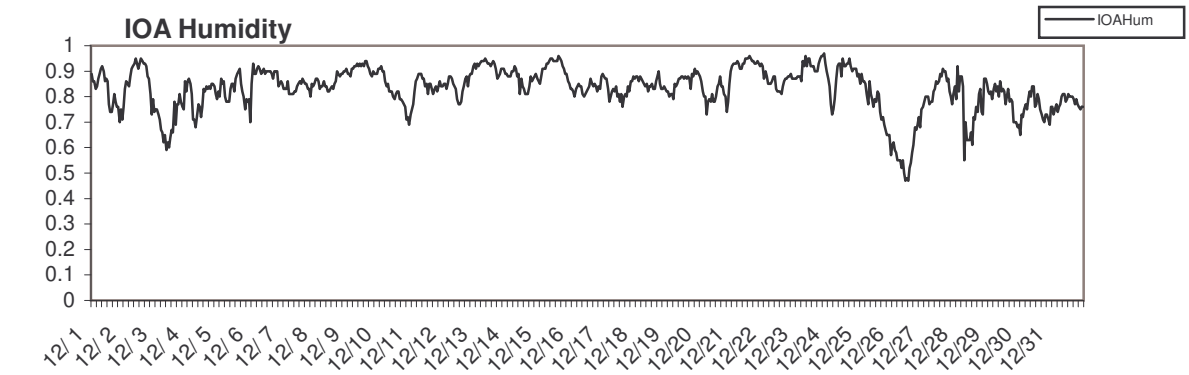


Alaska 5km 2004-12









Alaska 5km 2004-12