Sensitivity Analysis for a WRF v3.1.1 Annual Simulation Over the Central and Eastern U.S.

Iowa Department of Natural Resources | Air Quality Bureau

June 24, 2010

Ad-Hoc Meteorological Modelers Meeting | Boulder, CO

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The Iowa Department of Natural Resources

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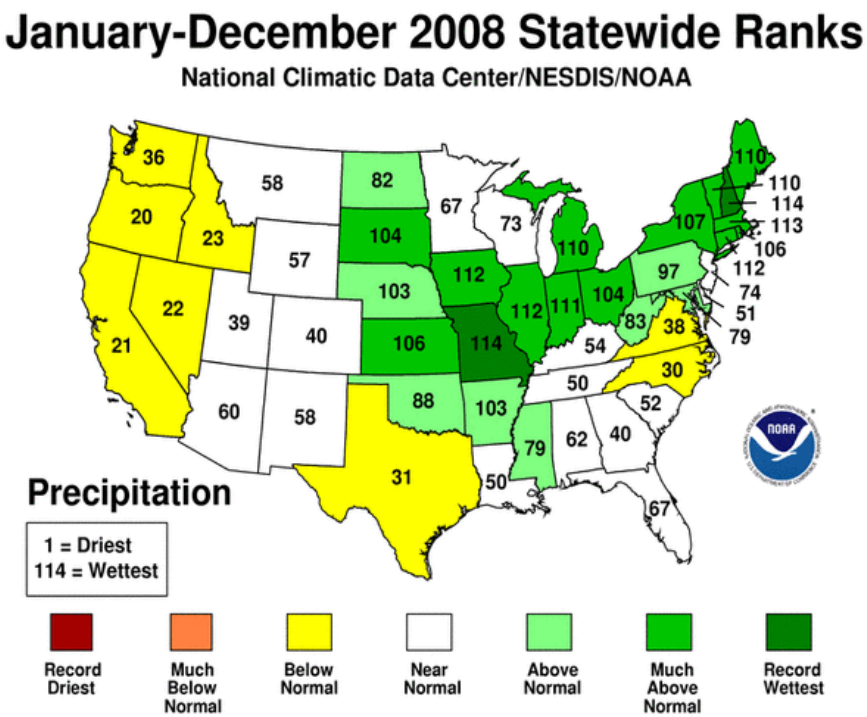
Overview

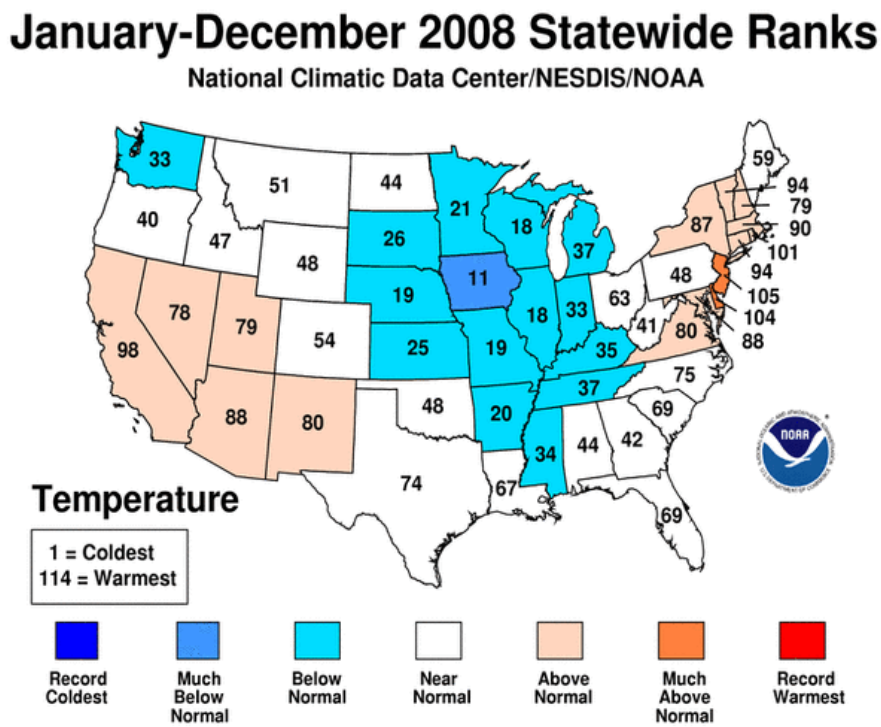
- **Multi-state Collaboration**
  - **UMD contract with MDE**
  - **Develop modeling protocol**
    - Modeling domain, vertical structure, benchmark, etc
  - **Conduct sensitivity analysis**
    - Summer and winter episodes
      - July 28–Aug 16
      - Dec 5–24
    - PBL, land surface, cloud microphysics
  - **Perform annual WRF simulation**
  - **Sensitivity analysis and model performance evaluation**
    - SESARM contract with AER

Overview

- **WRF ARW v3.1.1**
  - **2007 annual simulation**
  - **2008 also possible**
- **Support state SIP development**
  - **2006 $PM_{2.5}$ NAAQS**
  - **2008 Ozone NAAQS**
  - **Possibly 1997 Ozone NAAQS and Regional Haze**
    - Serious designations and 2012 review, respectively

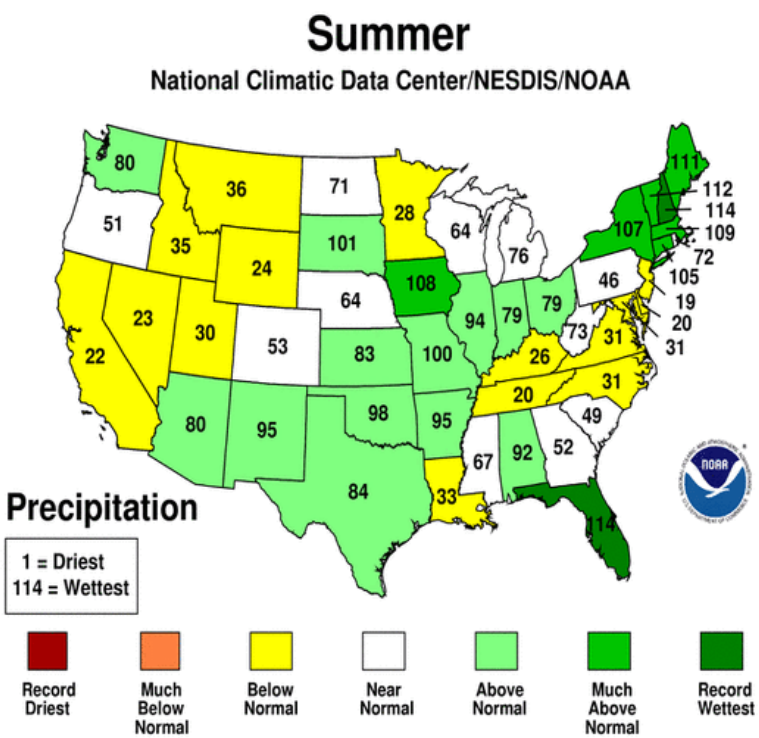
Episode Selection

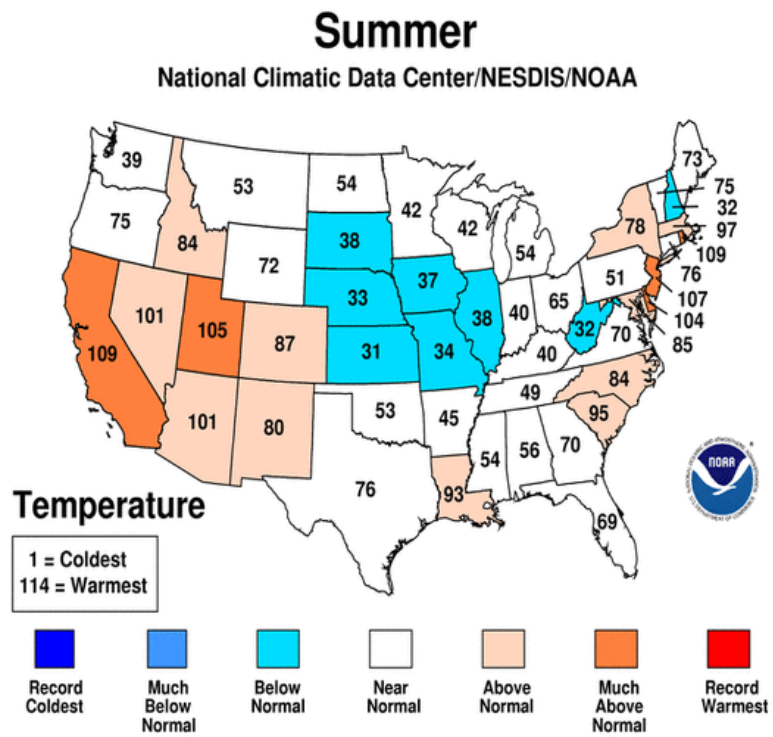




http://www.ncdc.noaa.gov/oa/climate/research/2008/ann/us-summary.html

Episode Selection



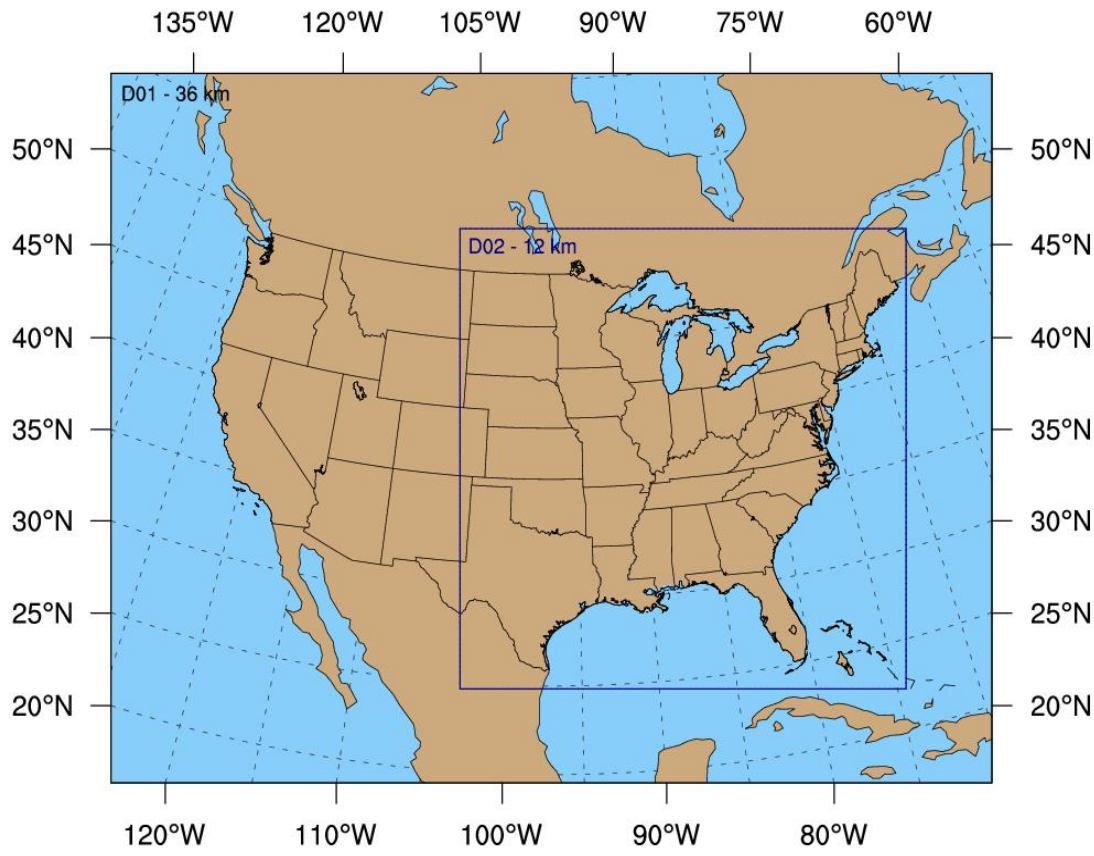


http://www.ncdc.noaa.gov/oa/climate/research/2008/ann/us-summary.html

Modeling Domain

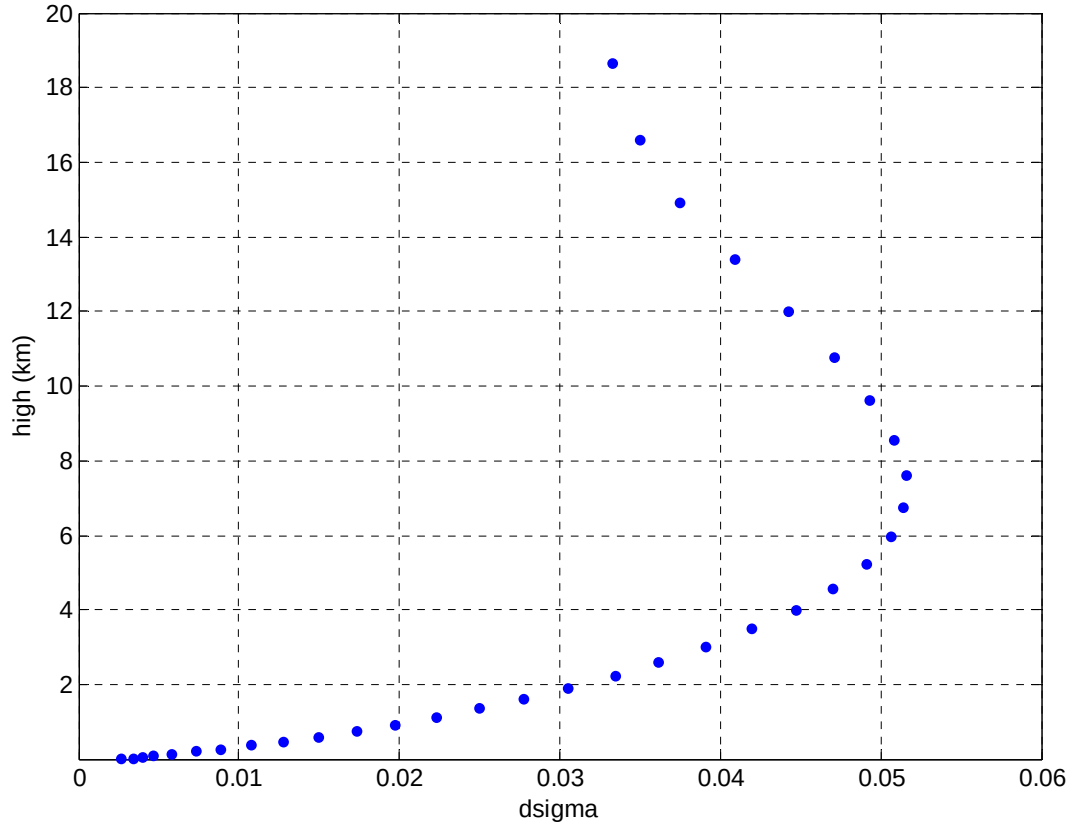
Map Projection	
Projection	Lambert
True Lat 1	33
True Lat 2	45
Stand Long	-97
Ref Long	-97
Ref Lat	40

Domains	1	2
NX (W-E)	165	250
NY (S-N)	129	250
Res (km)	36	12
Start Loc (i,j)	1,1	66,18
SW (x,y) (km)	-2952,-2304	-612,-1692
NE (x,y) (km)	-2952,-2304	2376,1296



Vertical Structure

- **35 levels**
- **Model top: 50 mb**
- **First layer depth ~20 m**
- **Increased resolution within PBL and near tropopause**



Vertical Structure

Level	Sigma	Height (m)	Pressure (mb)	Depth (m)	Level	Sigma	Height (m)	Pressure (mb)	Depth (m)
35	0.0000	18663	50	2034	17	0.7828	1924	794	293
34	0.0332	16629	82	1715	16	0.8133	1631	823	259
33	0.0682	14914	115	1515	15	0.8410	1372	849	228
32	0.1056	13399	150	1375	14	0.8659	1144	873	200
31	0.1465	12024	189	1255	13	0.8882	944	894	174
30	0.1907	10769	231	1145	12	0.9079	770	913	150
29	0.2378	9624	276	1045	11	0.9252	620	929	128
28	0.2871	8579	323	955	10	0.9401	492	943	108
27	0.3379	7624	371	870	9	0.9528	384	955	90
26	0.3895	6754	420	790	8	0.9635	294	965	74
25	0.4409	5964	469	715	7	0.9723	220	974	60
24	0.4915	5249	517	645	6	0.9796	160	981	48
23	0.5406	4604	564	580	5	0.9854	112	986	38
22	0.5876	4024	608	520	4	0.9900	74	991	30
21	0.6323	3504	651	465	3	0.9940	44	994	24
20	0.6742	3039	690	415	2	0.9974	20	998	20
19	0.7133	2624	728	370	1	1.0000	0	1000	0
18	0.7494	2254	762	330					

Input Data Acquisition

- **Static terrestrial data**
  - **USGS 24-Category Land Use**
  - **16-Category Soil Type**
  - **Elevation**
  - **Green Fraction**
  - **Snow Albedo**
- **Initial and Boundary Conditions**
  - **Eta Data Analysis System (EDAS) 3D and surface analyses**
  - **40 km resolution, 3-hrly**

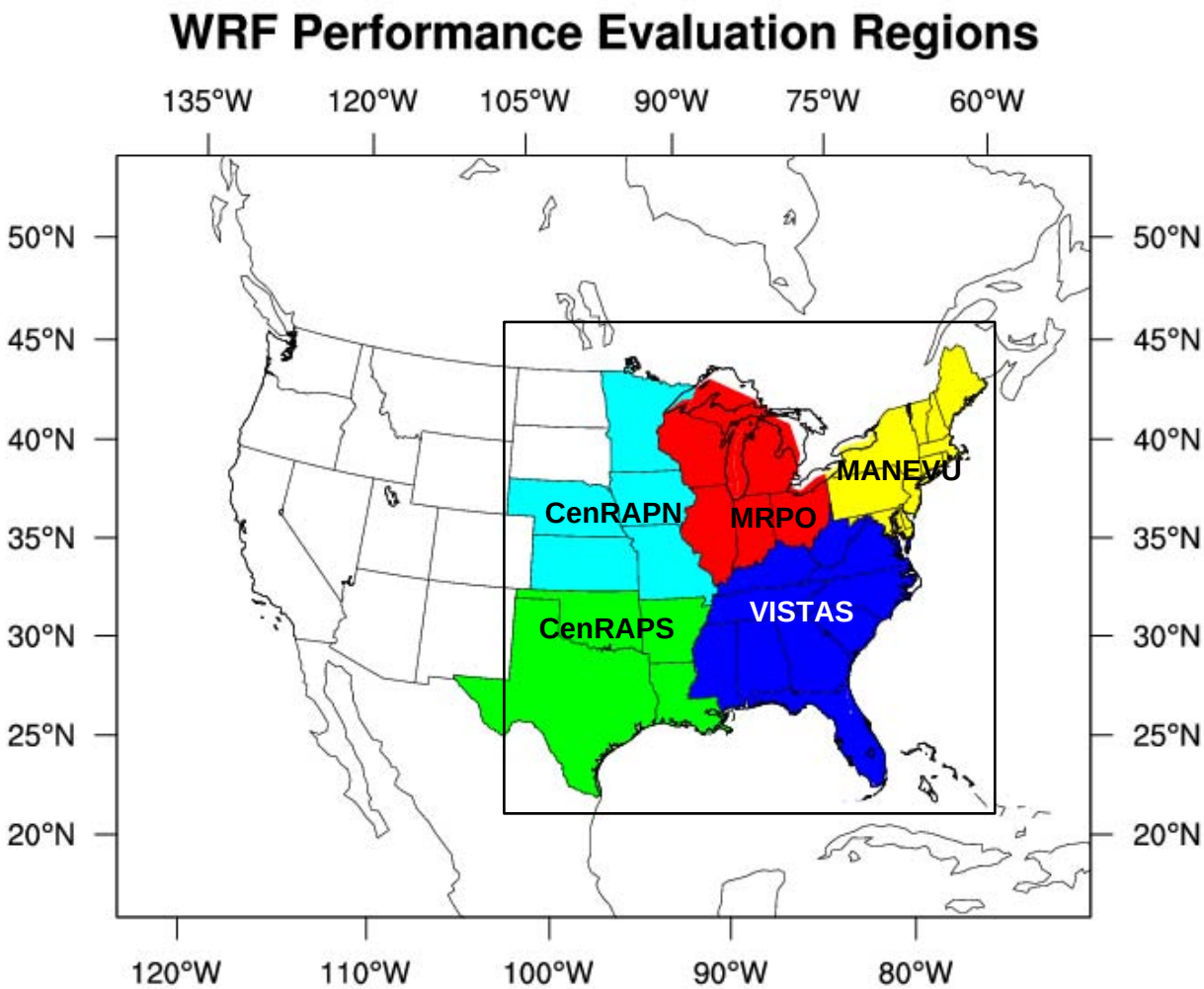
Input Data Acquisition

- **Four Dimensional Data Assimilation**
  - **Meteorological Assimilation Data Ingest System (MADIS)**
    - METAR
    - Canadian surface (SAO)
    - Modernized NWS co-op
    - Integrated mesonet
    - Maritime
    - Radiosonde
    - Automated aircrafts reports
    - 3-hrly satellite derived winds

Sensitivity Analysis

- Basic analysis to determine optimum configuration
- Final sensitivity analysis performed by AER
- Statistical performance evaluation
  - 2 m temperature
  - 2 m mixing ratio
  - 10 m wind speed
- Subjective spatial evaluation
  - Precipitation
  - Cloud cover
  - Low-level jet

Sensitivity Analysis



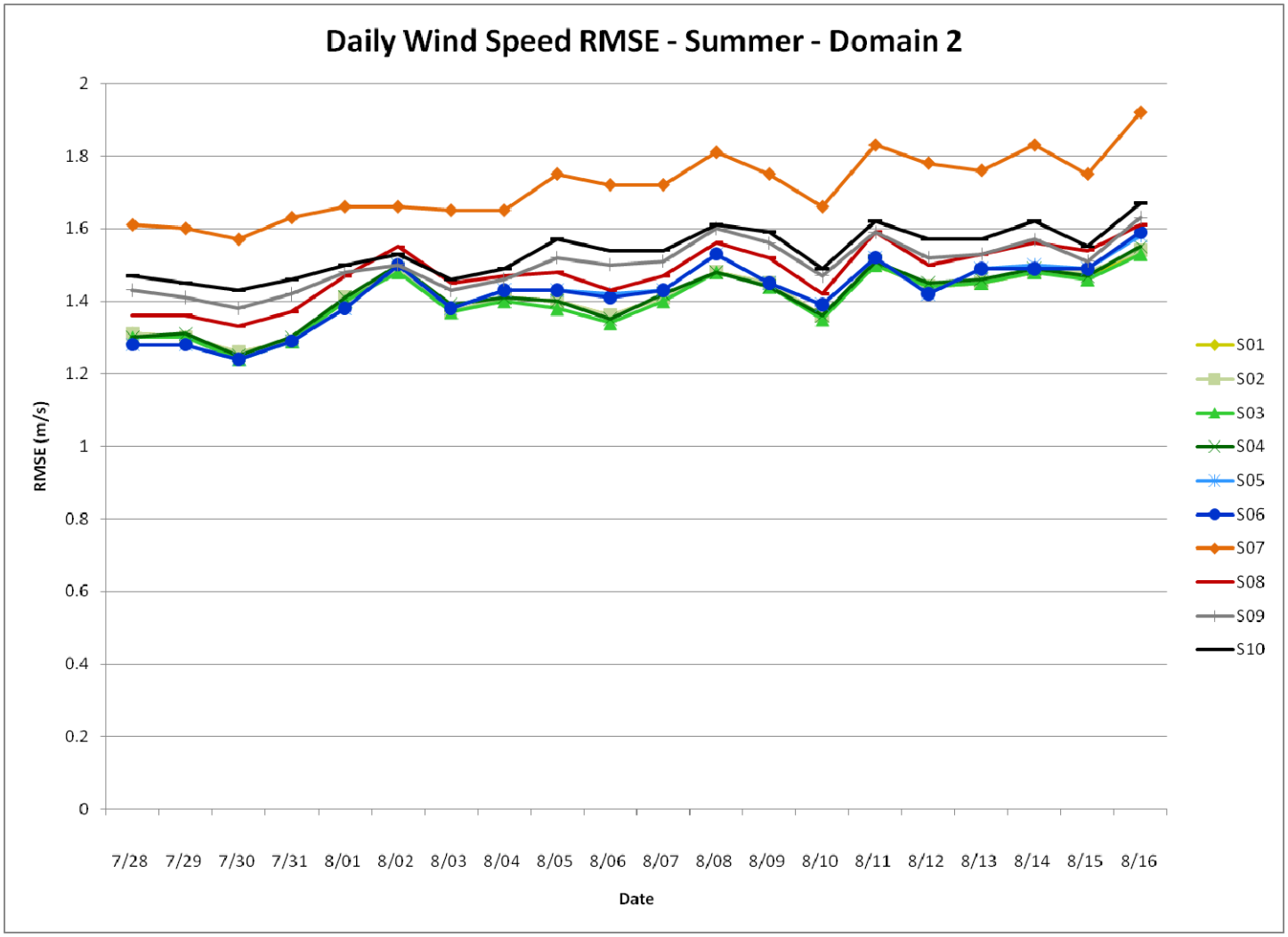
Sensitivity Analysis

Metrics	Formulation
Bias	$B = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P_j^i - O_j^i\right)$
Gross Error	$E = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left\lvert P_j^i - O_j^i\right\rvert$
Root Mean Square Error	$RMSE = \left[\frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P_j^i - O_j^i\right)^2\right]^{1/2}$
Systematic Root Mean Square Error	$RMSE_S = \left[\frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(\hat{P}_j^i - O_j^i\right)^2\right]^{1/2}$
Unsystematic Root Mean Square Error	$RMSE_u = \left[\frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P_j^i - \hat{P}_j^i\right)^2\right]^{1/2}$
Index of Agreement	$IOA = 1 - \left[\frac{IJ.RMSE^2}{\sum_{j=1}^{J}\sum_{i=1}^{I}\left\lvert P_j^i - M_o\right\rvert + \left\lvert O_j^i - M_o\right\rvert}\right]$

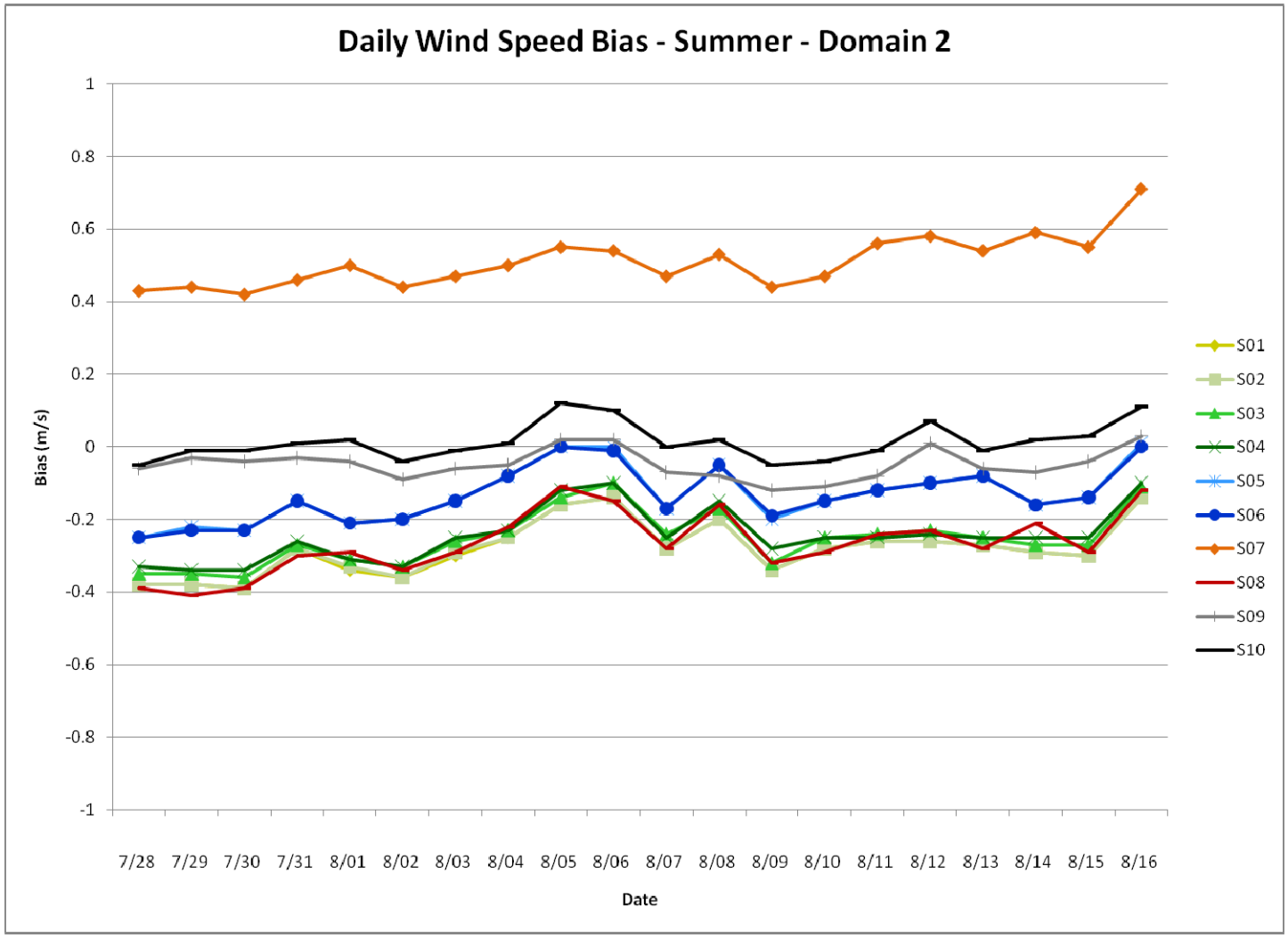
Sensitivity Analysis

	01	02	03	04	05	06	07	08	09	10
Planetary Boundary Layer	ACM2	ACM2	ACM2	ACM2	M-Y-J	M-Y-J	YSU	YSU	Blackadar	Blackadar
Land Surface Model	P-X	P-X	P-X	P-X (IPXWRF)	Noah	Noah	Noah	Noah	P-X	Noah
Surface Layer	P-X	P-X	P-X	P-X	M-O-J	M-O-J	M-O	M-O	P-X	M-O
Microphysics	WSM5	WSM6	Morrison	Morrison	WSM5	WSM6	WSM5	WSM6	WSM6	WSM6
Shortwave Radiation	RRTM	RRTM	RRTMG	RRTMG	RRTM	RRTM	RRTM	RRTM	RRTM	RRTM
Longwave Radiation	RRTM	RRTM	RRTMG	RRTMG	RRTM	RRTM	RRTM	RRTM	RRTM	RRTM
Cumulus	K-F	K-F	K-F	K-F	K-F	K-F	K-F	K-F	K-F	K-F

Surface Variables



Surface Variables



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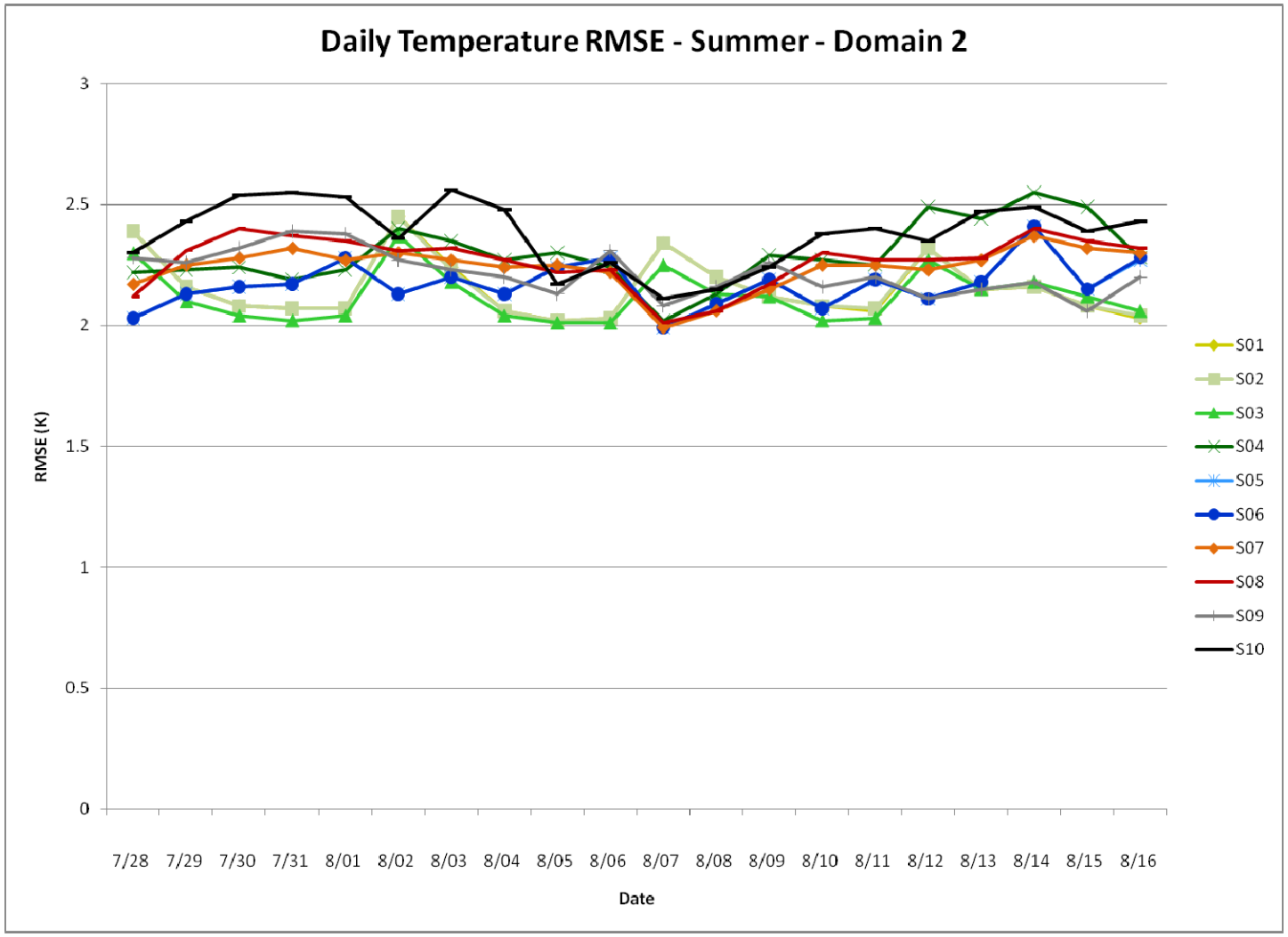

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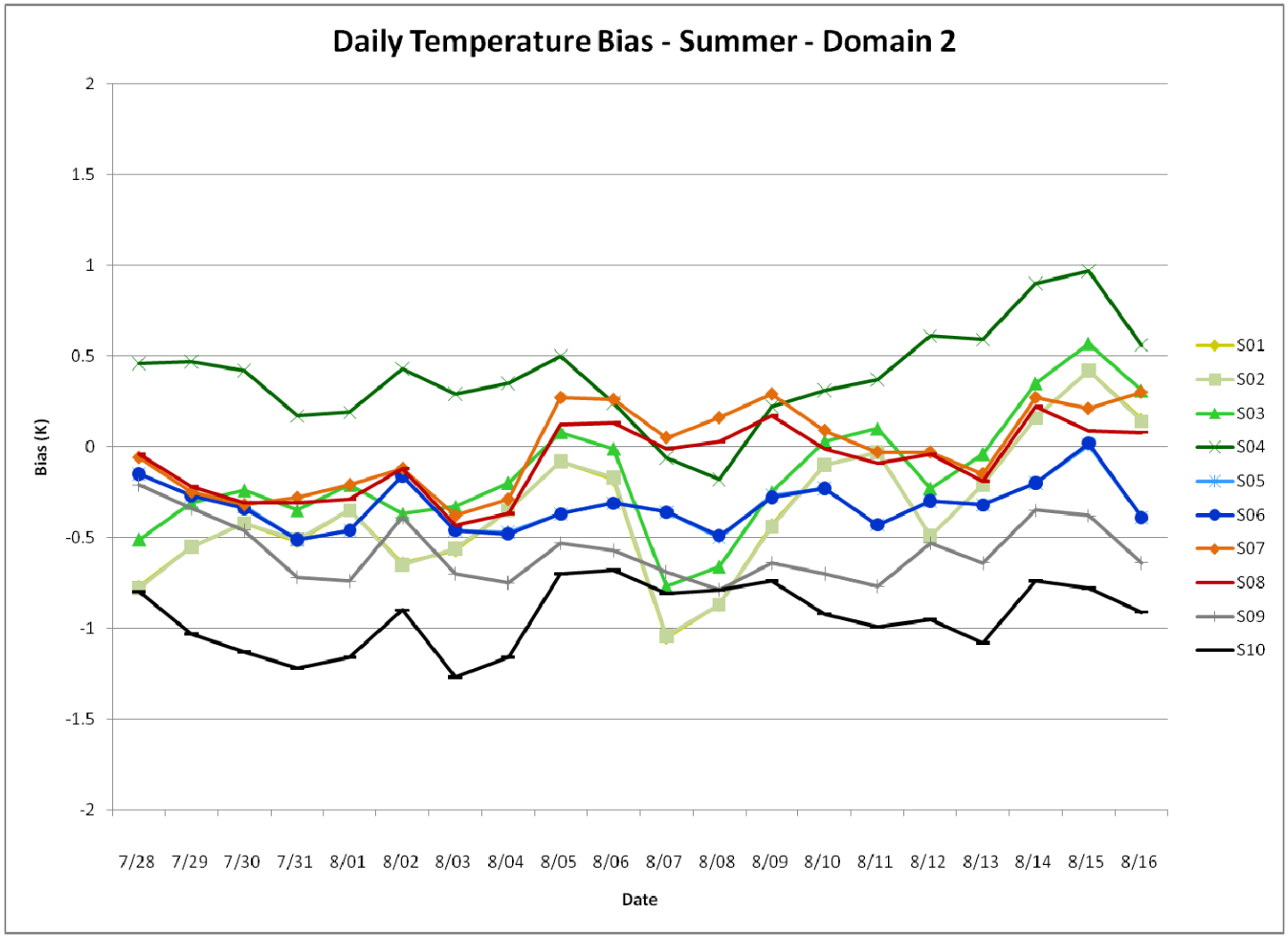

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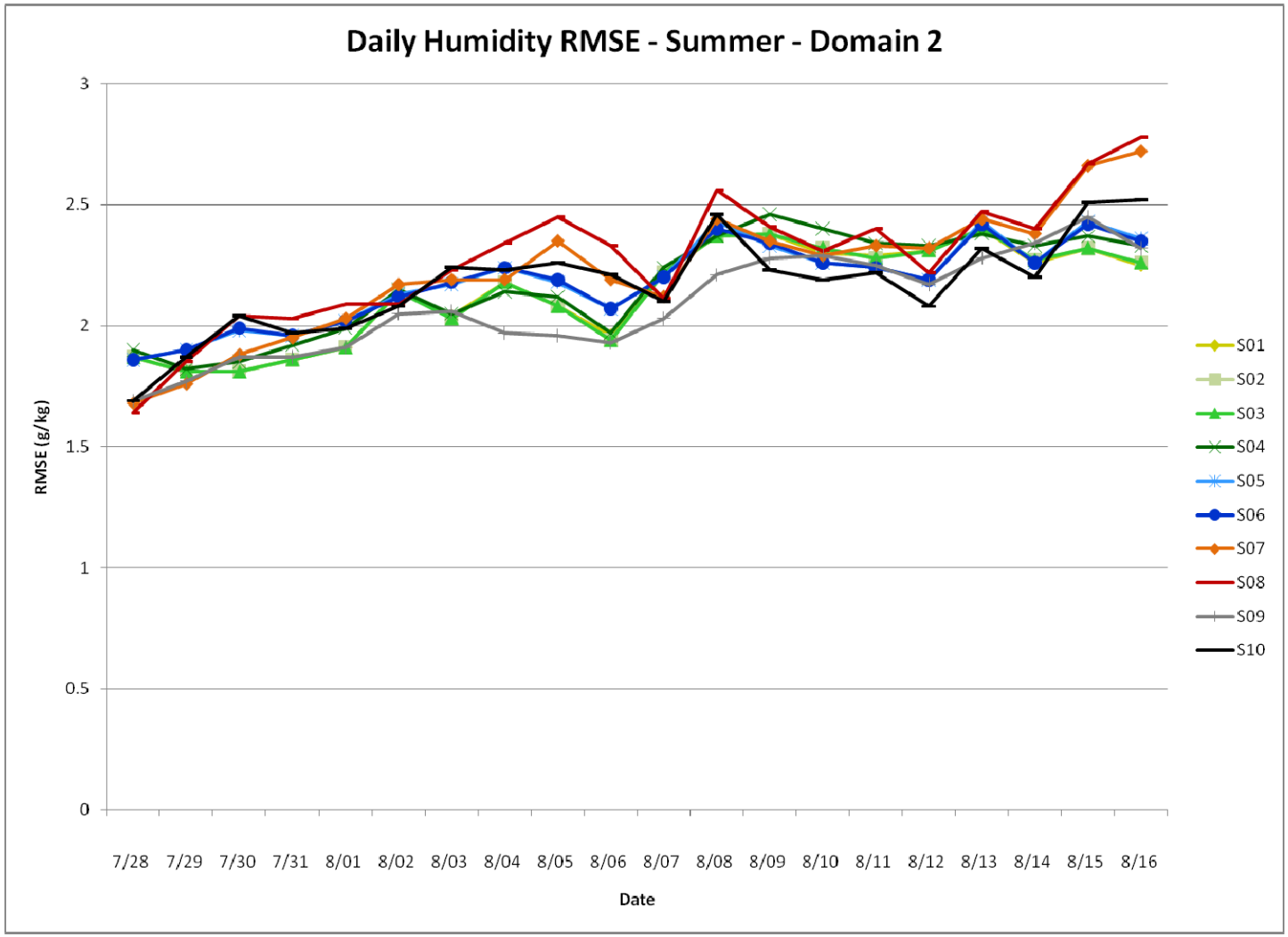
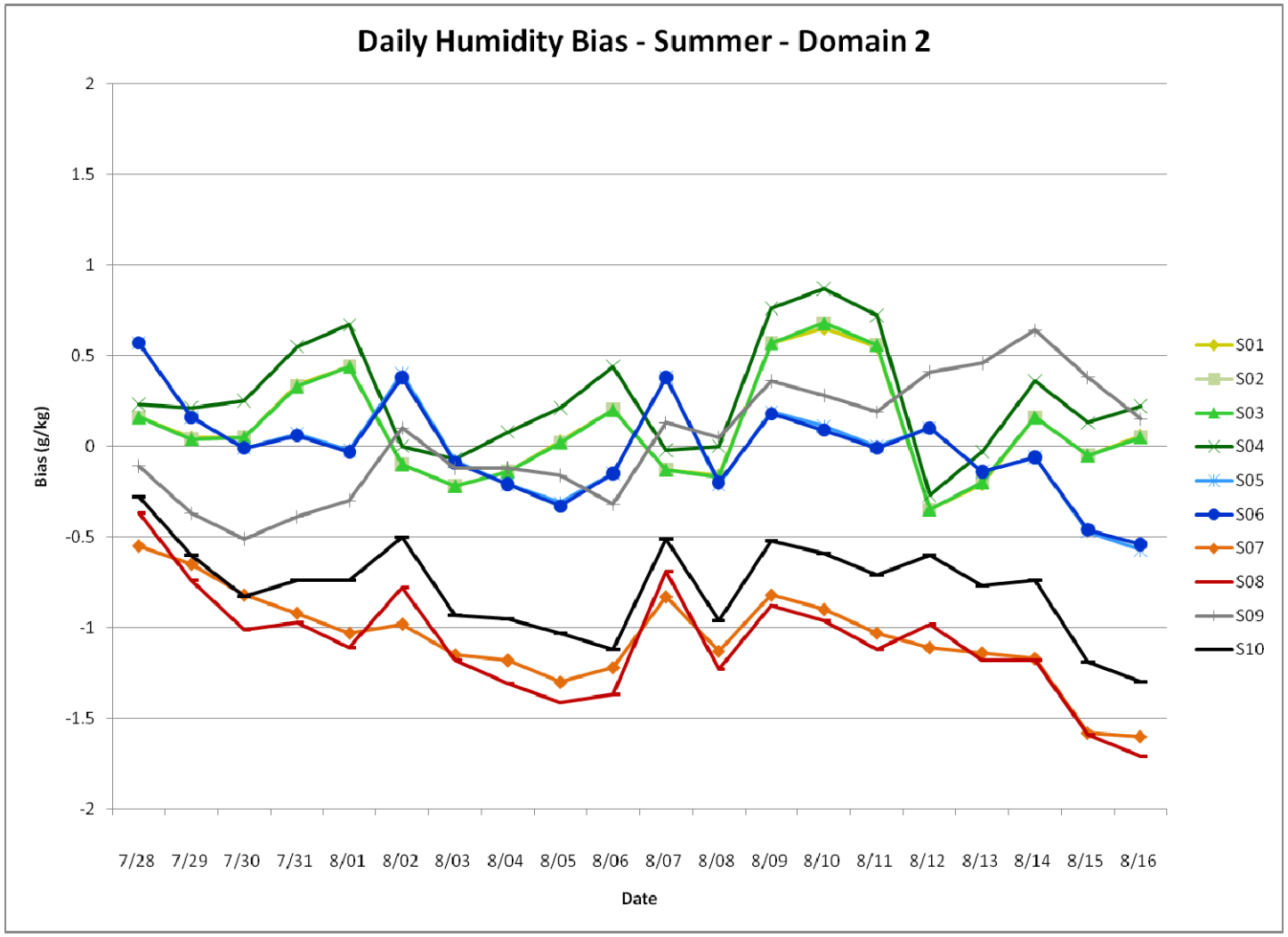


Surface Variables



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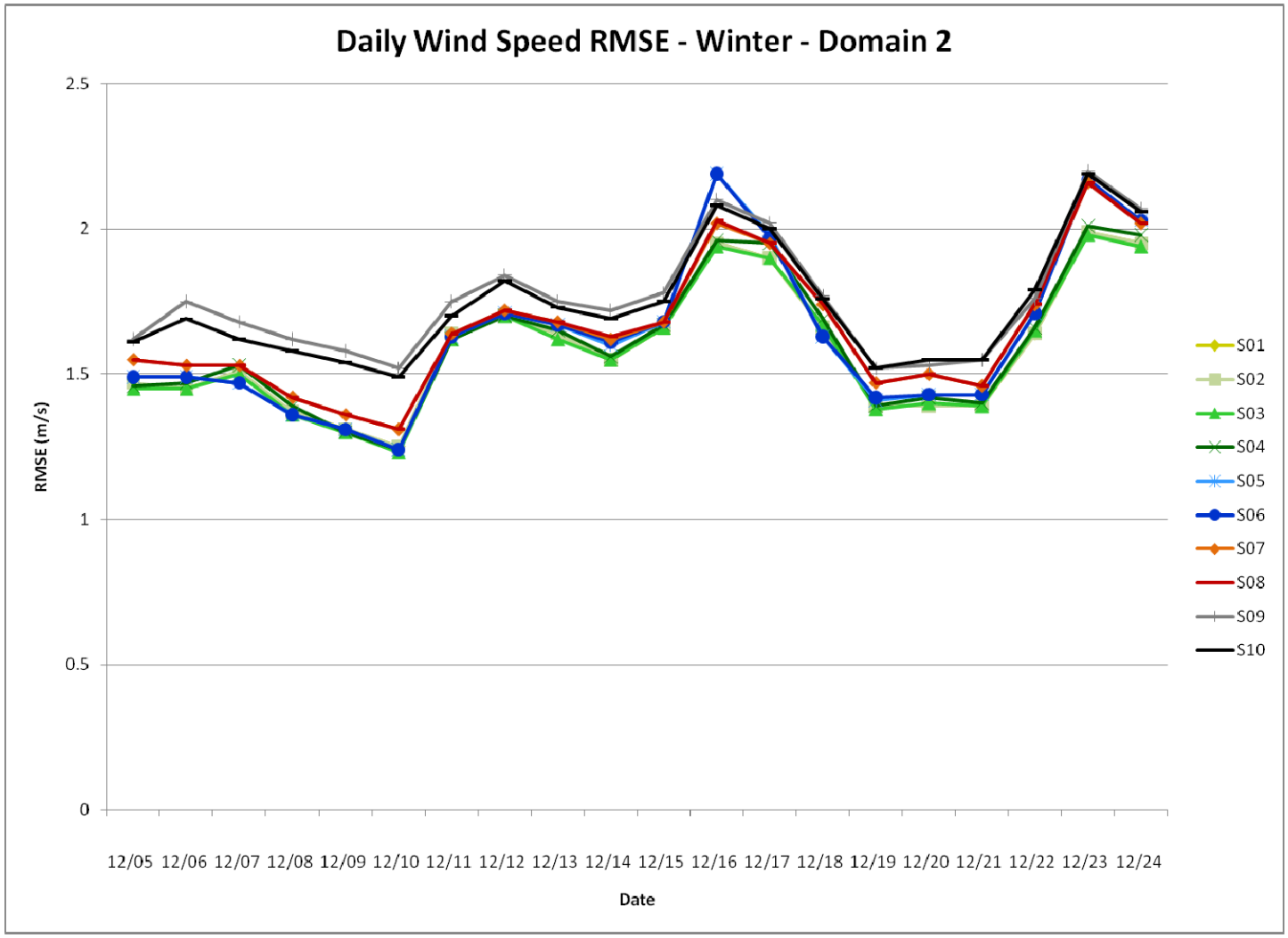

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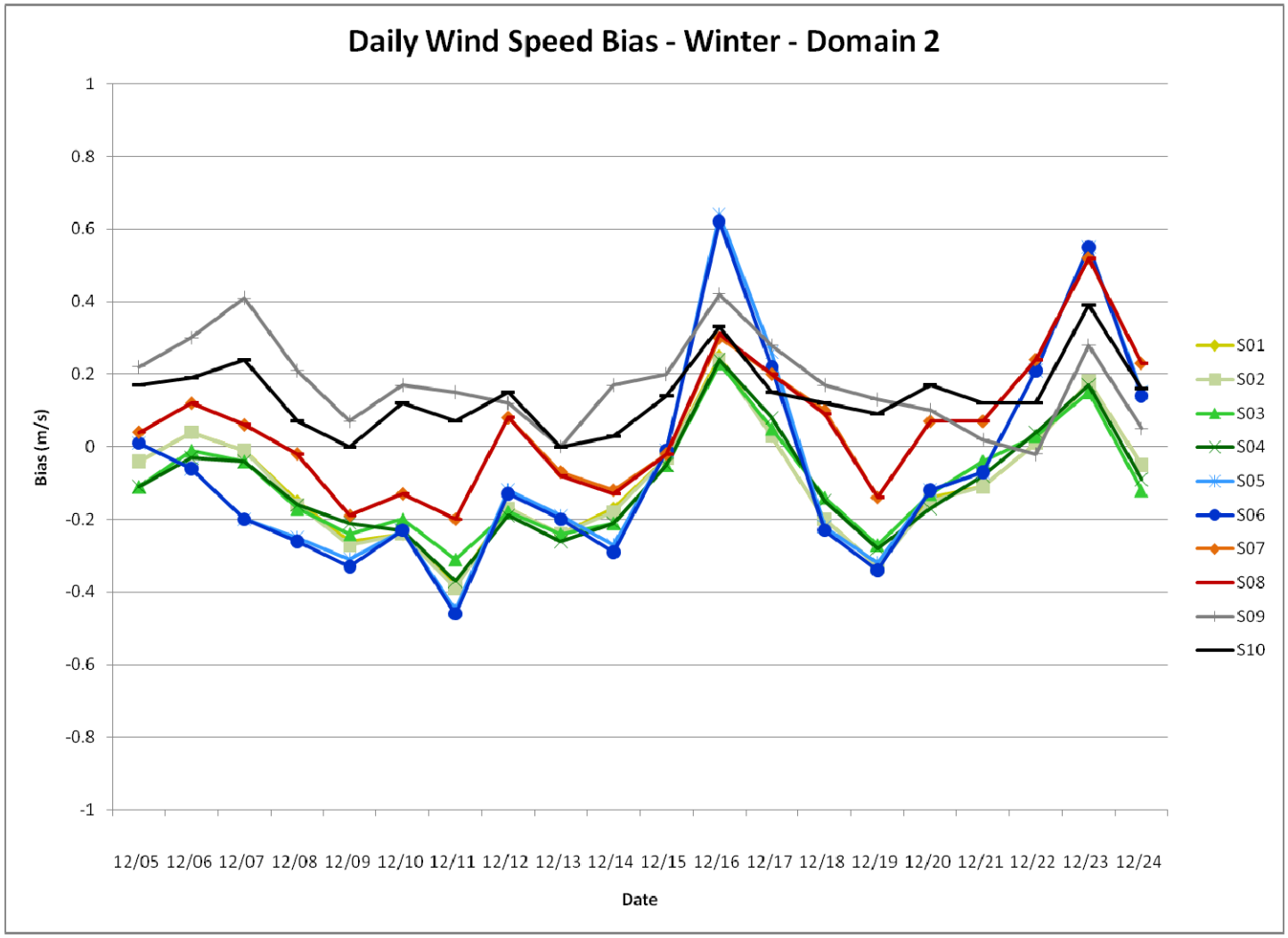

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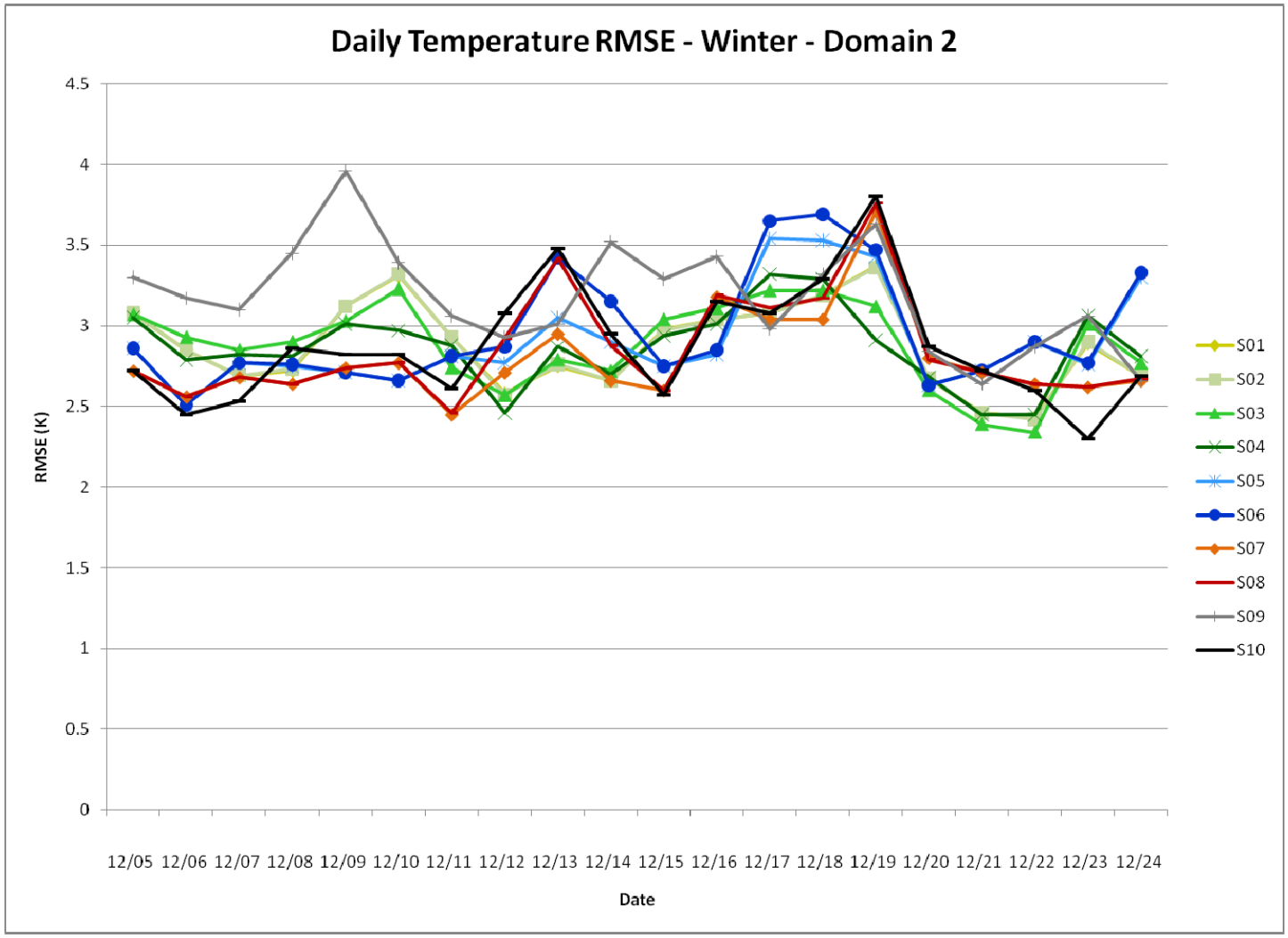

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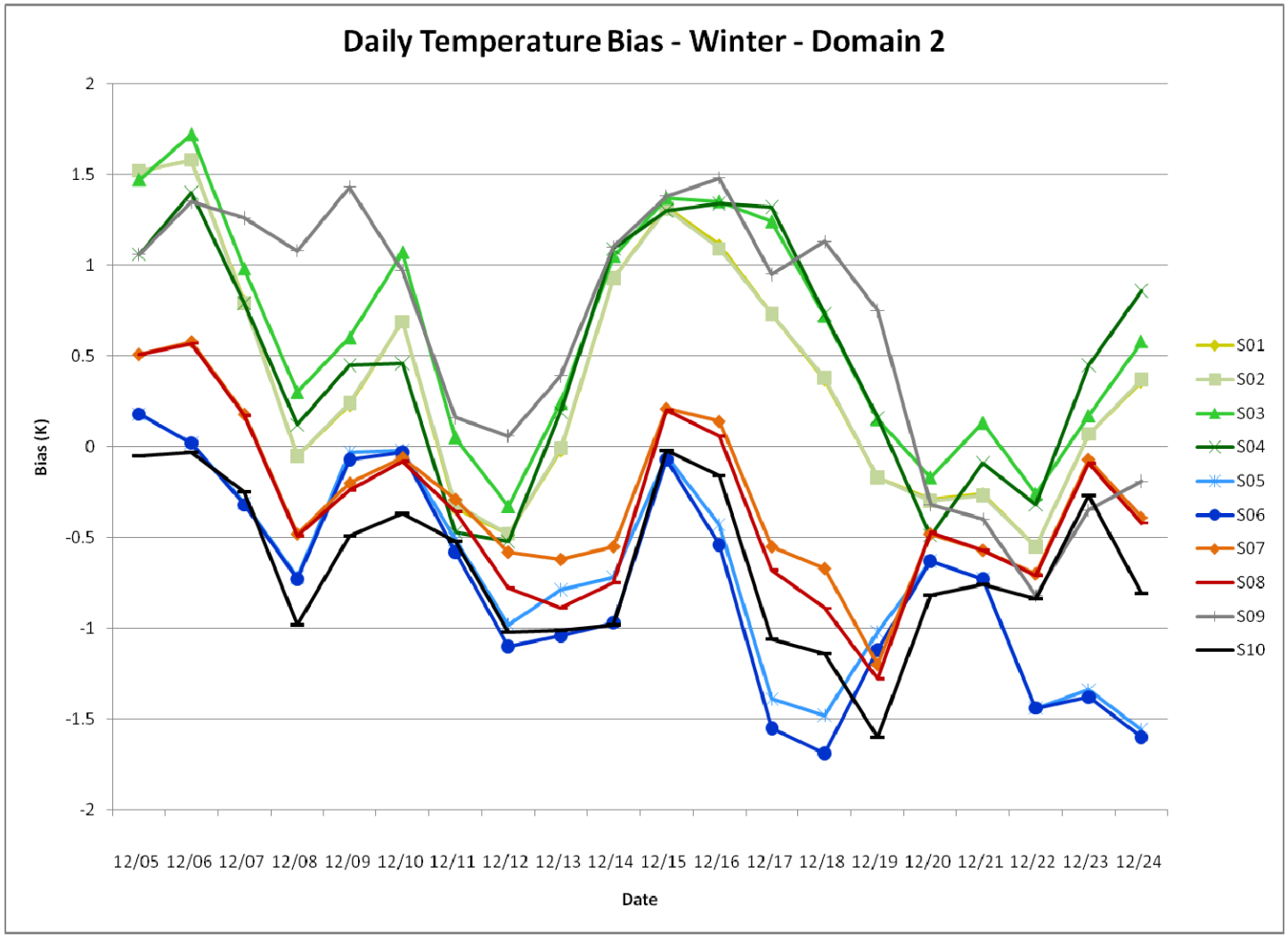

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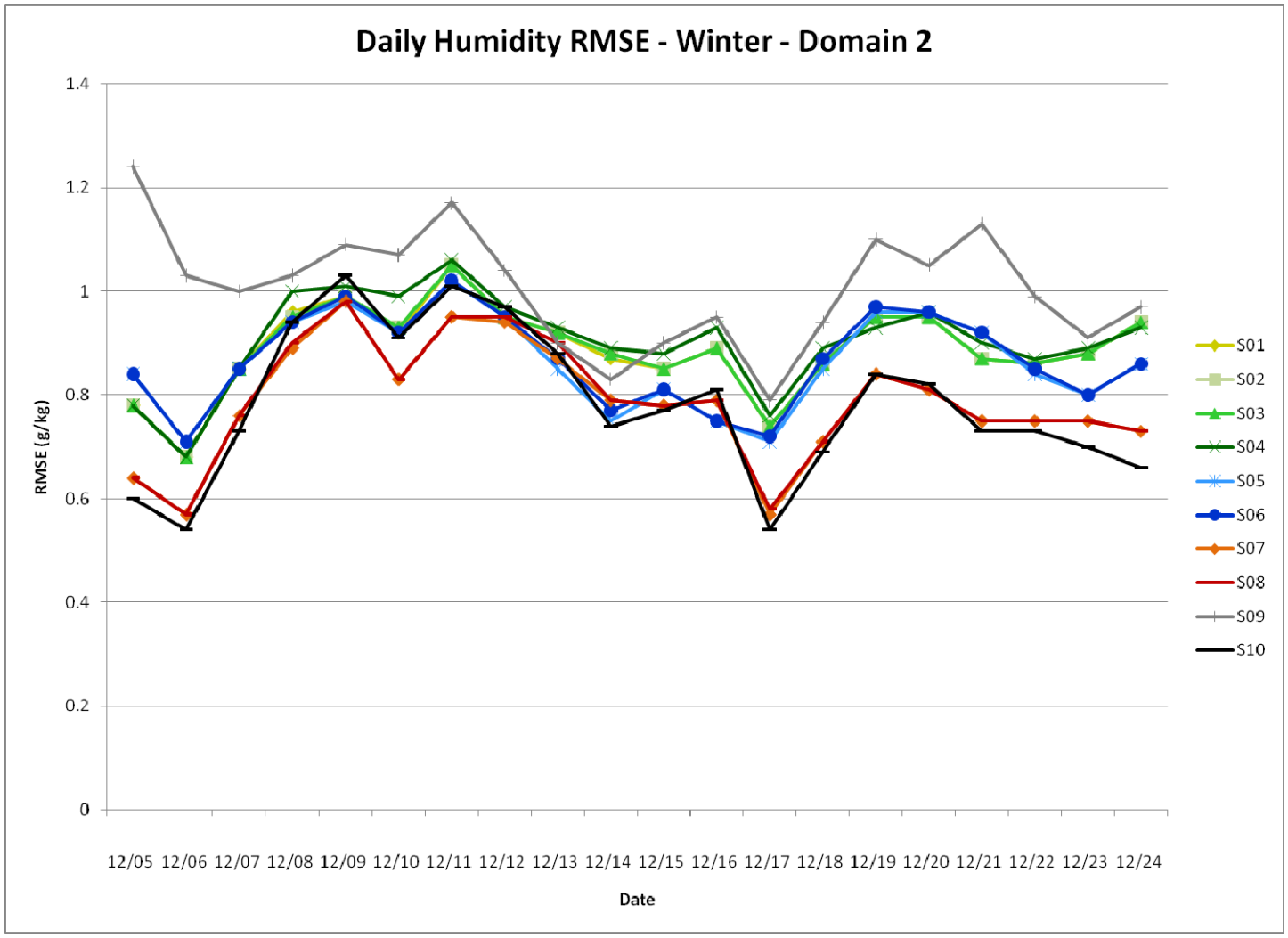

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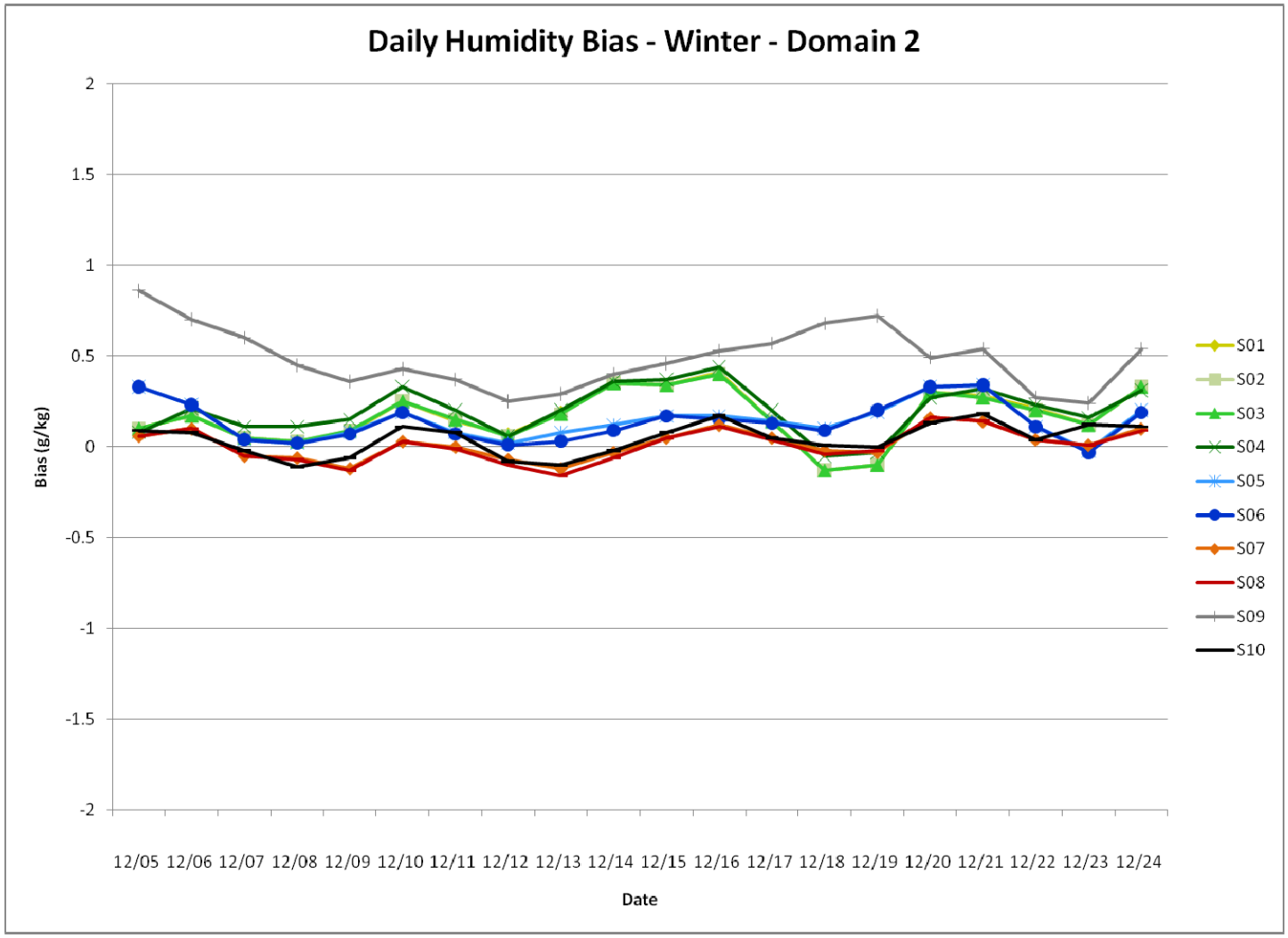
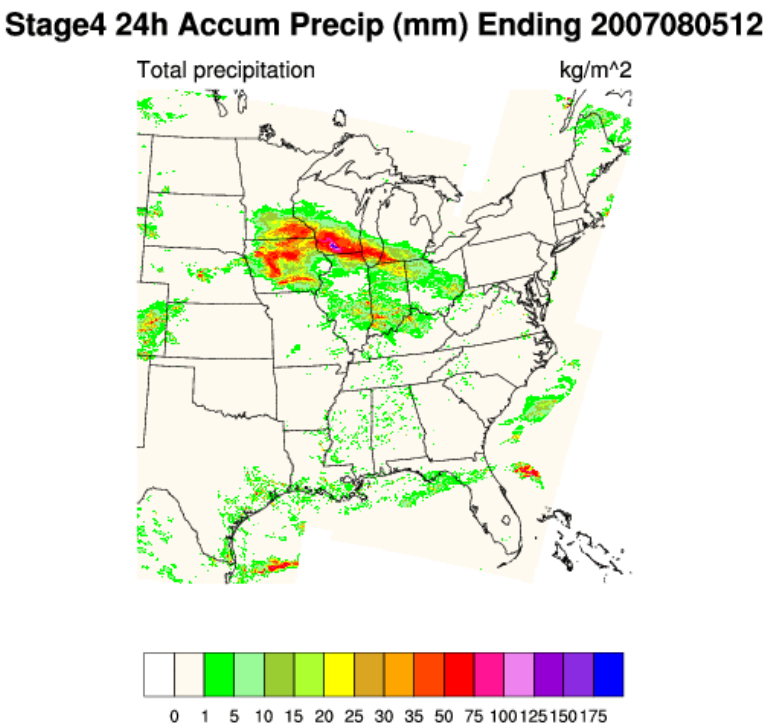
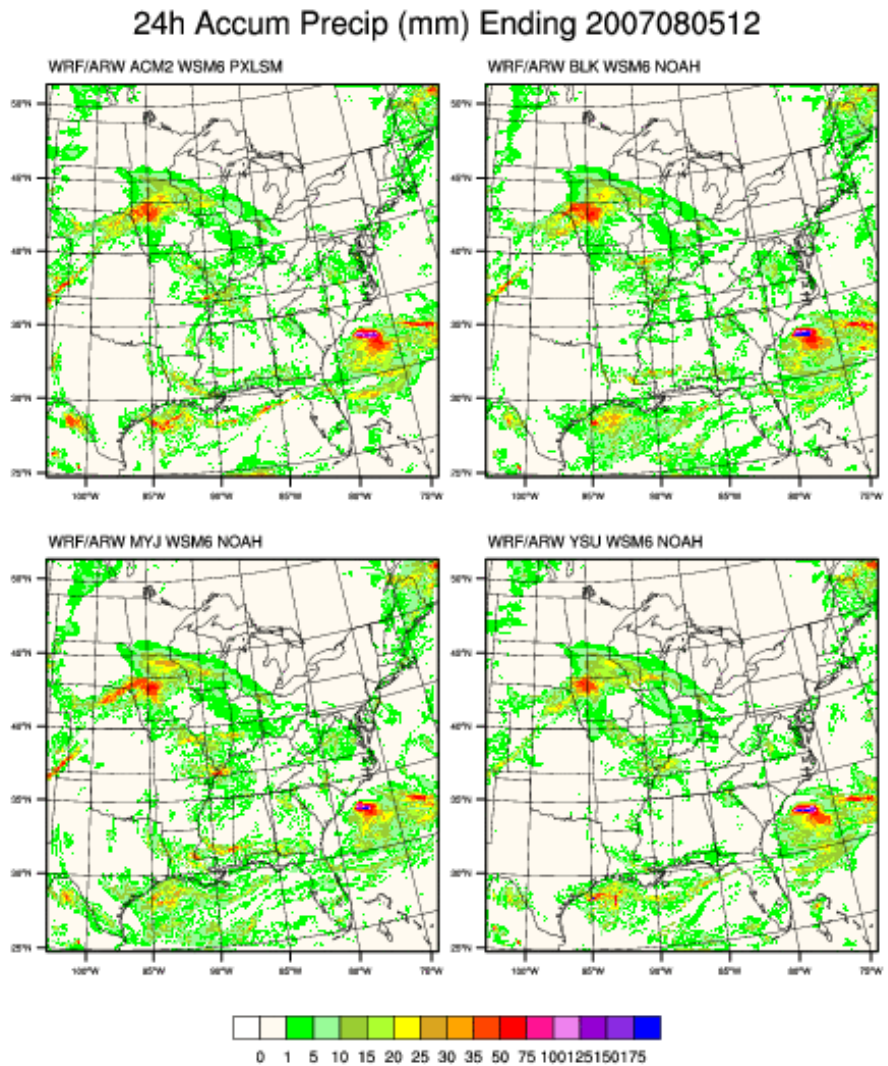
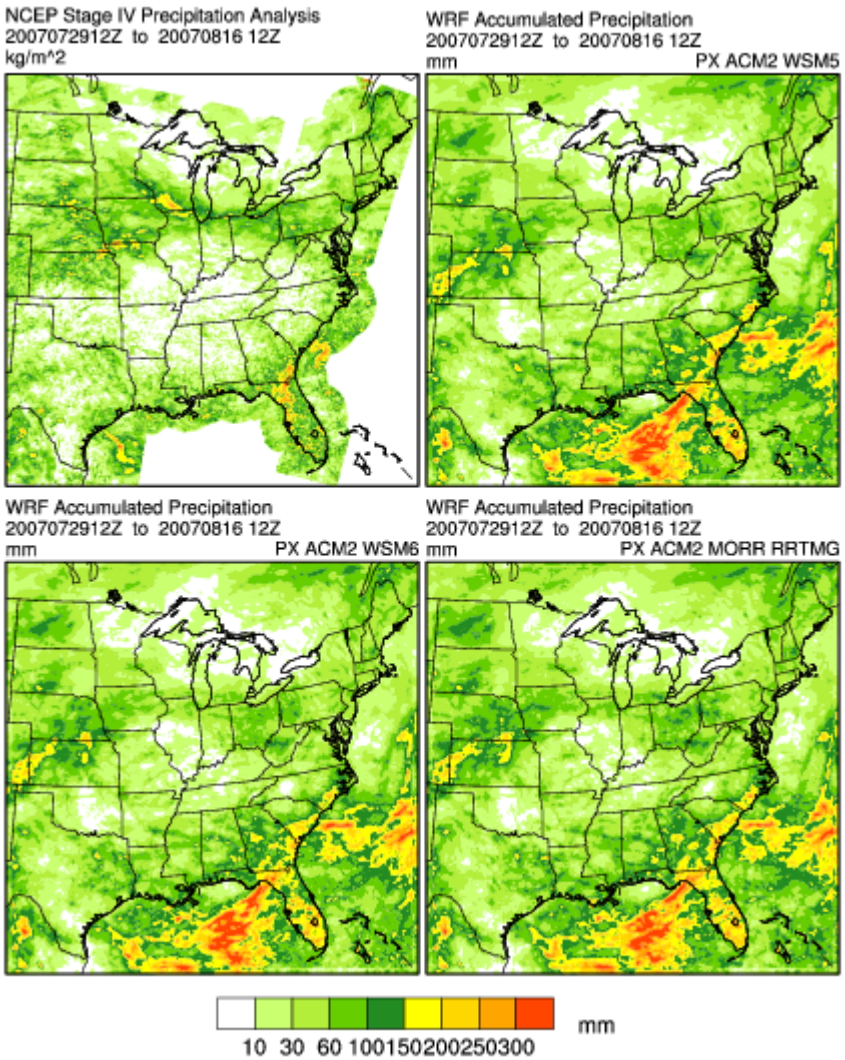


Precipitation



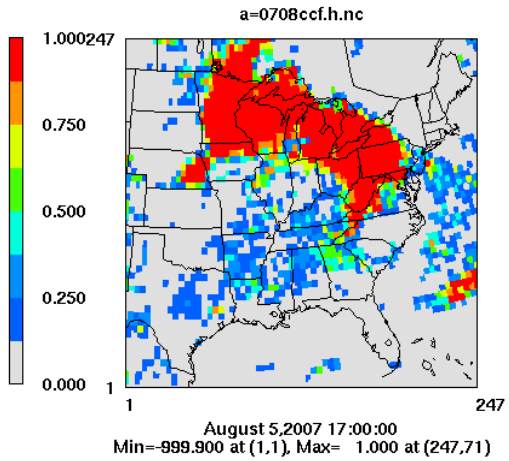


Precipitation

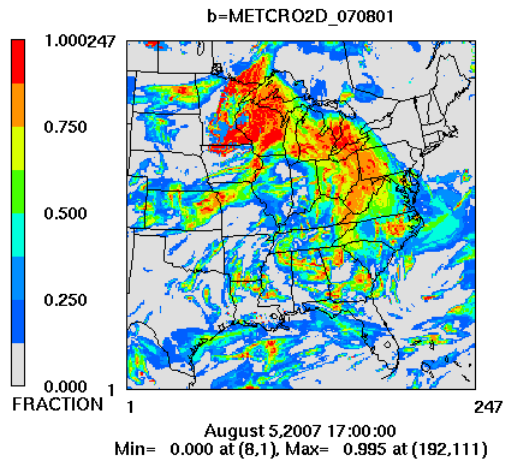


Cloud Cover

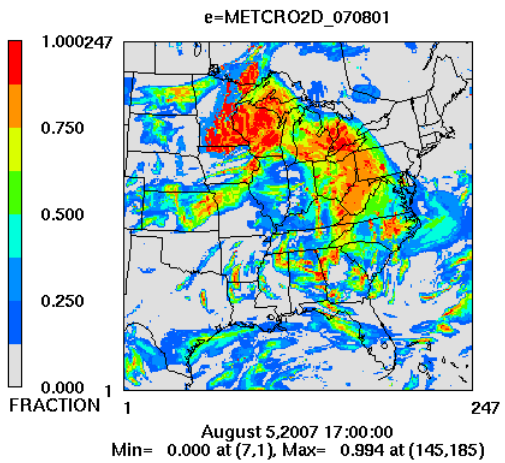
Satellite Layer 1 Clda



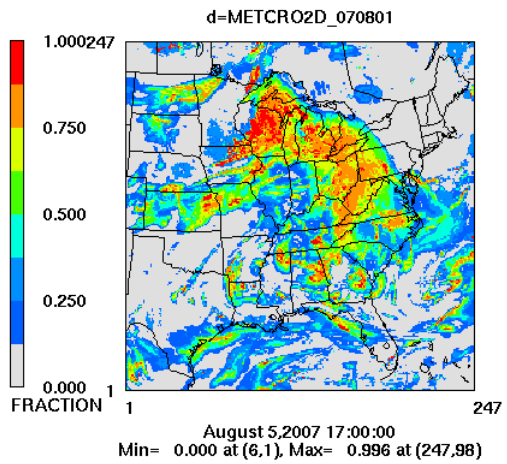
MYJ Layer 1 CFRACb



BLK Layer 1 CFRACe

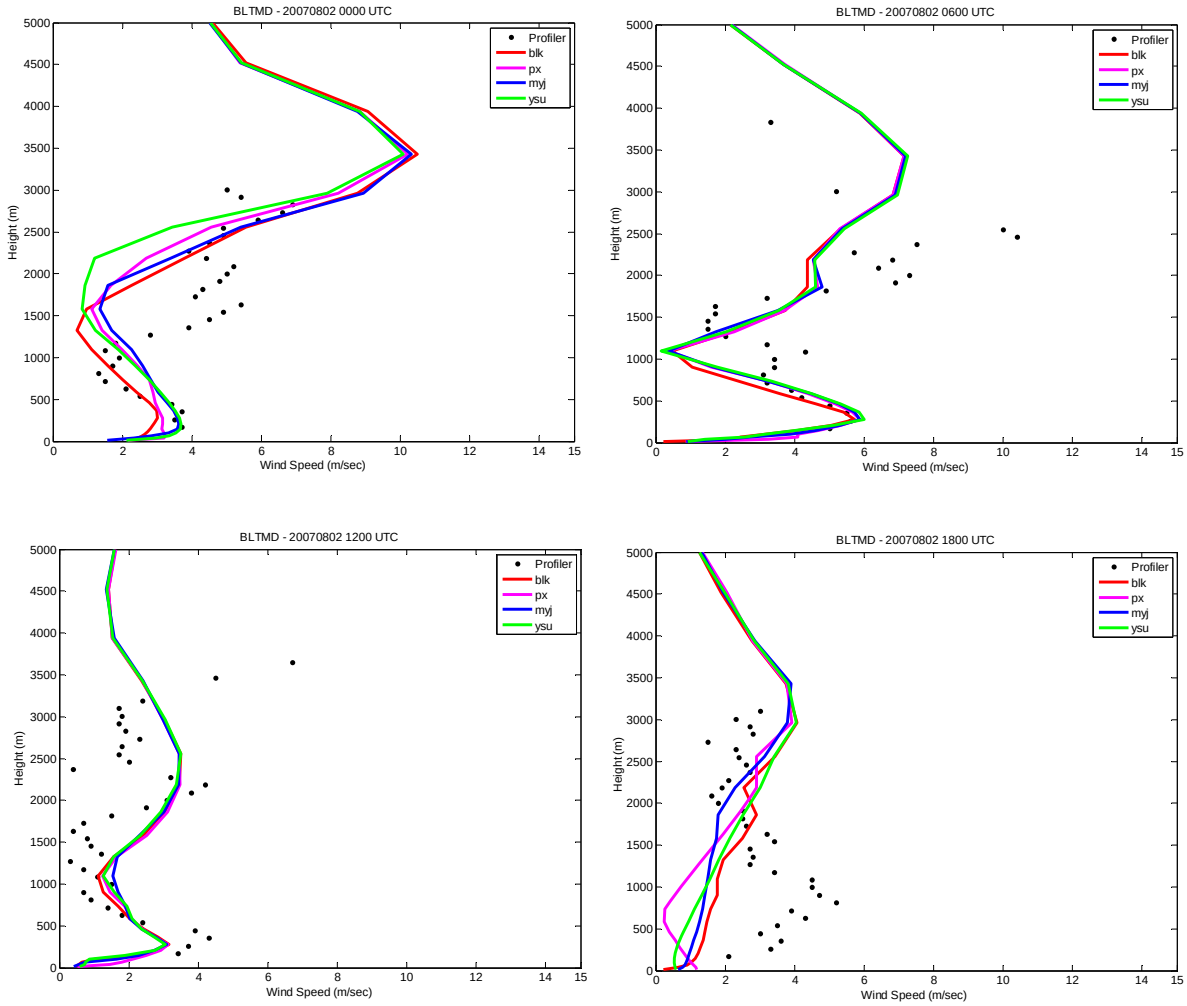


PX Layer 1 CFRACd



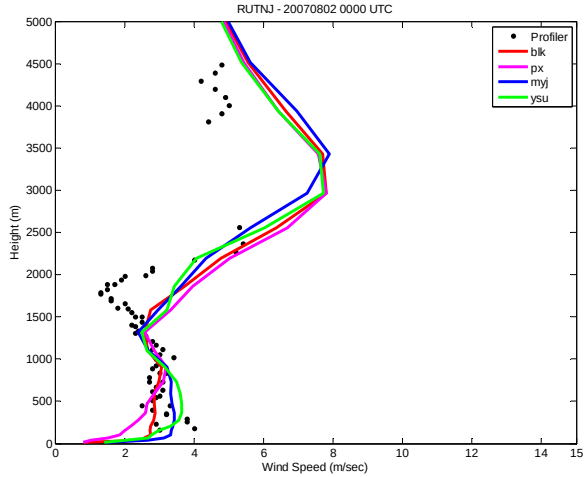
Low-Level Jet

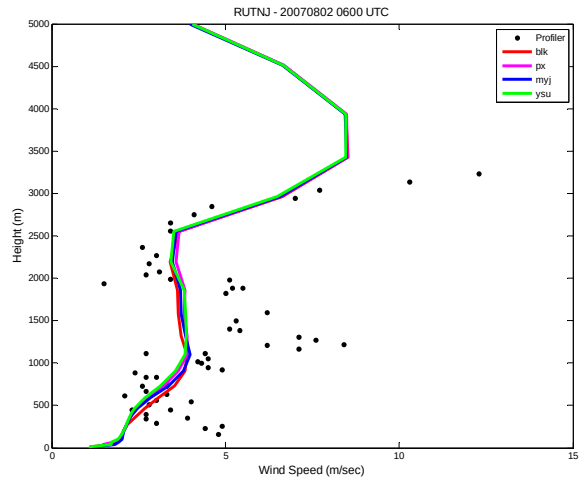
- **Beltsville, MD**
- **BLTMD**
- **2007-08-02**

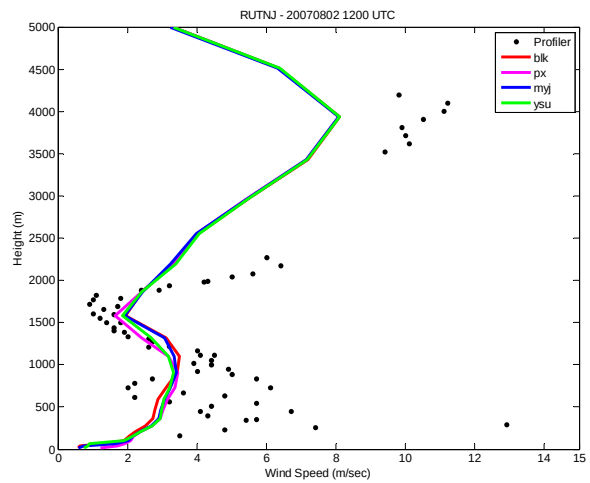


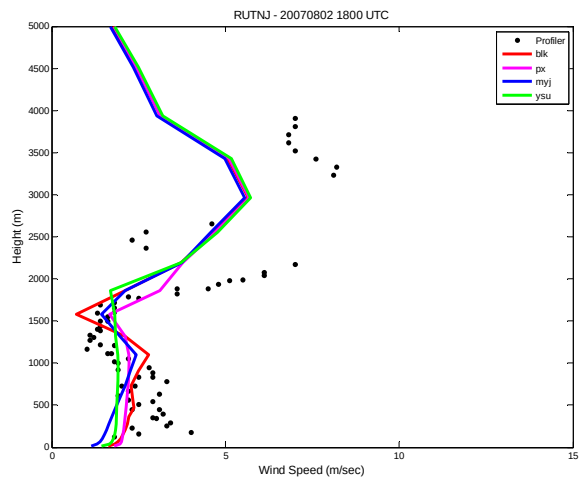
Low-Level Jet

- **New Brunswick, NJ**
- **RUTNJ**
- **2007-08-02**









Summary

- **The various physics options tested in WRF produced very similar performance for all meteorological variables. This was generally not the case for MM5, where the use of PX/ACM2 significantly improved performance of MM5 simulations. The one exception is the YSU pbl scheme, which consistently produced the poorest results.**

- **There was no clear winner as far as sensitivity configurations, however the PX/ACM2 configuration (S03) was preferred.**

- **Other sensitivity simulations were completed after the final configuration was selected for future reference. These runs tested the QNSE pbl scheme and the Betts-Miller-Janjic and Grell-Devenyi ensemble cumulus schemes. The results from these runs will be provided in future work.**

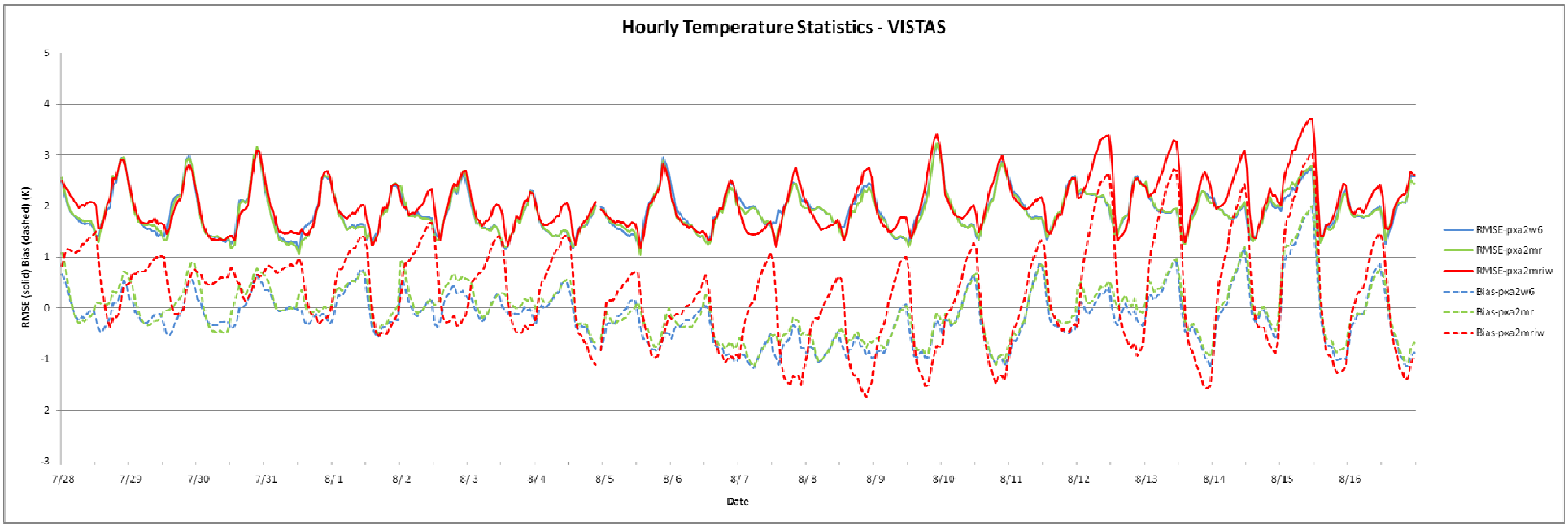
Summary

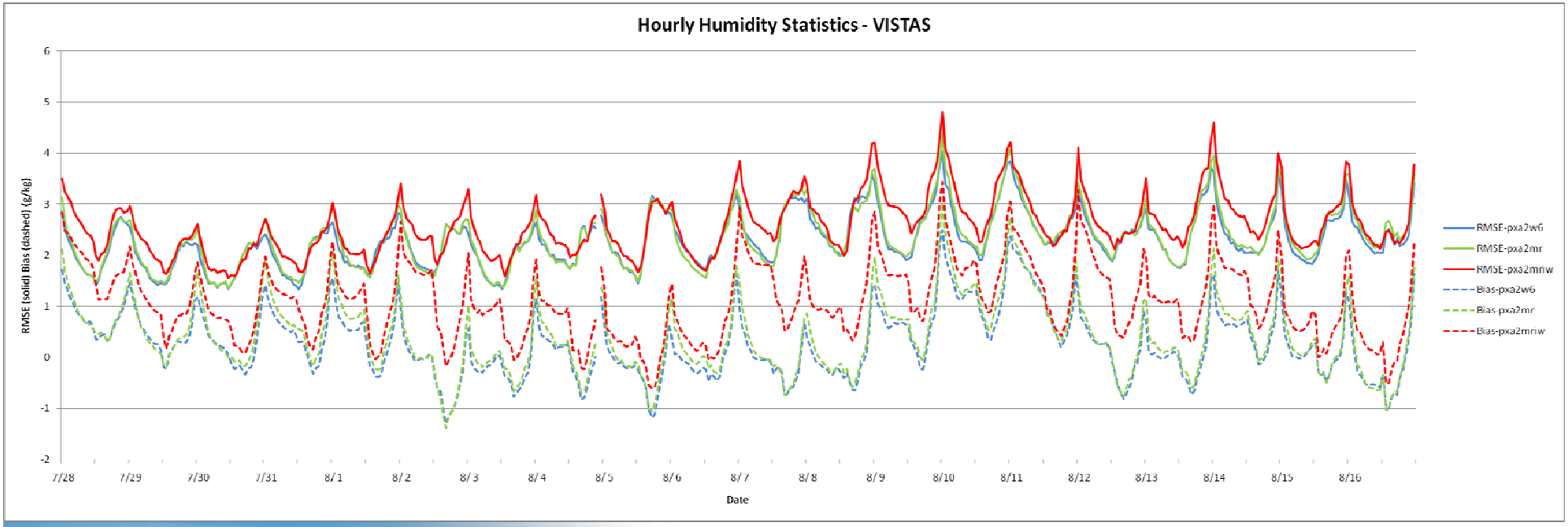
- **Final configuration: S03**
  - **ACM2**
  - **PX**
  - **Morrison**
  - **RRTMG**
  - **K-F**

- **OTC/MANEVU chose S09**
  - **Blackadar**
  - **PX**
  - **WSM6**
  - **RRTM**
  - **K-F**

Questions?

IPXWRF Hourly Statistics


Hourly Temperature Statistics - VISTAS
RMSE (solid) Bias (dashed) (K)
5
4
3
2
1
0
-1
-2
-3
7/28
7/29
7/30
7/31
8/1
8/2
8/3
8/4
8/5
8/6
8/7
8/8
8/9
8/10
8/11
8/12
8/13
8/14
8/15
8/16
Date
RMSE-pxa2wG
RMSE-pxa2mr
RMSE-pxa2mriw
Bias-pxa2wG
Bias-pxa2mr
Bias-pxa2mriw


Hourly Humidity Statistics - VISTAS
RMSE (solid) Bias (dashed) (g/kg)
6
5
4
3
2
1
0
-1
-2
7/28
7/29
7/30
7/31
8/1
8/2
8/3
8/4
8/5
8/6
8/7
8/8
8/9
8/10
8/11
8/12
8/13
8/14
8/15
8/16
Date
RMSE-pxa2wG
RMSE-pxa2mr
RMSE-pxa2mriw
Bias-pxa2wG
Bias-pxa2mr
Bias-pxa2mriw

AER Evaluation Details

Verification regions: RPO (VISTAS, CENRAPN, CENRAPS, MRPO, MANEVU, CONUS), FULL (entire d2), state (AL, FL, GA, KY, MS, NC, SC, TN, VA, WV, AR, DC, IL, IN, IA, LA, MD, MI, MI, OH, PA, WI)

Forecast hours: Bin by daily (all hours), day (15-20Z) and night (3-8Z), dropping the first 12 h of forecasts

Observational dataset: PrepBufr observations, ds337.0

Metrics: BIAS, RMSE and CORR (r)

Fields: T, SPECF (specific humidity), WIND, WDIR, and 24-h precip (12Z-12Z).

Heights: Surface for T, SPECF, WIND, WDIR, precip, plus at least mandatory levels for T, SPECF, WIND, WDIR aloft.

Will not restrict verification of calm winds.