This supplemental material contains verification of WRF v3.5.1 simulations for the 2012 and 2013 Campaigns.

1 WRF v3.5.1 monthly bias and RMS errors

Bias statistics for the 2012 Campaign from WRF v3.5.1 (Table 1) show minor overall differences compared to v3.4.1, with the most pronounced impact being on the surface wind speed. For the entire campaign, the wind speed bias for v3.5.1 was -0.29 m s^{-1}, with corresponding decreases in wind speeds across all months of about 0.1 m s^{-1}. This increases the negative bias in all months, except for a reduction in the positive bias in September. The minimal overall influence on temperature of the additional snow and ice fields over bodies of water suggests that changes likely are limited to those relatively few land sites immediately adjacent to the near-freezing water (see later in this section). The influence will be further reduced by late spring and summer as coastal snow and ice increasingly is restricted in spatial extent. For wind speed, there are no obvious model changes between WRF v3.4.1 and v3.5.1 that would explain the systematic decrease in wind speeds of approximately 0.1 m/s and again we suspect that the addition of the cryospheric ancillary data is unlikely to be the cause of a persistent domain-wide reduction in winds, absent a substantial and spatially large influence on temperature. It is not uncommon, however, for a new version of a model to affect summary statistics despite use of identical physics and input fields. Bromwich et al., (2013), for instance, reported for an Antarctic domain an even more substantial change in wind speed bias for the months of January (July) for Polar WRF v3.2.1 versus v3.3.1 of 1.07 (1.76) and 0.86 (1.36) m s^{-1}, respectively.

For the longer 2013 simulation period (Tables 2 and 3), a pronounced negative bias in 2-m temperature is largest in May and June, while a positive (moist) bias in 2-m dewpoint temperature changes sign in July-September, then returns in October-November. The sign of the wind speed bias also changes from negative in the spring and summer to positive starting in September. The wind direction bias is smallest during the summer months. Overall, the character of bias errors is similar in 2012 and 2013, despite the substantially different character of the two growing seasons.

RMS error statistics for WRF v3.5.1 for 2012 (Table 4) show minimal overall impact owing to use of v3.5.1 and inclusion of the supplemental snow and ice fields. Tables 5 and 6 for WRF v3.5.1 during 2013 show that the campaign-average RMS errors for this longer campaign are heavily influenced by seasonal patterns similar to those for the shorter 2012 Campaign. Temperature and dewpoint temperature RMS errors are largest from March-June (~4 K) and decrease substantially during the summer to ~2 K, before a sharp increase in November – presumably as snow cover becomes well established. (October 2013 was the warmest on record in Alaska (NOAA, 2013)). In contrast to 2012, wind speed RMS errors of approximately 2 m s^{-1} are smallest in the summer months. Wind direction errors during 2013 exhibit a modest minimum of approximately 44 degrees in October, compared to a June maximum of approximately 56 degrees.

2 WRF v3.5.1 spatial distribution of bias and RMS errors

Despite the inclusion in WRF v3.5.1 simulations of supplemental snow and ice fields over water, including the persistent sea ice in close proximity to the North Slope over the Beaufort Sea, temperature, dewpoint temperature and wind speed biases at individual sites were very similar to those from v3.4.1. This pattern is again repeated during the 2013 Campaign.

3 WRF v3.5.1 model performance at representative stations

McGrath: Implementation in v3.5.1 of the snow and ice fields did not have a large effect on the model time series compared to v3.4.1, except for several occurrences of strong surface moisture advection that lead to too high dewpoint temperatures around 15 August 2012. It is expected that, overall, the improved snow and ice fields over water will have minimal influence given the interior location of McGrath.

Deadhorse: The time series of v3.5.1 model temperature and dewpoint temperature differs only by the occurrence of a small number of days with lower temperature and moisture model values. In these cases, model values were already too low and the changes did not improve model performance.

Barrow: Similar to the effects at Deadhorse, model values for temperature and dewpoint temperature at Barrow differ only by the occurrence of a small number of days with lower temperature and moisture values.

4 Upper air campaign bias and RMS errors

Tables 7 and 8 for WRF v3.5.1 for the 2012 and 2013 Campaigns, respectively, show only minor differences compared to the WRF v3.4.1 simulations for 2012 and, overall, reflect consistency in the modeling strategy year-to-year.

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Figure Captions

Figure S1. Spatial distribution of WRF v3.4.1 2012 temperature bias (K) on innermost domain (3.3-km grid spacing) for the months of a) May, b) June, c) July, d) August, and e) September.

Figure S2. As in Fig. S1, but for dewpoint temperature bias (K).

Figure S3. As in Fig. S1, but for temperature RMS error (K).

Figure S4. As in Fig. S1, but for dewpoint temperature RMS error (K).

Tables

Table 1. 2012 WRF v3.5.1 Model Biases for Selected Surface Variables.

Surface Variable	May	June	July	August	September	2012 Campaign
2-m Temperature (K)	-2.24	-1.81	-1.60	-1.08	-0.70	-1.44
2-m Dewpoint temperature (K)	1.11	0.11	-0.74	-0.63	-0.04	-0.10
10-m Wind speed (m s^{-1})	-0.67	-0.47	-0.30	-0.32	0.25	-0.29
10-m Wind direction (deg)	4.7	3.3	1.6	4.6	4.1	3.7

Table 2. March-July 2013 WRF v3.5.1 Model Biases for Selected Surface Variables.

Surface Variable	March	April	May	June	July
2-m Temperature (K)	0.12	-0.95	-2.64	-2.25	-1.59
2-m Dewpoint temperature (K)	2.08	2.08	1.19	0.32	-0.74
10-m Wind speed (m s^{-1})	-0.22	-0.29	-0.69	-0.68	-0.48
10-m Wind direction (deg)	6.1	4.6	1.9	2.2	1.8

Table 3. 2013 Campaign and August-November 2013 WRF v3.5.1 Model Biases for Selected Surface Variables.

Surface Variable	**August**	**September**	**October**	**November**	**2013 Campaign**
2-m Temperature (K)	-1.23	-0.45	-0.8	-0.01	-1.09
2-m Dewpoint temperature (K)	-0.86	-0.11	0.33	0.87	0.56
10-m Wind speed (m s^{-1})	-0.29	0.03	0.16	0.17	-0.26
10-m Wind direction (deg)	3.0	3.3	5.2	5.4	3.7

Table 4. 2012 WRF v3.5.1 Model RMS Error for Selected Surface Variables.

Surface Variable	May	June	July	August	September	2012 Campaign
2-m Temperature (K)	3.41	3.49	3.04	2.40	2.01	2.99
2-m Dewpoint temperature (K)	2.97	2.73	2.53	2.17	2.09	2.56
10-m Wind speed (m s^{-1})	2.14	2.00	1.99	2.09	2.45	2.18
10-m Wind direction (deg)	57.9	55.3	53.0	48.6	46.8	51.9

Table 5. March-July 2013 WRF v3.5.1 Model RMS Error for Selected Surface Variables.

Surface Variable	March	April	May	June	July
2-m Temperature (K)	3.73	3.51	4.00	3.99	3.10
2-m Dewpoint temperature (K)	4.47	3.95	3.29	2.95	2.35
10-m Wind speed (m s^{-1})	2.76	2.37	2.25	2.04	1.92
10-m Wind direction (deg)	49.7	48.2	53.5	55.6	50.9

Table 6. 2013 Campaign and August-November 2013 WRF v3.5.1 Model RMS Error for Selected Surface Variables.

Surface Variable	**August**	**September**	**October**	**November**	**2013 Campaign**
2-m Temperature (K)	2.68	1.98	2.21	3.75	3.45
2-m Dewpoint temperature (K)	2.35	2.09	2.00	4.12	3.30
10-m Wind speed (m s^{-1})	1.92	2.12	2.47	2.81	2.35
10-m Wind direction (deg)	51.2	45.6	43.9	48.0	49.7

Table 7. 2012 Campaign model Bias/RMS Error for Upper-Level Variables for WRF v3.5.1.

Pressure Level (hPa)	**Temperature (K)**	**Geopotential Height (m)**	**Relative Humidity (%)**	**Wind Speed ($m\ s^{-1}$)**
200	0.20/1.72	6.8/16.5	-9.3/14.9	0.24/2.97
300	0.28/1.39	-1.6/17.4	10.9/21.5	-0.22/4.84
500	-0.11/0.98	-0.2/13.1	6.1/23.0	-0.06/3.16
700	-0.05/1.03	0.9/12.6	4.3/19.8	0.02/2.98
850	-0.14/1.14	-6.8/13.1	4.0/16.0	0.18/3.06

Table 8. 2013 Campaign Model Bias/RMS Error for Upper-Level Variables for WRF v3.5.1.

Pressure Level (hPa)	Temperature (K)	Geopotential Height (m)	Relative Humidity (%)	Wind Speed (m s^{-1})
200	0.23/1.69	5.5/15.3	-9.9/16.2	0.15/3.19
300	0.20/1.29	-3.1/17.1	5.5/20.2	-0.22/4.70
500	-0.19/1.05	-0.4/14.0	3.1/21.4	-0.01/3.46
700	-0.18/1.11	1.7/13.0	2.0/20.3	-0.01/3.03
850	-0.19/1.31	-5.1/12.5	1.8/17.8	0.32/3.17

References

Bromwich, D. H., Otieno, F. O., Hines, K. M., Manning, K., W., and Shilo, E.: Comprehensive evaluation of polar weather research and forecasting model performance in the Antarctic, Journal of Geophysical Research: Atmospheres, 118, 274-292, doi: 10.1029/2012JD018139, 2013.

NOAA: State of the Climate (2013): National Overview for October 2013, Tech. rep., NOAA, available from http://www.ncdc.noaa.gov/sotc/national/2013/10, 2013.