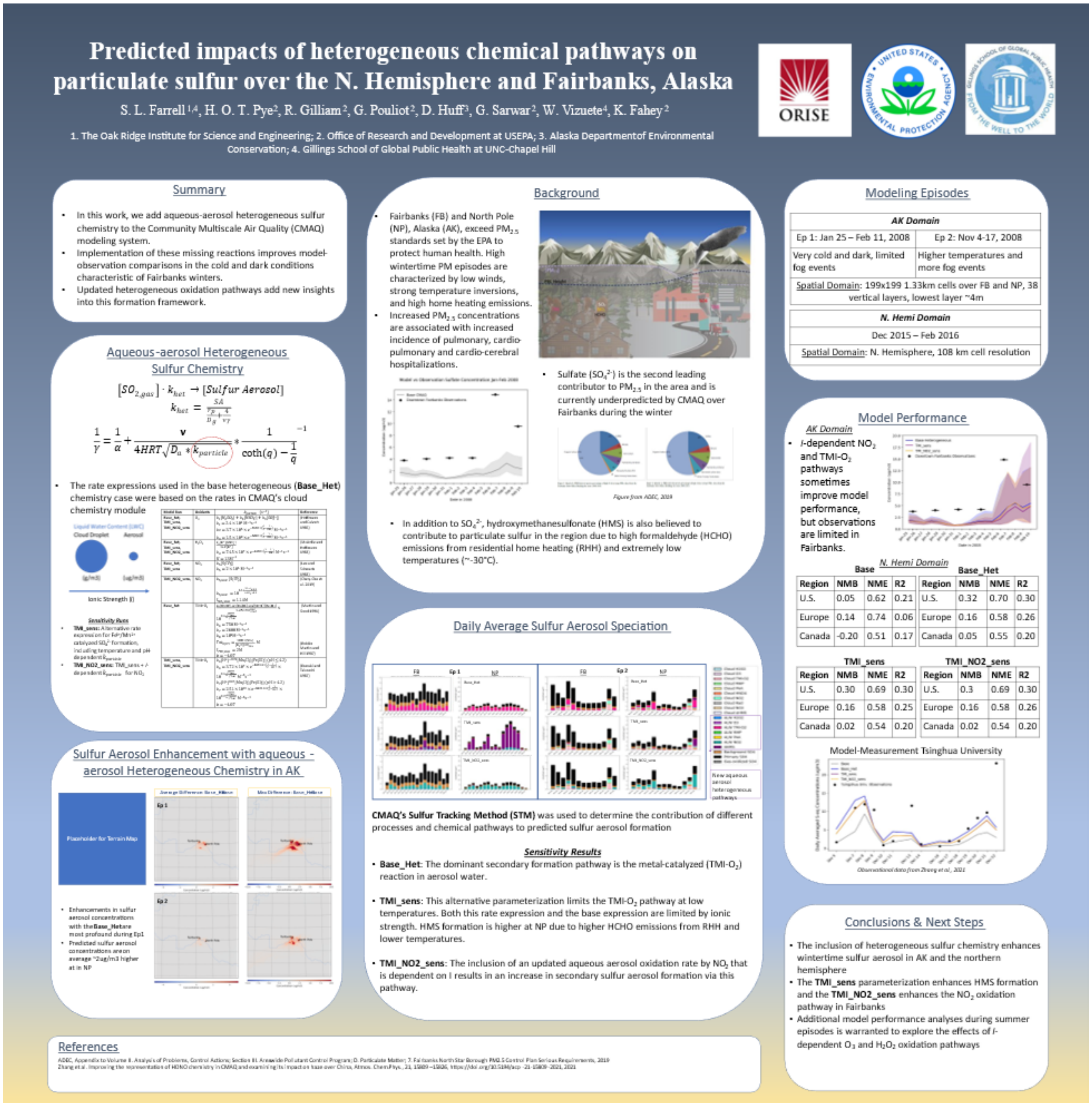
5. USEPA WRF Poster



Modeling the wintertime meteorology for the 2022 Alaskan Layered Pollution and Chemical Analysis (ALPACA) campaign

Robert Gilliam, Kathleen Fahey, George Pouliot, Havala Pye, Nicole Briggs, Deanne Huff and Sara Farrell

Fairbanks, Alaska is a nonattainment area for the 24-hour PM2.5 National Ambient Air Quality Standards (NAAQS). Violations of the NAAQS typically occur in winter when the cold conditions are associated with strong temperature inversions and air stagnation that are often difficult to simulate. These weather regimes in urban areas of higher emissions (i.e.; residential wood combustion, mobile sources and energy production) result in a buildup of particulate pollution at the surface. The Alaskan Layered Pollution and Chemical Analysis (ALPACA) field campaign was conducted in January and February of 2022 to address some of the knowledge gaps with a focus on better understanding emissions, meteorology, and atmospheric chemistry.

Notes on US EPA WRF modeling for Fairbanks, AK (Dec 2019-Feb 2020)

Introduction

Final narrative of WRF modeling for Dec 2019-Feb 2020 SIP modeling period for Fairbanks, AK. The ALPACA field campaign in early 2022 provided an opportunity to refine our fine-scale modeling in complex winter regimes where strong temperature inversions limit vertical mixing of surface-based emissions and cause high concentration of PM2.5 and other pollutants. Using field campaign data for evaluation and then observational nudging, the result was a new model configuration with adjustments to the observation nudging settings and enabling FDDA with constraints on how close to the surface grid-based nudging is applied. Because these settings proved to improve model performance, dramatically in some cases, we have applied this configuration to the 2019-2020 SIP modeling period for the State of Alaska. Original modeling for Alaska was done by Ramboll and documented in a 2021 report. This will be referenced in the narrative below where appropriate.

Configuration & Issues

General WRF configuration follows the original modeling done by Penn State under a US EPA contract completed in 2010. This research defined a quality WRF model configuration to model Fairbanks, AK based on a simulation of a 2008 winter case study. The configuration at the time was a 12 km coarse domain with 4 and 1.33 km nested where the finest scale domain was centered over Fairbanks. Should be noted that Ramboll also used the 12-4-1.33 km domain configuration. In recent years, we have found that the 12 km outer domain is not required. The US EPA has been running a 4 to 1.33 km configuration (Figure 1) with good results when the 2008 case study was revisited with a WRF model code that had 10 years of development since the original modeling in 2010. Both ALPACA and the US EPA modeling for 2019-2020 used this new domain configuration.

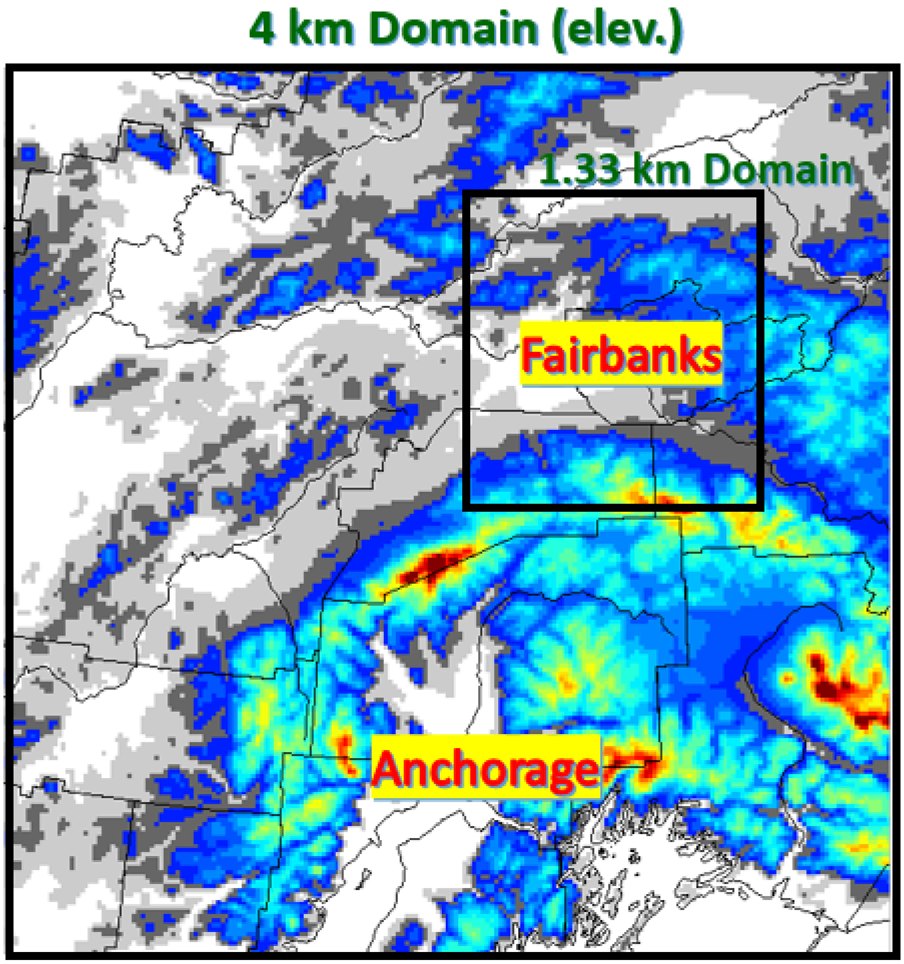


Figure 1: US EPA domain configuration with 4 km outer domain with a 1.33 km nested domain centered over Fairbanks, AK.

Another distinction is the vertical grid structure. Ramboll ran into model run stability issues using the Penn State 39 vertical layer structure where our typical 10 m thick first layer was split into three layers with center point at approx. 3, 6 and 9 m. The US EPA did not experience the same stabilty issues, so this 39-layer structure was preserved. This was used not only for the idealistic view that more detail near the surface will improve boundary layer modeling where strong inversions exist. It was used because Alaska Dept of Env. Conservation observations at NCore, AStreet and Hurst Rd have multi-level temperature and wind data at about 3, 6, 10, 23 m. Having model levels near the level of these observations so close to the surface should help refine model stability in Fairbanks in the lower 23 m of the atmosphere where emissions are released if the nudging is done correctly.

The US EPA modeling had a slight deviation from the Ramboll modeling in that the underlying global analysis for FDDA on the 4 km domain used 6-hourly GFS nudging of wind, temp and moisture above the boundary layer. Ramboll used ERA5 or ECMWF-based analyses. We used GFS for ALPACA 2022 and that worked well, so that was not changed for the 2019-2020 period. The US EPA did test a special version ERA5 with much finer vertical information. But some odd features in the temperature field was noted and the results of that test were on par with the GFS if not worse in terms of error. This would not matter much if the original configuration of "observational nudging only" on the 1.33 km domain was used, but US EPA found a benefit in the ALPACA modeling of using FDDA-based grid nudging with constraints that it is never applied below vertical level 9 of the model (~ 250 m). This allows the near-surface observation nudging to run without interference from FDDA that is based on coarse analyses.

US EPA run based on the 2008 configuration used the RUC land-surface model where Ramboll used the Noah LSM. But the US EPA did follow the same updated PBL scheme as Ramboll. The US EPA run used 24-class USGS landuse where Ramboll updated to the MODIS 20 class landuse. We do not think these are as important with deep snow cover for the winter period except for the PBL scheme where we did find improvements when we tested the Ramboll settings for the MYNN 2.5 TKE closure scheme.

The US EPA modeling is completely distinct from Ramboll in that all inputs were developed independently. The WRF modeling started by doing a full spin-up from Nov 10-30, 2019 (20 day). This allows the model to develop the snowpack at the model resolution rather than poorly defined snow from coarse analyses. It also spins up all the surface properties like soil and surface temperature. WRF was then reinitialized on Nov 30, 2019 with these spun up values for the key Dec 2019 through Feb 13, 2020 modeling period for CMAQ. The reinitialization was done because we found some issues restarting WRF with restart files and the observation nudging. At least on the US EPA supercomputer we found the observational nudging does not work properly when WRF is restarted. So, we run via reinitialization for the complete SIP modeling period without any restarting. For contrast, Ramboll ran fifteen, 5.5 overlapping run segments to cover the 74-day modeling period. From the Ramboll report, these segments were run concurrently because of computational limitation so completely independent of each other. Evidence documented by Otte (2008) found continuity issue running

5.5 overlapping run segments for CMAQ modeling. In WRF, the surface properties like temperature, snow, moisture, etc are reinitialized from coarse analyses each run segment rather than carried over in a more continuous manner. The US EPA model simulation has no breaks and will not suffer any negative impacts of reinitialization.

Several issues were found during the US EPA's testing. A primary issue was the nudging files. We used the observations in the nudging file to evaluate the initial WRF simulation. It was discovered (Figure 2) that ADEC observations seemed to have an offset relative to the WRF simulation. This is clear in the Hurst Road timeseries in Figure 2 for Dec 2019. A comparison with nearby NOAA sites discovered that the date/time stamp of the Astreet, NCore and Hurst Rd sites were in local time, not UTC. This effectively causes WRF to nudge towards ADEC temperatures 9 hours earlier than reality. This impact would probably be greatest on days of the period with the most sunlight as WRF would think it is mid-day as an example but being nudged towards near-surface temperature that is at night, so cooling the model when it should be warming. Now there are other observations in the area that would blunt the impact some, but in our testing, the wrong time of day increases model error substantially based on all observation sites around Fairbanks. In the timeseries below the RMSE of 3-m temperature is 4 K. When we fixed this issue, the RMSE dropped significantly to about 1.75 K. These are critical for surface stability, so it is expected that these improvements will improve the representation of mixing in CMAQ.

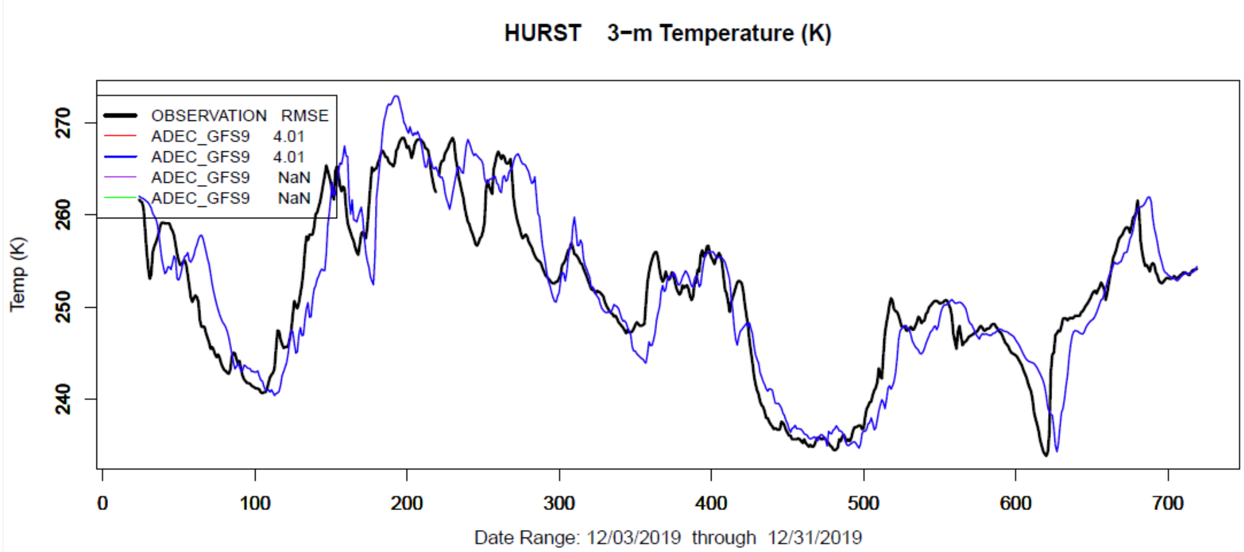


Figure 2: US EPA domain configuration with 4 km outer domain with a 1.33 km nested domain centered over Fairbanks, AK.

The US EPA leveraged the raw ADEC measurements in several text files to develop a new observational nudging file for the whole period that also include all MADIS observations including NOAA and Mesonet sites and the twice-daily PAFA upper-air sounding. The US EPA did not use the Ramboll observation nudging records from NOAA and Mesonet sites and elected to use an internal MADIS2LITTLER code that extracts these observations for a specified domain. From a look at the Ramboll files, they may have used a database of LittleR files directly. It was not clear if all Mesonet sites in MADIS were included in Ramboll's files, so safe to just recreated knowing all data available was included. We also cast ADEC 3-m observations as 2-m observation nudging records as well as a multi-level observation per sensitivity testing of the ALPACA period that showed some benefit. To be clear on other differences based on ALPACA testing, the US EPA limited obs nudging of surface data to the lower 50 m of the atmosphere rather than Ramboll's setting of 500 m (obs_nudgezmax =50). The MM5 vertical obs spreading scheme was used instead of default option. And finally, the time window for an observation to be nudged was doubled from 40 min to 80 min. In ALPACA testing this smooth the WRF temperature time series and improve the representation of temperature.

One last issue was found in the Ramboll nudging file that may have impacted results. It seems that many hourly observations were set to missing during the Obsgrid development of observation nudging files. The US EPA found this in their initial development of these files because QA gross and buddy checks were too strict for a Fairbanks in winter where temperature frequently varies by 5 deg or more over small distances. And the QA is done using a coarse analysis. When we completely turned off QA many observations were uncovered that were previously set to missing. The US EPA decided to relax QA rather than completely turn off. Gross temperature difference for example between the observation and analysis was increased from 4 to 8 K. The fact that so many observations were missing in the observation nudging file may explain some of the poor statistics in the Ramboll modeling at a site like PAFA.

Results: Model Evaluation & Discussion

Key metrics in this evaluation is the temperature near the surface. Evaluation has been done in the past on how PAFA RAOB compares with WRF using observation nudging and the twice daily sounding indicates solid if not outstanding model performance on average over winter period. An indication that observational nudging is effective. Figure 3 is an example using temperature where RMSE is near 1 K at the surface and decreases aloft to around 0.50 K. The bias is also low and distribution of model difference with the observed temperature show tight distribution where the model is almost never more than 1 deg from the observed profile. WRF similarly performed well for moisture and wind.

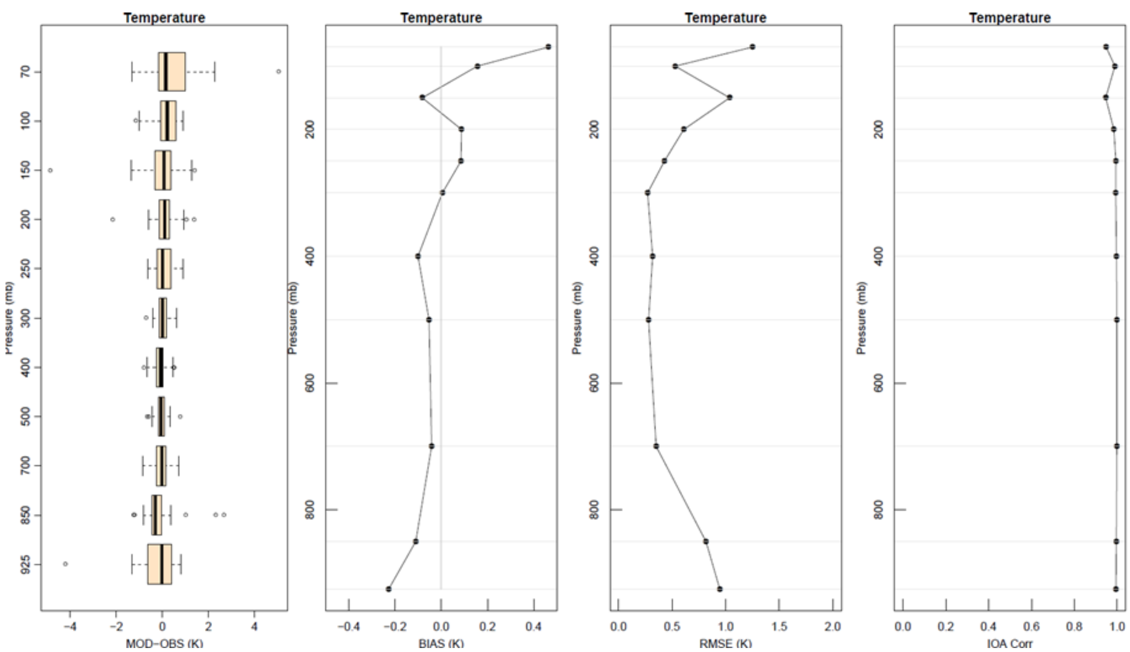


Figure 3: Temperature profile statistics for the modeling period at PAFA. Tiles include the distribution of temperature difference (mod-obs), model bias, error (RMSE) and index of agreement.

Figure 4: Location of key observation sites used to evaluate the 2019-2020 WRF simulations.

Table 1 provides the most direct comparison with the Ramboll simulation(s) and demonstrates model performance gains with the updated US EPA configuration. This is most clear comparing the WRF simulations at the standardized NOAA sites PAFA, PAFB and PAEI. No large difference at PAEI. This site is away from Fairbanks more than all others, so was likely not affected by the date/time issue for the ADEC sites in the nudging file. The smaller, but clear improvement at PAEI likely reflects the change of the nudging configuration options more than any fixes to the observation nudging file. The Ramboll files has PAEI represented the same as the US EPA nudging file.

Fairbanks International (PAFA) indicates a significant improvement in the WRF representation of near surface temperature. The 2.20-2.40 K monthly RMSE is much lower than the ~3.55-4.70 K values reported by Ramboll. It was found that PAFA had many missing values in the Ramboll observation nudging file share with the US EPA. This was corrected with relaxed QA in Obsgrid and a full record was found in the US EPA nudging file. PAFB sits on the east side of Fairbanks and indicates this area is one where WRF performs the best with monthly RMSE values between 1.70 to 1.90 K. Ramboll has errors from ~2.40 to 2.70 K. This site surely suffered some in the Ramboll run with nearby Astreet and NCore data being nudged 9 hours early.

Table 1: WRF RMSE of 2-m temperature at key observation sites around Fairbanks. ADEC values are based on the 2021 Ramboll report. USEPA is the best US EPA simulation with corrections to observation nudging files and updated configuration.

2-m Temp RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
	Dec	Dec	Jan	Jan	Feb	Feb
PAFA	4.38/3.55	2.20	4.70/3.84	2.60	4.41/3.56	2.40
PAFB	2.77/2.41	1.70	3.09/2.56	1.90	2.82/2.73	1.70
PAEI	2.68/2.57	2.40	2.94/2.13	2.20	3.36/3.03	2.70
ASTREET (10m)	1.54	NA/2.54	1.39	2.63	2.15	1.90
NCORE (3/10m)	1.23	1.72/2.09	1.32	2.22/2.69	2.00	1.39
HURST (3/10/23m)	2.34	2.02/1.96/1.96	2.39	1.66/1.52/1.40	2.66	1.65/1.48/1.32
BRHA2	X	1.70	X	1.90	X	2.00
FAEA2	X	2.30	X	2.10	X	1.60
AWCA2*	X	2.80*	X	X	X	X
LTPA2	X	2.10	X	2.10	X	2.30*
F4513	X	1.90	X	2.10	X	1.70
F3318	X	1.90	X	1.90	X	1.60

The ADEC sites and model performance is a key in this model evaluation. US EPA run verified extremely well at Hurst Rd. The Jan and Feb model performance is as precise as any modeling in terms of temperature error. The 3, 10, 23-meter temperature RMSE is 1.66, 1.52 and 1.40 K in January 2020. The mean absolute error is close to 1 K. Specific times will be discussed in a time series analysis, but for context, WRF is performing perhaps best during the cold periods over this 23 m layer above the surface. This informs that the temperature inversion and stability are well represented in WRF. NCore only has two levels (3 and 10 m), but both are simulated well in Dec. The errors rise in January (significant missing data) and fall again in Feb. The timeseries analysis will analyze this in more detail. Astreet has a lot of missing data including all 3 m temperature in the file shared with the US EPA. It is unclear how Ramboll derived statistics, but the Ramboll errors are quite low in most cases. The US EPA run is much lower across the board at all levels (Ramboll only reports what is assumed 3 m temperature statistics). Ramboll reports lower errors in general at NCore and Astreet. More discussion in the timeseries analysis at NCore and Hurst Rd.

Other observation sites listed are Mesonet sites around Fairbanks. We do not have specific errors at these sites based on the Ramboll simulations, but confirm these sites were used in their nudging. However, the monthly temperature RMSE at other sites in Fairbanks are as low as 1.60 K. Most monthly errors (9 of 14) are below 2 K which signifies quality temperature modeling. A few are just above 2 K. Note that site F3318 is near the ADEC Hurst Rd monitor. The monthly statistics at F3318 are in line with Hurst Rd performance with temperature error between 1.6 and 2.0 K. Several values with asterisks are questionable after looking at the observations where odd features exist (spikes) and large consistent bias (AWCA2) not seen at sites within a few kilometers that suggest site data quality issues. Overall, these statistics are consistent with the other observation platforms.

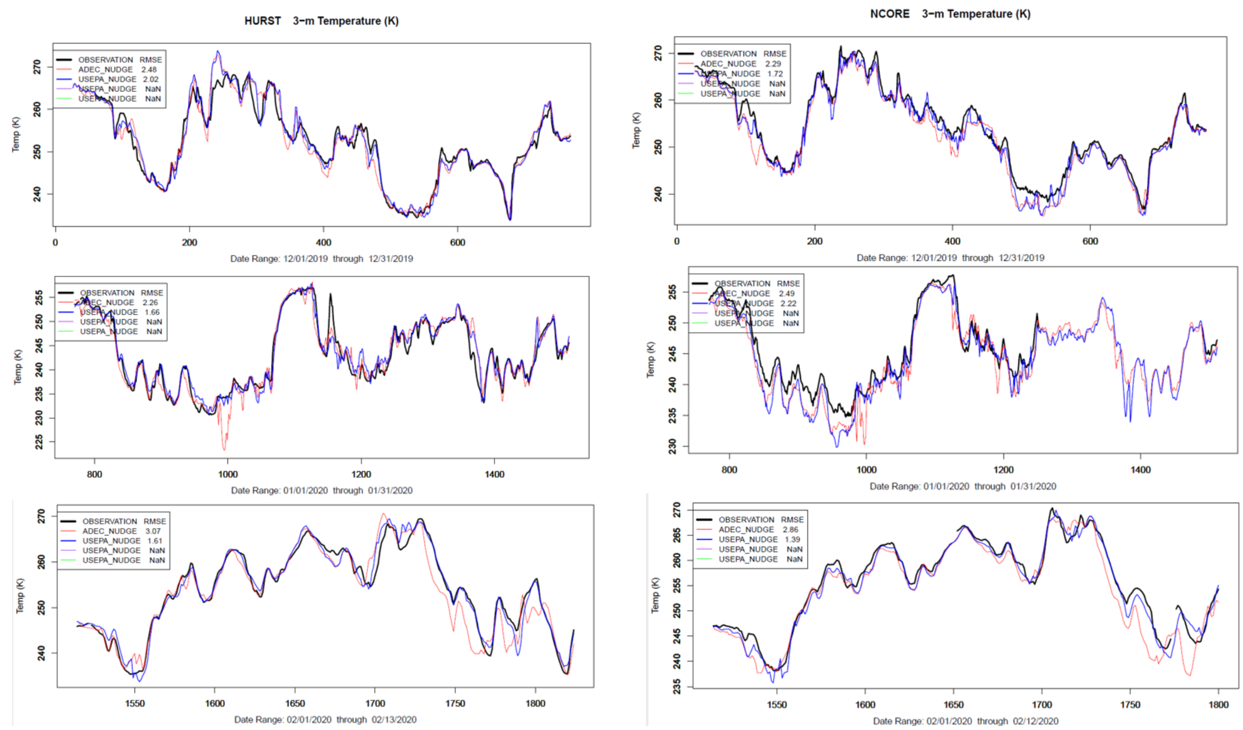


Figure 5: Temperature timeseries at Hurst Rd and NCore sites for Dec (top), Jan (middle) and Feb (bottom). RMSE values are provided for the WRF simulation that used the ADEC observation nudging file (red) and the US EPA develop observation nudging file (blue).

Timeseries at the two ADEC sites, NCore and Hurst Rd that have close to complete 3-m temperature records are provided for each month in Figure 5. The RMSE for both sites for all months are around 1.75 K. This level of error is superb. Looking closer at cold periods, US EPA WRF has a clear cold bias during the early Jan 2020 cold pool event. This event is examined closer with Ramboll modeling next, but otherwise, US EPA WRF captures other cold periods with high precision, especially at Hurst Rd.

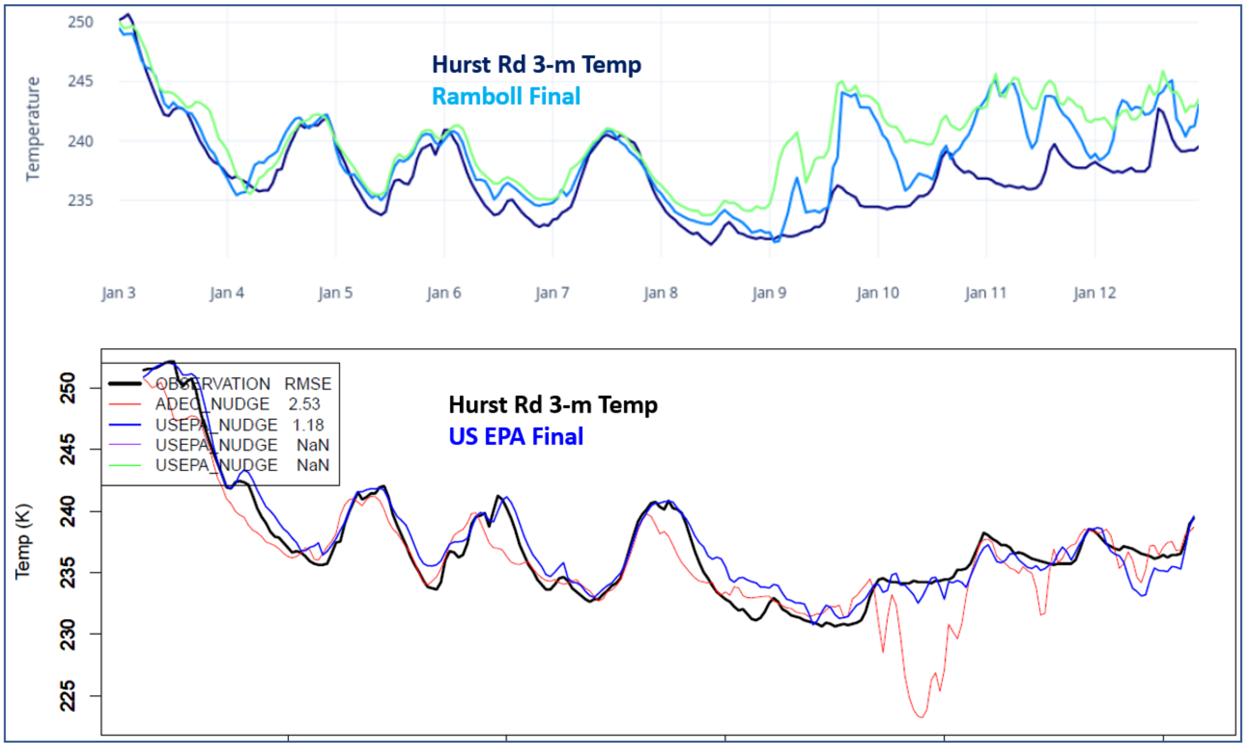


Figure 6: 3-m temperature timeseries at Hurst Rd. from the Ramboll report (top) and US EPA WRF (bottom).

Using the Ramboll report, a case study comparison is provided at several key sites where a more direct comparison of the US EPA and Ramboll simulations can be done. This case study is the Jan 3-12, 2020 period shown in section 6.3.2 of the Ramboll report. Hurst Rd. comparisons are presented in **Figure 6**. US EPA simulation has a low RMSE at 1.18 K and follows the observed temperature closely over this period. The Ramboll simulation performs well for the first half of the period, but a warm bias of almost 10 K spikes on Jan 10 and 11, where the US EPA run is almost exact.

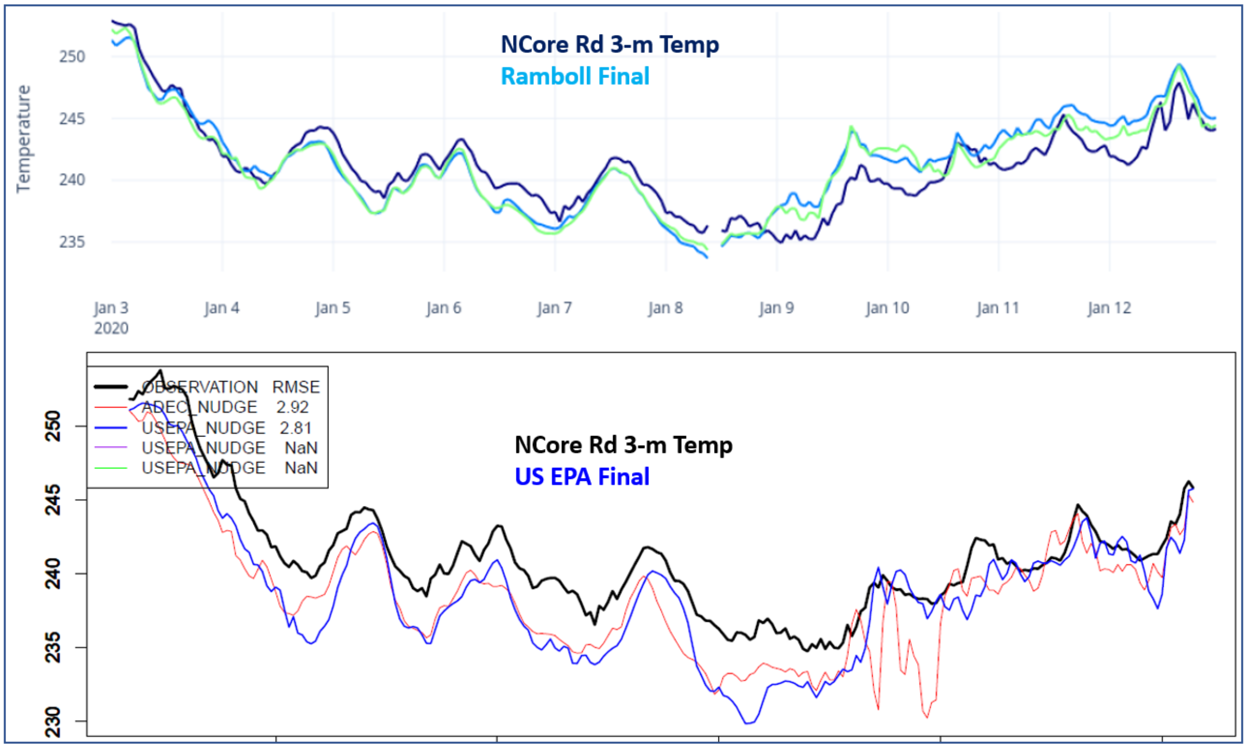


Figure 7: 3-m temperature timeseries at NCore from the Ramboll report (top) and US EPA WRF (bottom).

NCore comparison for the same case is presented in **Figure 7**. In this case the US EPA simulation performs the worst of the whole modeling period as already discussed using full period timeseries in Figure 5. A cold bias of about 5 K over these few days, but the US EPA simulation does match NCore well after Jan 9. Ramboll simulation also has a consistent cold bias but slightly better for the first part of this period and slightly worse perhaps the second part. It is not clear on why the US EPA run had issues for these few days, but the comparison below at PAFB may provide some clues.

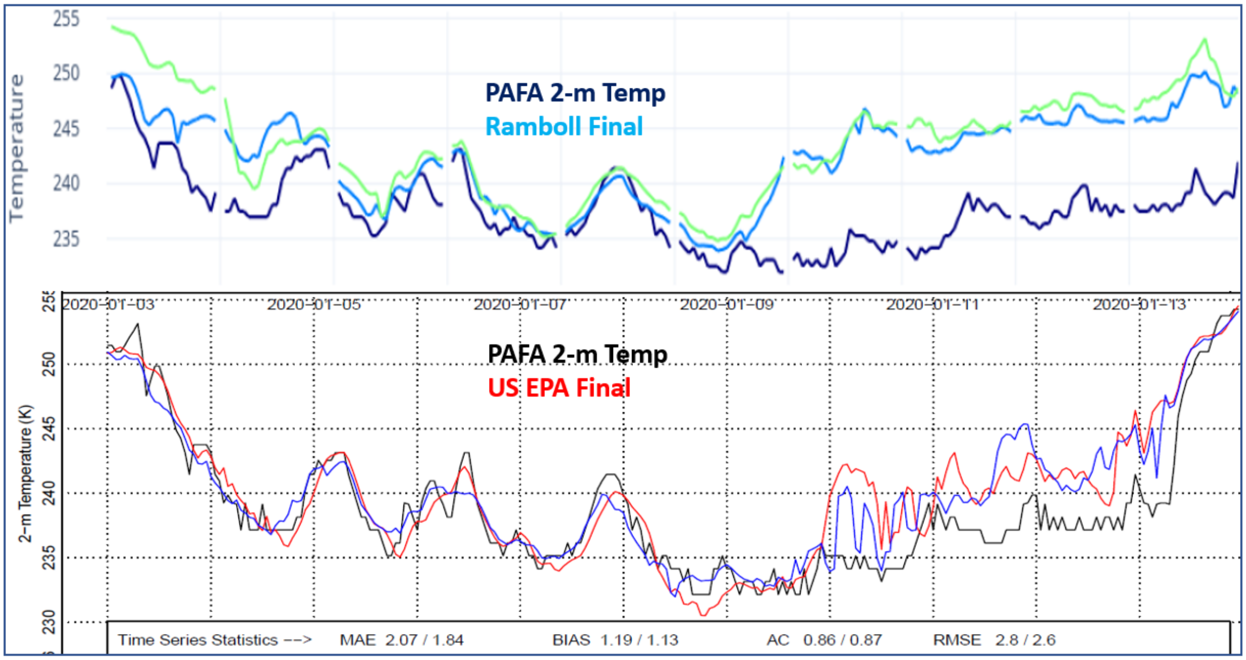


Figure 8: 3-m temperature timeseries at Fairbanks International (PAFA). from the Ramboll report (top) and US EPA WRF (bottom).

In **Figure 8**, the same comparison is provided for PAFA. Here Ramboll and US EPA final perform similarly well Jan 5-8, but the US EPA final run performs much better otherwise. The Ramboll simulation has a large warm bias Jan 3-4 and Jan 9-12. The US EPA run is almost exact on Jan 3-4 and has a warm bias Jan 9-12, but about half the Ramboll warm bias.

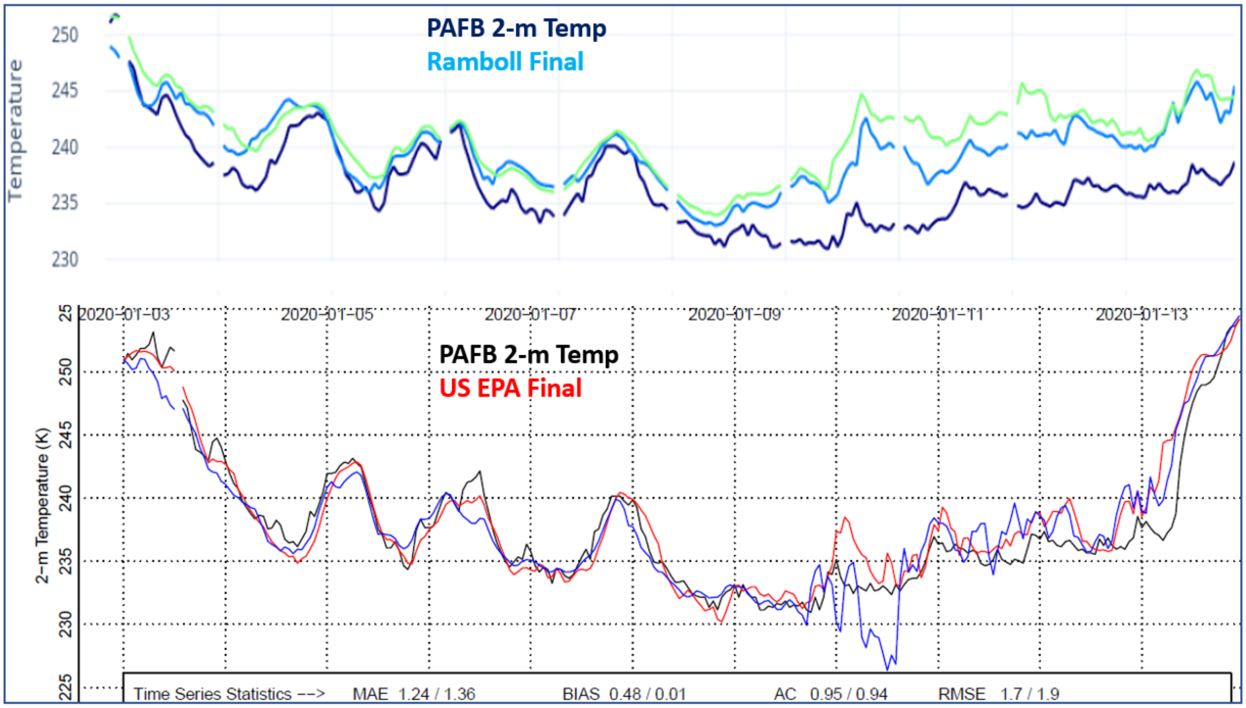


Figure 9: 3-m temperature timeseries at Hurst Rd. from the Ramboll report (top) and US EPA WRF (bottom).

The final comparison for this case study is at PAFB (Ladd Army Airfield) in **Figure 9**. The 2-m temperature at PAFB is simulated similarly as PAFA in the Ramboll model run. A clear warm bias early and late in the period, with better performance Jan 5-8. Again, like PAFA, the US EPA final simulation at PAFB is quite accurate where on average the model is within 1.25 K of the observed temperature. The bias is small at about +0.50, but most of that is a slight warm bias after Jan 10 with most of that a spike in warm bias early on Jan 10.

Figure 10: Temperature timeseries at PAFA (left - black) and PAFB (right - black) for the full modeling period along with the US EPA final simulation (red).

Figure 10 provides the full timeseries over the modeling period for the two NOAA sites in Fairbanks. These two sites also represent how WRF performs on both the east (PAFB) and west (PAFA) side of Fairbanks. If the focus is on cold period modeling, the US EPA final WRF simulation simulates 2-m temperature with high precision for the three cold periods Dec. 2019. The Dec 14-22, 2019 period was discussed in the Ramboll report in section 6.3.1 where their best simulation had a consistent warm bias in the 2.0-5.0 K range at PAFA. The warm bias is slightly less at PAFB (+1-2 K bias). The US EPA final run may have a slight warm bias for this period (1.5 K at PAFA and 0.5 K at PAFB), but matches the reported temperature better, especially the cold period starting on Dec 20 where the lowest temperatures are captured by WRF. A possible reason for the better performance in the US EPA simulation could be the largely incomplete record of temperature in the observation nudging file for PAFA. These were fixed in the US EPA observation nudging file by relaxing the QA in Obsgrid. As indicated before, stricter QA may have filtered many observations from the Ramboll observation nudging file.

January and the early cold pool period was discussed already. The US EPA final run did not perform as well for the early part of Jan, but does very well capturing the cold temperature at the end of Jan and all of Feb. at PAFB and PAFA, but does have a slight warm bias several days in Feb.

For completeness, a few other meteorological variables are examined and errors documented in **Table 2**. Wind measurements as Ramboll states, have some issues in this region where cold = calm wind. Wind speed and direction errors below have many missing hourly values because of the reporting protocols. The US EPA cannot verify that the data count is the same. The Atmospheric Model Evaluation Tool (AMET) filtered out low wind speed observations < 0.5 m/s and associated wind directions. From timeseries in the Ramboll report (Fig 16-9) it appears many wind observations were missing in their PAFA, PAFB and PAEI statistics. With that said, the observations available show comparable errors with low levels over all. However, it is difficult to conclude if one run is better than the other based on the small sample of data. This obviously holds true for the wind direction as well and also acknowledged in the Ramboll report in section 6.2.2.

Mixing ratio and relative humidity are the two moisture variables we can evaluate using AMET. Ramboll reports errors of water vapor mixing ratio, but not in a table for each sites. In their Figure 6.8 the RMSE of moisture is generally around 0.25 g/kg and as high as 0.50 g/kg. Table 2 has the RH error for the US EPA final run as well as for water vapor mixing ratio. We cannot compare RH, but error levels in the US EPA final run where WRF is on average within 4-5% of the reported relative humidity seems reasonably accurate. The water vapor mixing ratio RMSE of the US EPA final run is extremely low because water vapor is low in cold air. But, these are complete time series and the comparison with Ramboll is direct. The US EPA run has errors around 0.1 g/kg at the PAFA, PAFB and PAEI sites. Ramboll modeling had these same metrics mostly 0.30 to 0.40 g/kg.

Table 2: WRF RMSE of 10-m wind speed and MAE of direction at key observation sites around Fairbanks. Also provided are moisture errors. ADEC values are based on the 2021 Ramboll report. USEPA is the best US EPA WRF simulation with corrections to observation nudging files and updated configuration.

10-m WS RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
	Dec	**Dec**	**Jan**	**Jan**	**Feb**	**Feb**
PAFA*	1.7	1.3	1.8	1.4	1.7	1.2

PAFB*	1.4	1.6	1.6	1.8	1.5	1.9
PAEI*	1.3	1.4	1.2	1.0	1.3	0.7
10-m WD MAE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
PAFA*	X	40	X	52	X	35
PAFB*	X	38	X	57	X	50
PAEI*	X	44	X	50	X	51
2-m RH/Q MAE/RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
PAFA	NA / ~0.4	5 / 0.07	NA / ~0.3	4 / 0.07	NA / ~0.4	5 / 0.23
PAFB	NA / ~0.3	5 / 0.15	NA / ~0.2	4 / 0.06	NA / ~0.3	4 / 0.13
PAEI	NA / ~0.4	5 /0.16	NA / ~0.2	4 /0.06	NA / ~0.4	5 / 0.23

Conclusions

The US EPA identified a few issues with the observation nudging file that were tested and resolved. Additionally, an observation nudging strategy developed from the evaluation of ALPACA period modeling was tested. The evaluation and comparison with prior modeling by Ramboll show some key areas where temperature modeling near the surface was improved. The most impressive WRF results were at the Hurst Rd site where temperature modeling at 3, 11 and 23 m was constant and accurate. There are also significant improvements in the temperature modeling at both PAFA and PAFB sites. Perhaps the more dissident result was the model performance at NCore and Astreet. The Ramboll error numbers were very small (~1.2-1.5 K) considering the time series examples presented in sections 6.3.1, 6.3.2 and 6.3.3. However, US EPA final runs performed well, but lowest monthly error levels were 1.39 K at NCore (3-m) in Feb and 1.32 K at Hurst Rd. (23 m) in Feb. Most monthly errors were in the 1.6-2.2 K range. When using this data and trying to interpret results though, it will be useful to look at the timeseries. In most cases the US EPA final simulation captures the cold period very well.

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Eric Engman/Fairbanks Daily News-Miner via AP

UAF, Geophysical Institute

Disclaimer: The views expressed in this presentation are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA.

Outline

- Meteorology model (WRF) configuration(s)
- Initial WRF simulation post-ALPACA
- WRF evaluation using independent ALPACA observations
- Using ALPACA observations in the data assimilation
- Using ALPACA modeling for 2019-2020 winter case

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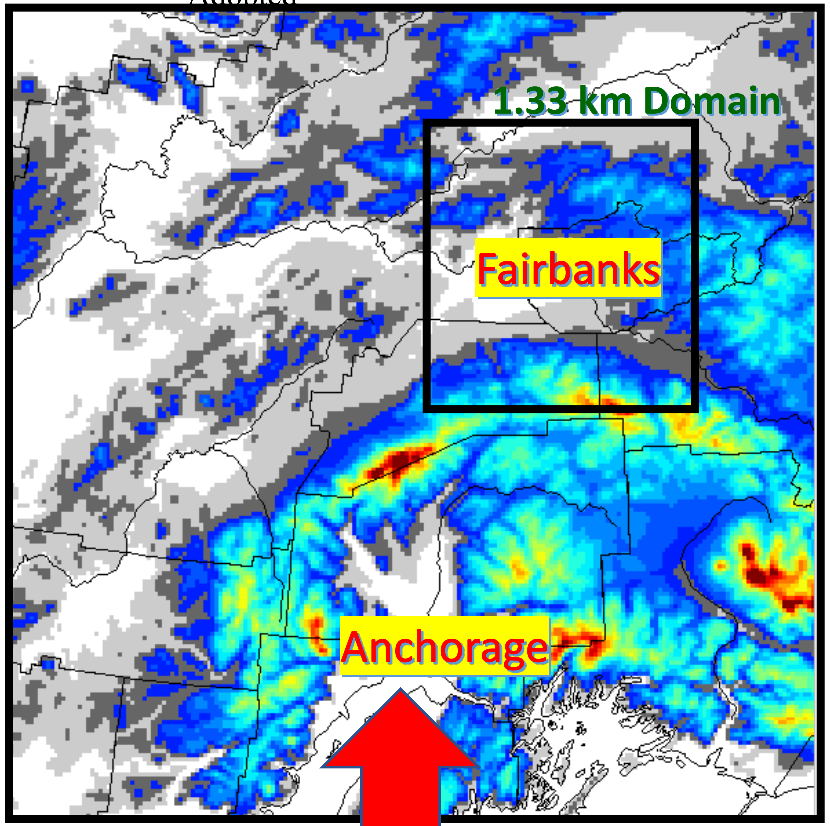
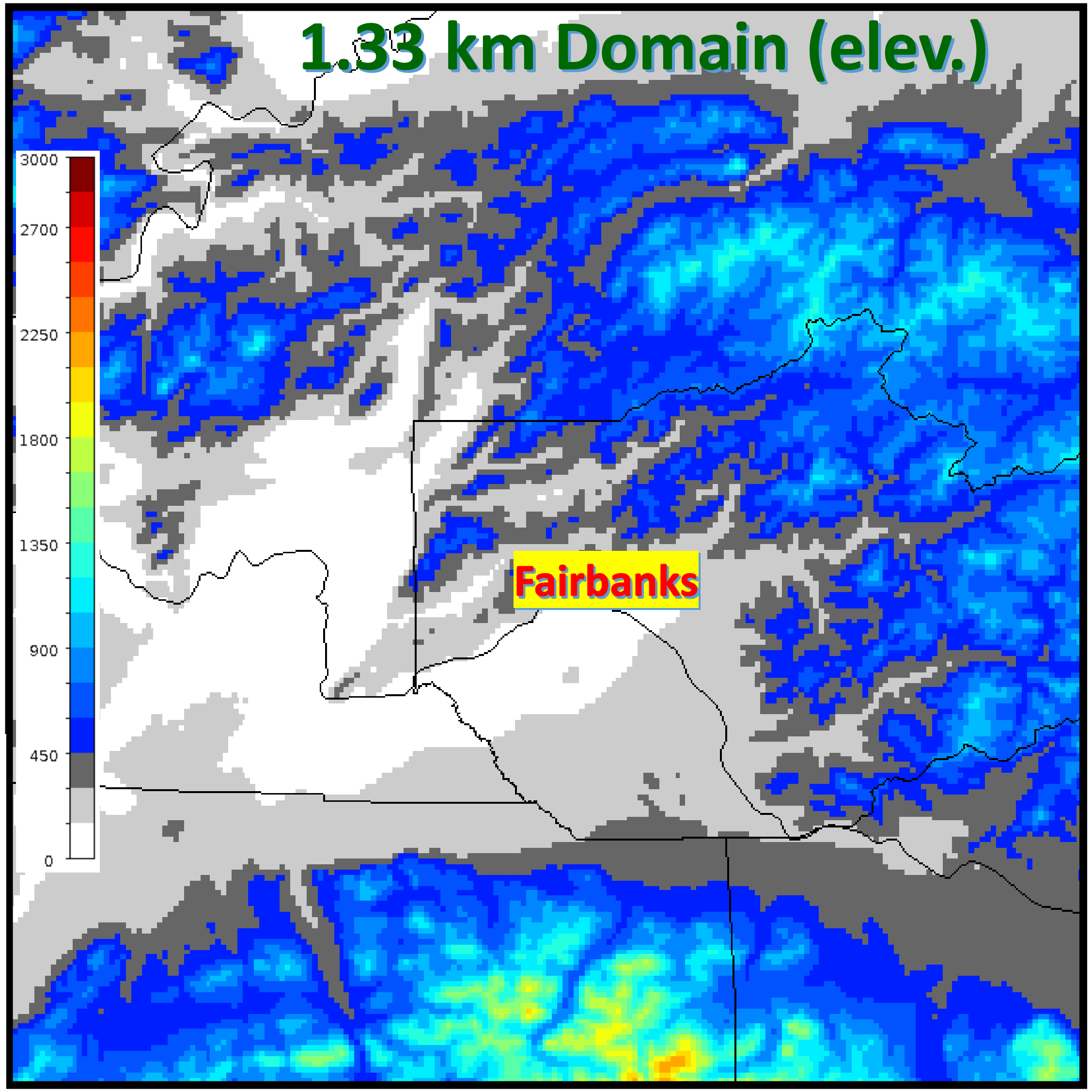
ADEC E. Dieudonne & H. Delbarre @ LPCA/ULCO for **Doppler LIDAR measurements**

WRF Configuration

4 km Domain (elev.)





WRF/CMAQ model omain

- 4 km outer domai h nested 1.33 km centered over Fairb
- WRF Jan 1-Feb 28 for ALPACA (Jan 17-Feb 28)
- 38 total vertical levels with extra fine spacing below 500 m
- 11 lowest layers @ approx. 2, 5, 9, 17, 32, 52, 82, 132, 207, 311, 433, 555 meters

WRF Physics (WRFv4.3)

- RUC LSM
- MYNN TKE PBL
- Morrison Mp
- RRTMG SW/LW
- No subgrid Cp scheme

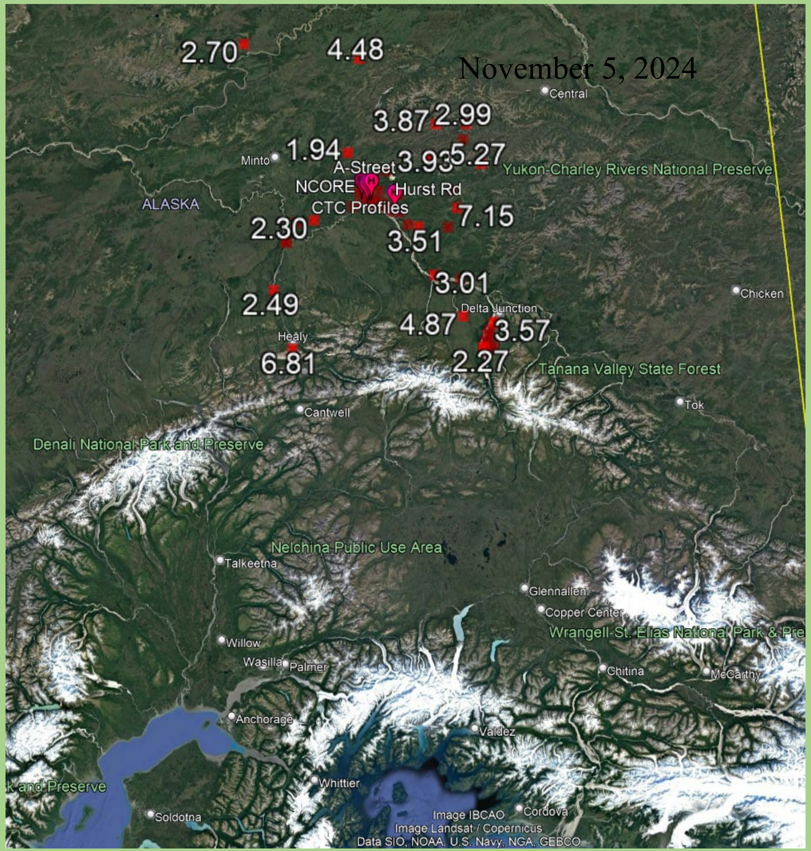
BC & Data Assimilation (DA)

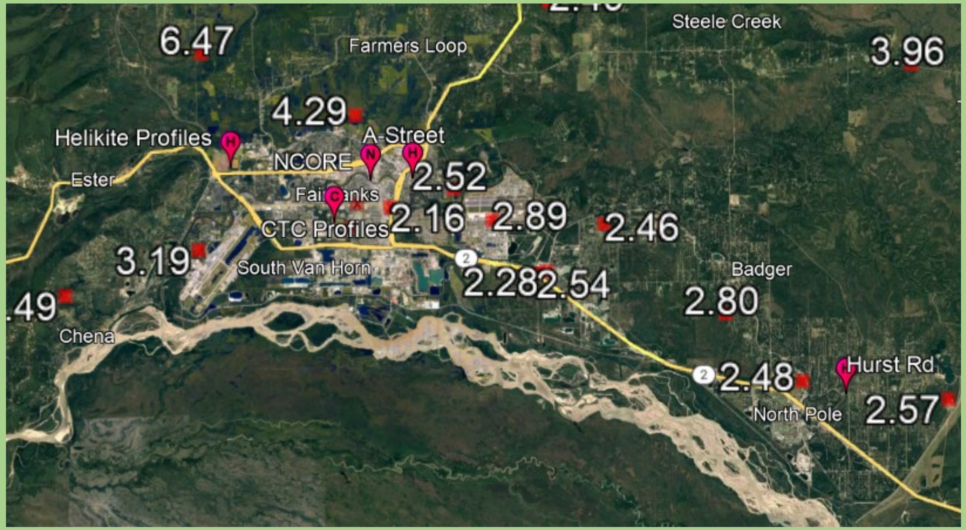
- NCEP GFS boundaries
- GFS FDDA (4 km)
- Obs nudging (1.33 km): METAR and Mesonet
- Obs nudging (1.33 km): RAOB (PAFA)

Simulations

- Daily DA simulations with 72 hr forecast during ALPACA
- Continuous Obs Nudging run post-ALPACA
- 1.33 km Sensitivities
    - No DA
    - FDDA Only
    - FDDA + ON
- **DA with ALPACA field campaign obs**

Post-ALPACA continuous 1.33 km WRF simulation using a base model configuration

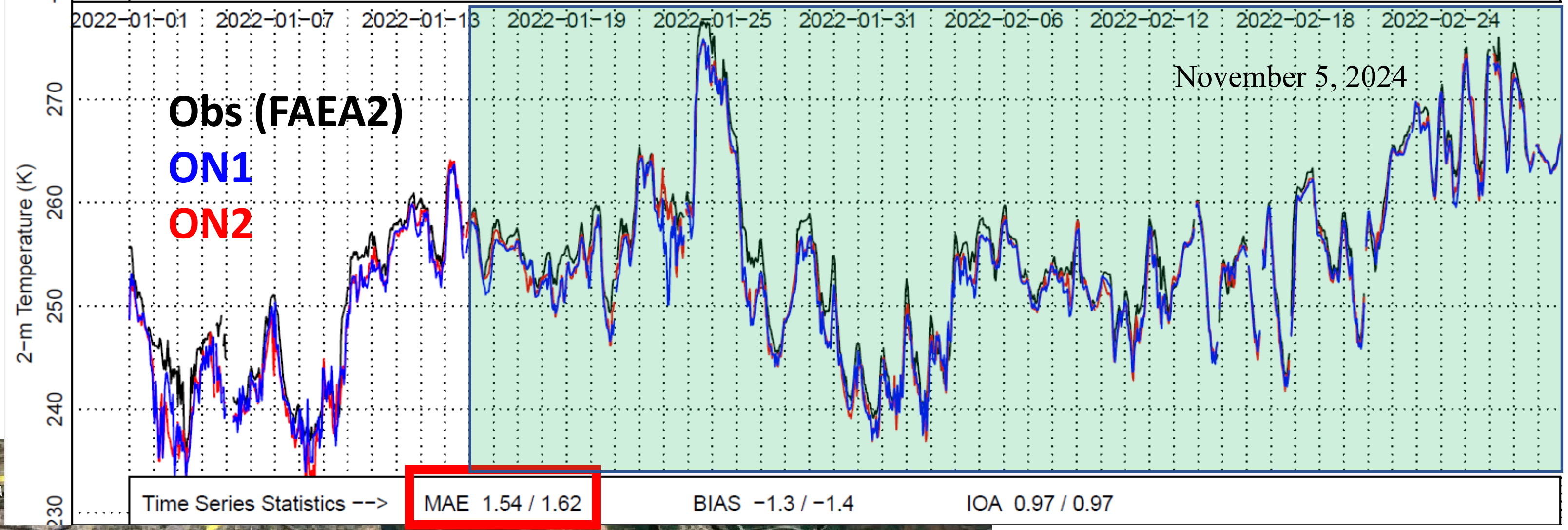


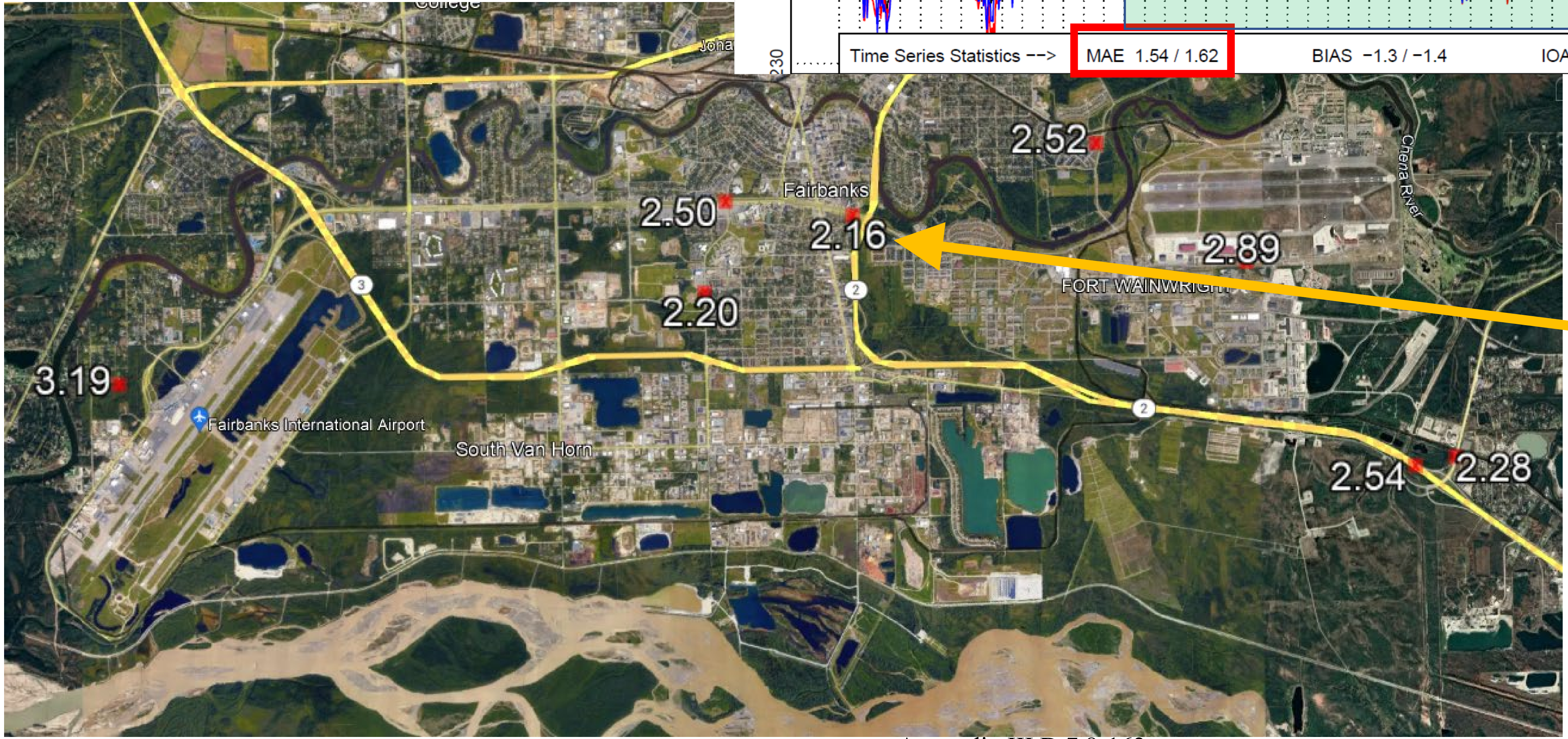


WRF configuration was based on a Feb 2008 case study & more recent Ramboll testing

Gaudet, B., Stauffer, D., Seaman, N., Deng, A., Schere, K., Gilliam, R., Pleim, J. and Elleman, R., 18.1 MODELING EXTREMELY COLD STABLE BOUNDARY LAYERS OVER INTERIOR ALASKA USING A WRF FDDA SYSTEM. AMS 13th Conf. Mesoscale Processes, Salt Lake City, UT, Aug 17-20, 2009.

2-m Temperature RMSE
(Jan 1-Feb 28, 2022)

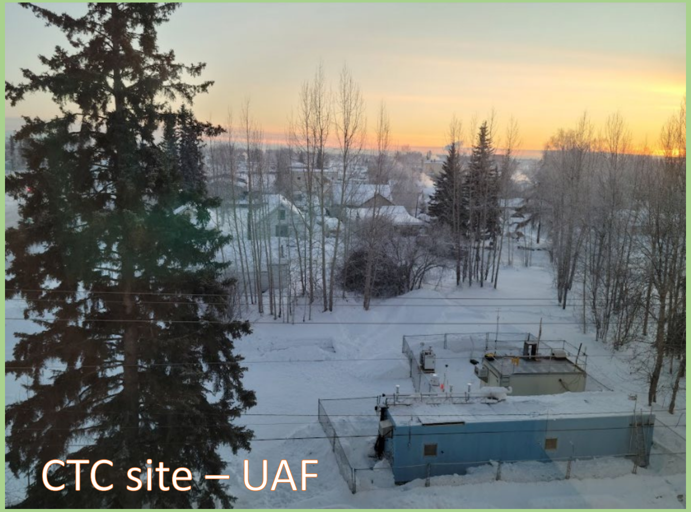




Best WRF performance @FAEA2

RMSE = 2.16 K
MAE = 1.54 K
BIAS = -1.3 K
IOA = 0.97

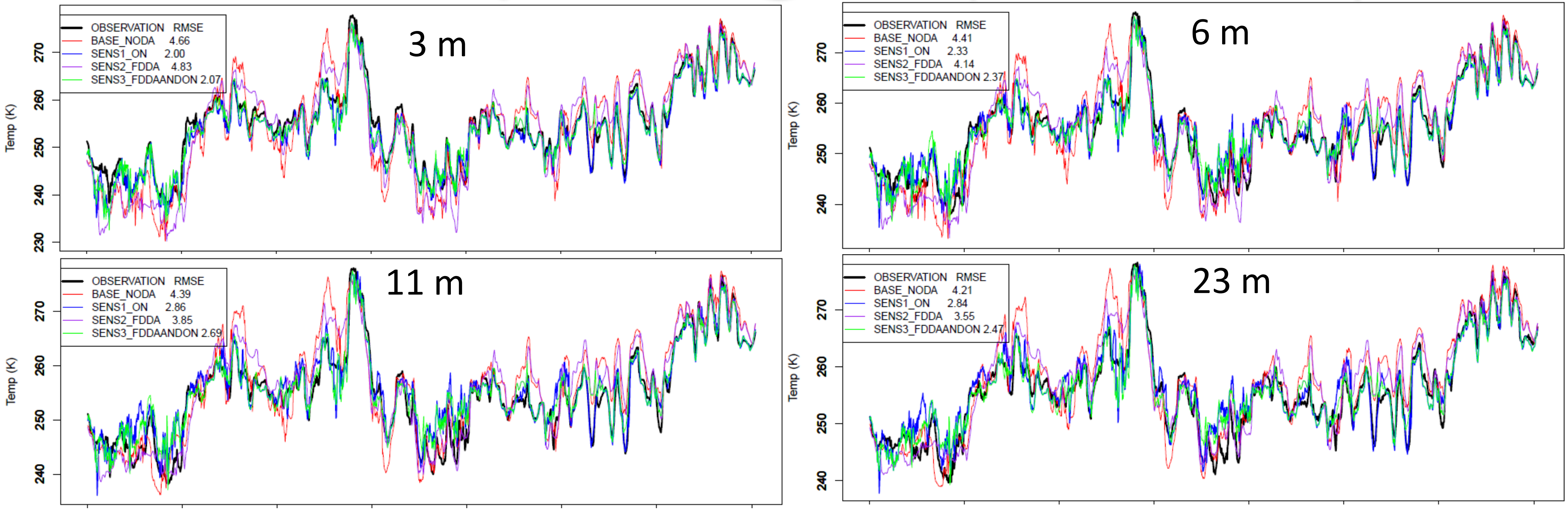
Evaluation of WRF using <u>independent</u> ALPACA field data



WRF Sensitivity Experiments

- No data assimilation on the nested 1.33 km grid. FDDA was used on the 4 km parent grid **(BASE_NODA)**
- Observation nudging on the 1.33 km grid using standard NOAA observations and local mesonet measurements + PAFA sounding twice daily **(SENS1_ON)**
- Grid nudging on the 1.33 km grid similar as the parent 4 km grid. Grid nudging or four-dimensional data assimilation is done using global GFS analyses every 3 hours and applied only above the planetary boundary layer on both domains **(SENS2_FDDA)**
- FDDA like above with observation nudging **(SENS3 FDDAANDON)**

WRF Temperature @ CTC (Jan-Feb 2022)



GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

Temperature RMSE (K)	CTC	CTC	CTC	CTC	A-ST	A-ST	NCORE	NCORE	HURST	HURST	HURST	AVG
Simulation	3m	6m	11m	23m	3m	10m	3m	10m	3m	10m	23m	
BASE_NODA	4.66	4.41	4.39	4.21	4.64	4.74	4.81	4.80	5.34	4.80	4.60	**4.67**
SENS1_ON	2.00	2.33	2.86	2.84	1.99	3.73	1.71	3.13	2.73	3.11	2.83	**2.66**
SENS2_FDDA	4.83	4.14	3.85	3.55	4.51	4.09	4.57	4.08	6.42	5.05	4.47	**4.51**
SENS3_FDDAANDON	2.07	2.37	2.69	2.47	2.08	3.34	1.83	2.86	2.98	3.09	2.78	**2.60**

WRF Wind Profiles vs. Independent LIDAR CTC Site (Jan 17- Feb 08, 2022)

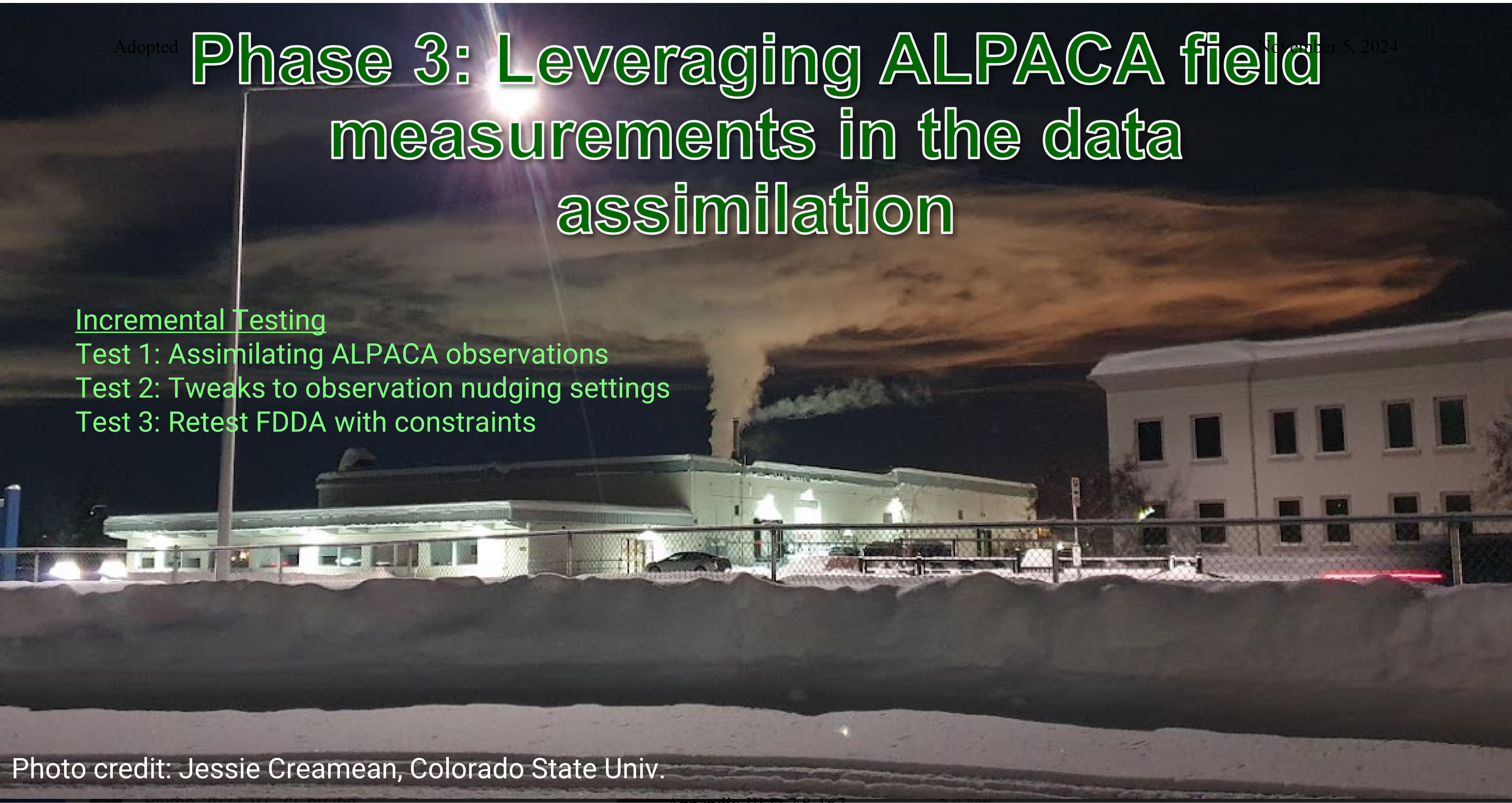
GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

- FDDA only generally results in the lowest wind speed error
- ON and FDDAANDON configs increase error… in some cases substantially
- NODA has lower error than the ON and FDDAANDON sensitivities below ~200 m

CTC SITE Jan 17-Feb 08, 2022

RMSE Wind Speed (m/s)	BASE_NODA	SENS1_ON	SENS2_FDDA	SENS3_FDDAANDON
40 m	1.26	1.60	1.43	1.77
60 m	1.42	1.66	1.41	1.99
80 m	1.50	1.84	1.45	2.26
100 m	1.61	2.06	1.54	2.43
120 m	1.85	2.14	1.68	2.43
140 m	2.06	2.26	1.77	2.34
160 m	2.04	2.16	1.87	2.03
180 m*	2.04	2.03	1.69	1.94
200 m*	2.44	1.77	2.02	2.21
230 m*	2.82	1.74	2.05	2.30
260 m*	3.04	2.02	1.94	2.30
290 m*	3.88	3.44	2.88	3.11

Phase 3: Leveraging ALPACA field measurements in the data assimilation



<u>Incremental Testing</u>

Test 1: Assimilating ALPACA observations

Test 2: Tweaks to observation nudging settings

Test 3: Retest FDDA with constraints

Photo credit: Jessie Creamean, Colorado State Univ.

Test 1: Assimilating ALPACA Observations

Standard Obs Nudging (STDOBS)
Standard + ALPACA Obs (ALLOBS)
Valid: Jan 1 to Feb 28, 2022

The comparison below of temperature and wind error at each observation site in Fairbanks tests the impact of adding ALPACA field measurements (CTC, ADEC and Wind LIDAR) to the observation nudging input file.

Temperature RMSE (K)

RMSE/MAE Temp	CTC	CTC	CTC	CTC	A-ST		AFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	F1202	BRHA2	F3318
SENS	3m	6m	11m	23m	3m		2m	2m	2m	2m	2m	2m	2m	2m	2m
STDOBS (BASE -- 256 procs)	2.00	2.33	2.86	2.84	1.99		.40	1.99	1.89	1.62	1.62	1.81	1.87	1.57	1.76
[redacted]															
ALLOBS (256 procs)	1.76	1.98	2.38	2.38	1.70		.26	1.83	1.77	1.51	1.49	1.73	1.76	1.42	1.82
[redacted]															

GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

Wind Speed Error (MAE – m/s)

MAE WS	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
STDOBS (BASE -- 256 procs)	1.12	1.78	1.55	2.09	2.21	3.27	1.98
[redacted]							
ALLOBS (256 procs)	1.11	1.74	1.54	2.10	2.16	3.12	1.74
[redacted]							

Wind Direction Error (MAE -- deg)

MAE WD	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
STDOBS (BASE -- 256 procs)	37	43	59	45	118	34	65
[redacted]							
ALLOBS (256 procs)	35	43	58	46	123	39	64
[redacted]							

Wind sample sizes are highly variable because of frequent calm reports

Test 2: Alternative Obs Nudging Settings

Standard + ALPACA Obs (ALLOBS)
Obs nudging settings (ALLOBS TWEAKS)
Valid: Jan 1 to Feb 28, 2022

The comparison below tests the impact of “tweaks” to the observation nudging impact model error. Tweaks include (1) Alternative vertical spreading of nudging term, (2) limit vertical extent of nudging at 50 m AGL instead of default 200 m and (3) larger time window and (4) cast 3m temperature obs as surface-base 2m obs

Temperature RMSE (K)

GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

RMSE/MAE Temp	CTC	CTC	CTC	CTC	A-ST							AFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	F1202	BRHA2	F3318
SENS	3m	6m	11m	23m	3m							2m	2m	2m	2m	2m	2m	2m	2m	2m
[redacted]																				
ALLOBS (256 procs)	1.76	1.98	2.38	2.38	1.70							.26	1.83	1.77	1.51	1.49	1.73	1.76	1.42	1.82
[redacted]																				
ALLOBS TWEAKS (256 procs)	1.64	1.66	1.79	1.86	1.48	2.37	1.43	2.07	2.35	1.77	1.53	2.12	1.73	1.62	1.38	1.36	1.59	2.01	1.45	1.59
[redacted]																				

Wind Speed Error (MAE – m/s)

MAE WS	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
[redacted]							
ALLOBS (256 procs)	1.11	1.74	1.54	2.10	2.16	3.12	1.74
[redacted]							
ALLOBS TWEAKS (256 procs)	1.17	1.72	1.59	2.28	2.25	3.44	1.55
[redacted]							

Wind Direction Error (MAE -- deg)

MAE WD	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
[redacted]							
ALLOBS (256 procs)	35	43	58	46	123	39	64
[redacted]							
ALLOBS TWEAKS (256 procs)	38	50	60	46	119	42	67
[redacted]							

Test 3: FDDA/Grid Nudging with Contraints

Obs nudging settings (TWEAKS)
Tweaks + FDDA (TWEAKS FDDA9)
Valid: Jan 1 to Feb 28, 2022

This tests FDDA/Grid nudging in addition to Obs Nudging on model levels above level 9 (~ 300 m) or above the PBL if higher than level 9.

Temperature RMSE (K)

GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

RMSE/MAE Temp	CTC	CTC	CTC	CTC	A-ST							AFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	F1202	BRHA2	F3318
SENS	3m	6m	11m	23m	3m							2m	2m	2m	2m	2m	2m	2m	2m	2m
[redacted]																				
ALLOBS TWEAKS (256 procs)	1.64	1.66	1.79	1.86	1.48	2.37	1.43	2.07	2.35	1.77	1.53	2.12	1.73	1.62	1.38	1.36	1.59	2.01	1.45	1.59
ALLOBS TWEAKS FDDA9	1.68	1.52	1.46	1.54	1.50	2.07	1.40	1.72	2.32	1.76	1.42	2.03	1.73	1.62	1.41	1.35	1.58	2.11	1.46	1.63

Wind Speed Error (MAE – m/s)

MAE WS	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
[redacted]							
ALLOBS TWEAKS (256 procs)	1.17	1.72	1.59	2.28	2.25	3.44	1.55
ALLOBS TWEAKS FDDA9	1.12	1.79	1.58	2.34	2.36	3.79	1.67

Wind Direction Error (MAE -- deg)

MAE WD	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
[redacted]							
ALLOBS TWEAKS (256 procs)	38	50	60	46	119	42	67
ALLOBS TWEAKS FDDA9	36	35	58	53	127	26	63

Evaluation using CTC & FARM LIDAR Wind

*Wind sample size (hourly) is significantly smaller above 160 m

CTC SITE Jan 17-Feb 08, 2022

RMSE Wind Speed (m/s)	STDOBS ON	ALLOBS	ALLTWEAKS	ALLTWEAKS FDDA9
40 m	1.60	1.23	1.06	1.26
60 m	1.66	1.02	0.97	1.20
80 m	1.84	0.97	0.95	1.16
100 m	2.06	1.17	1.07	1.23
120 m	2.15	1.34	1.23	1.24
140 m	2.28	1.30	1.38	1.22
160 m	2.17	1.32	1.25	1.33
* 180 m	2.04	1.30	1.13	1.10
* 200 m	1.78	0.95	1.19	1.11
* 230 m	1.75	1.09	1.33	1.19
* 260 m	2.04	1.48	1.71	1.31
* 290 m	3.44	2.90	3.07	2.61

FARM SITE Feb 10-28, 2022

RMSE Wind Speed (m/s)	STDOBS ON	ALLOBS	ALLTWEAKS	ALLTWEAKS FDDA9
40 m	2.08	1.85	1.48	1.55
60 m	1.64	1.39	1.22	1.28
80 m	1.55	1.16	1.14	1.16
100 m	1.77	1.22	1.24	1.20
120 m	1.85	1.25	1.29	1.18
140 m	1.68	1.07	1.05	1.01
160 m	1.63	0.99	1.02	0.99
* 180 m	1.60	0.93	0.98	1.00
* 200 m	1.64	0.89	0.96	1.03
* 230 m	1.64	0.87	1.03	1.15
* 260 m	1.66	1.06	1.18	1.36
* 290 m	2.83	2.14	2.18	2.34

GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

- Assimilation of LIDAR is working – significant decrease in errors from approx. 2 to 1 m/s
- Obs nudging “TWEAKS” help reduce error slightly
- FDDA9 impact is mixed – either does not degrade wind error much or improves slightly

Using knowledge gained from ALPACA for the 2019-2020 modeling period

Key Observation Sites in/around Fairbanks

ADEC
Mesonet
NOAA

Initial Simulation

- Inputs were developed independently using GFS ~25 km analyses (Ramboll used ERA)
- No 12 km parent domain.
- Nov 15-30 spinup for snow cover and surface fields
- Final ALPACA WRF configuration
- ADEC observation nudging files (5.5 day concatenated to full period)

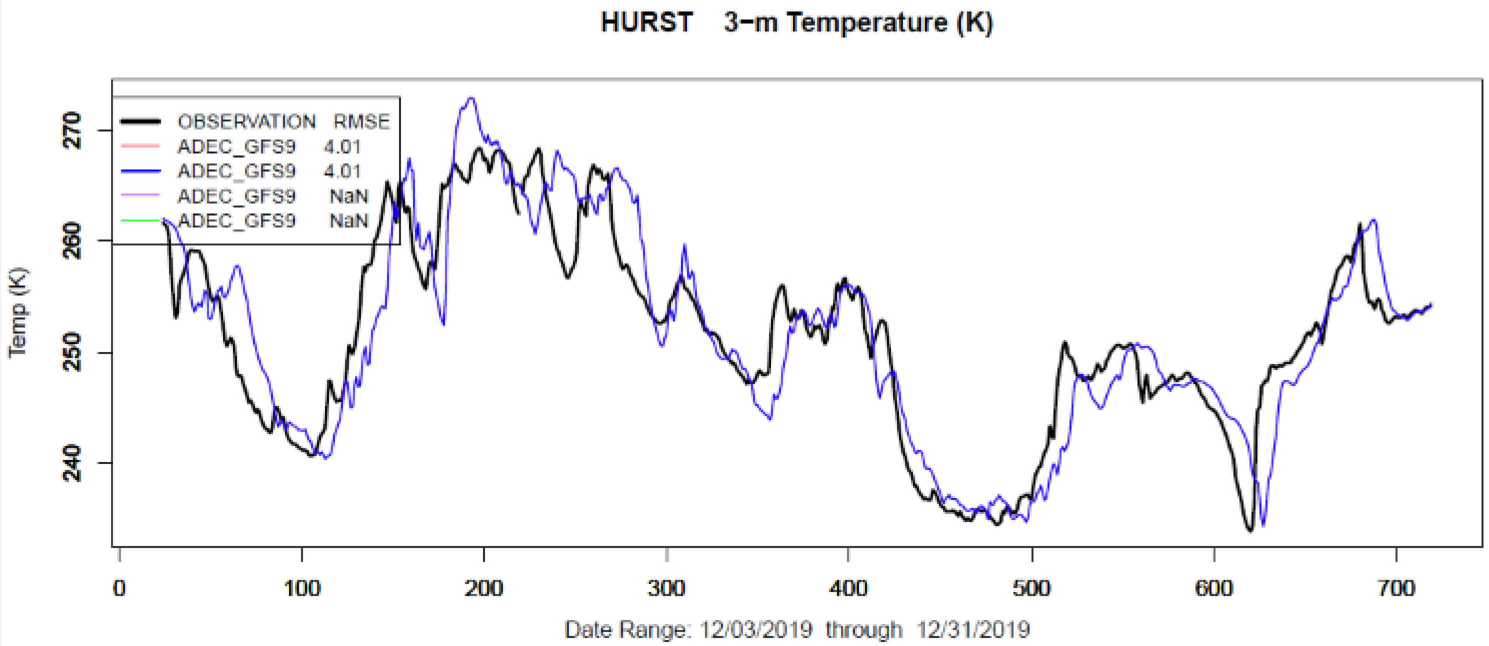
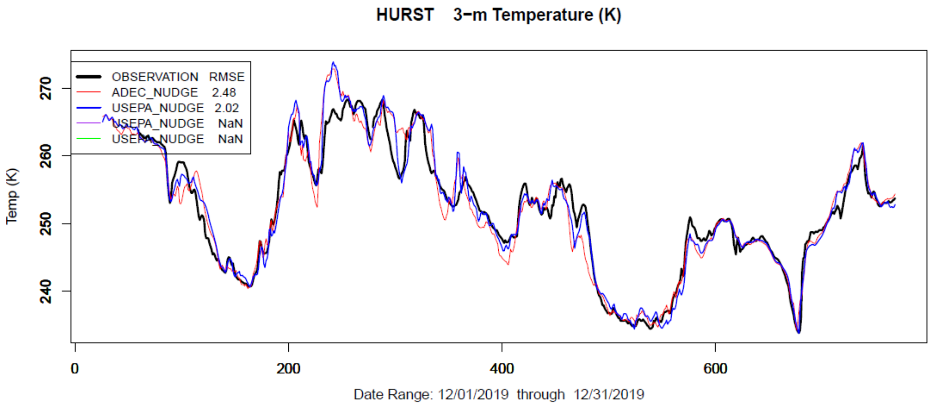
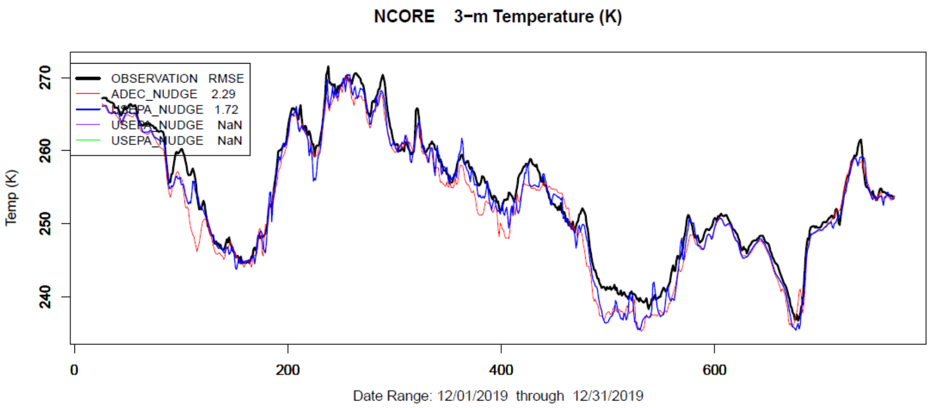


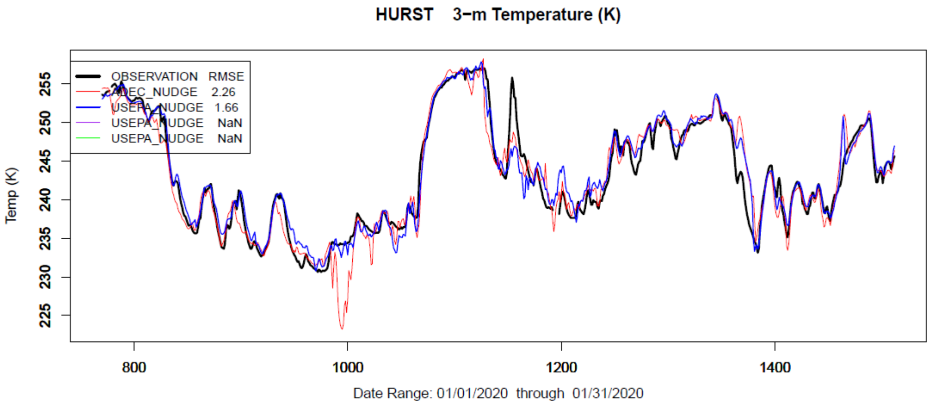
Figure 2: US EPA domain configuration with 4 km outer domain with a 1.33 km nested domain centered over Fairbanks, AK.

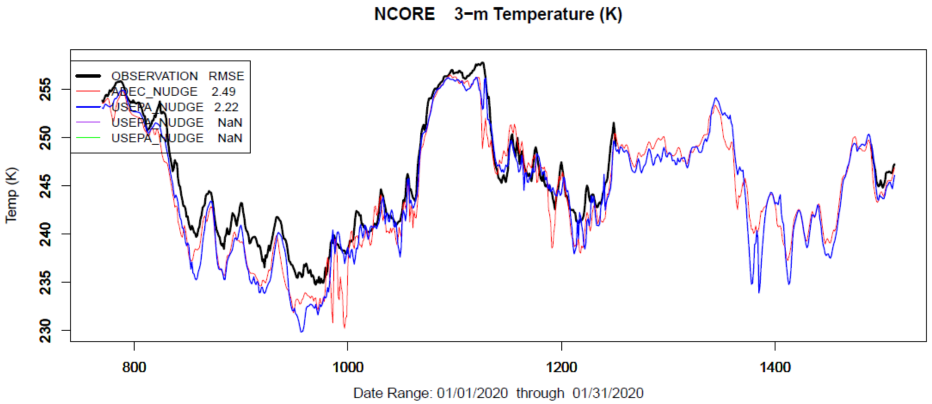
Offline R script that reads WRF and Hurt obs showed an odd phase shift in the temperature time series

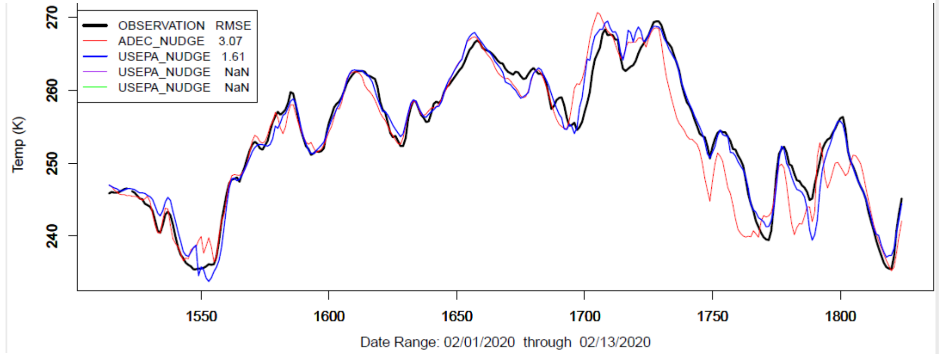
Final Simulations

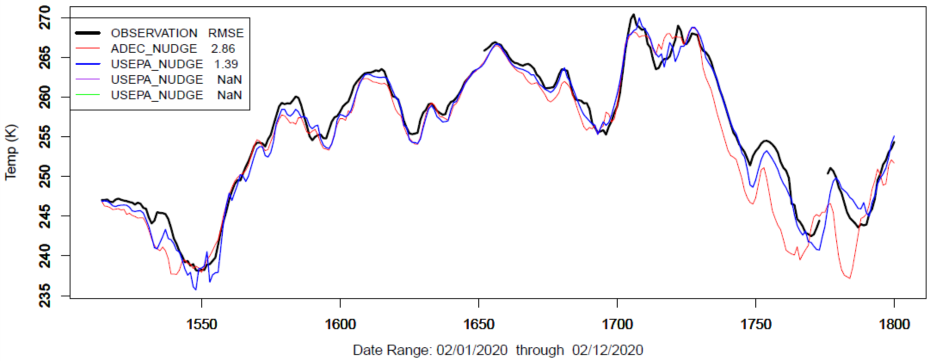












Final Simulation

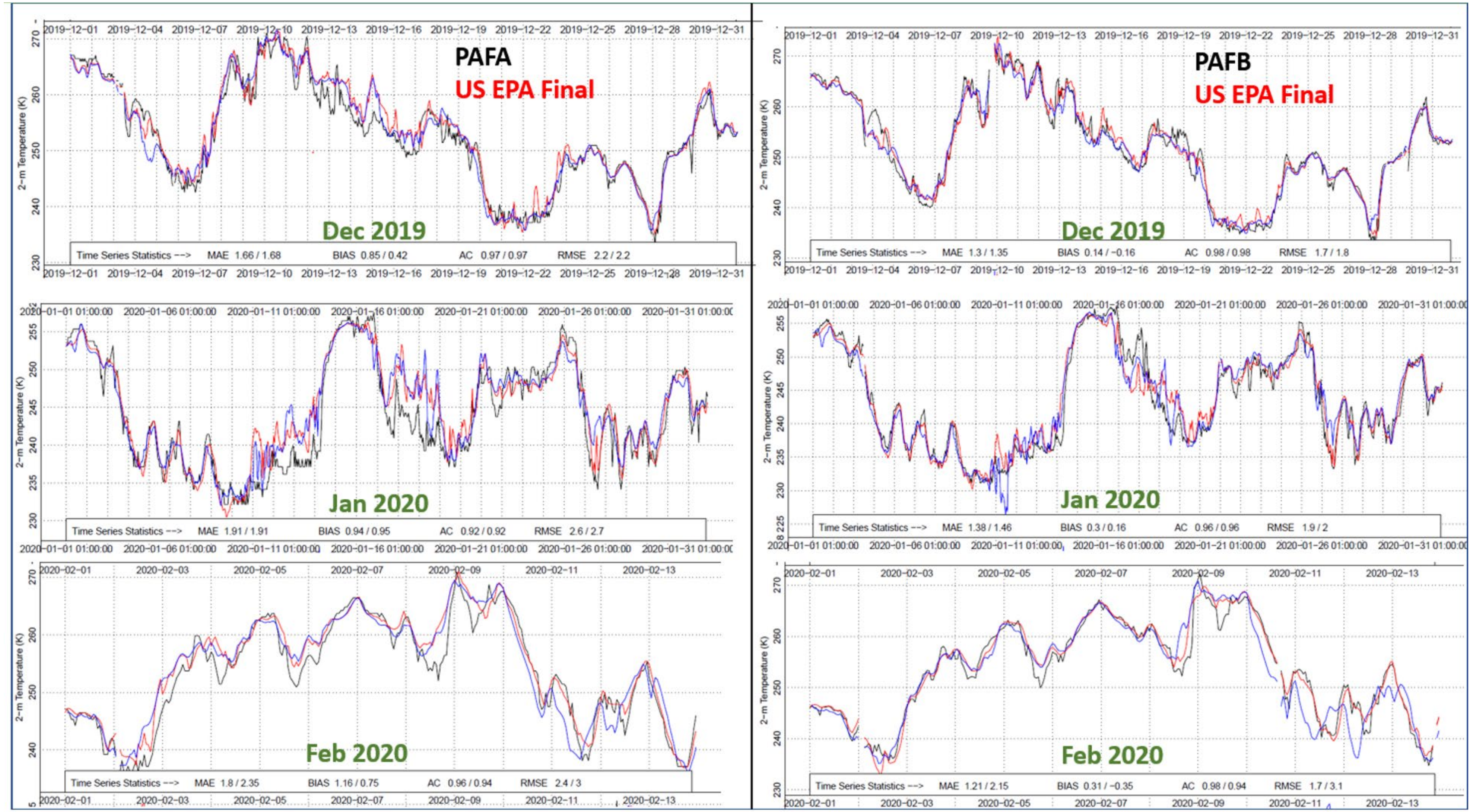


Figure 10: Temperature timeseries at PAFA (left - black) and PAFB (right - black) for the full modeling period along with the US EPA final simulation (red).

Final Simulation

Table 1: WRF RMSE of 2-m temperature at key observation sites around Fairbanks. ADEC values are based on the 2021 Ramboll report. USEPA is the best US EPA simulation with corrections to observation nudging files and updated configuration.

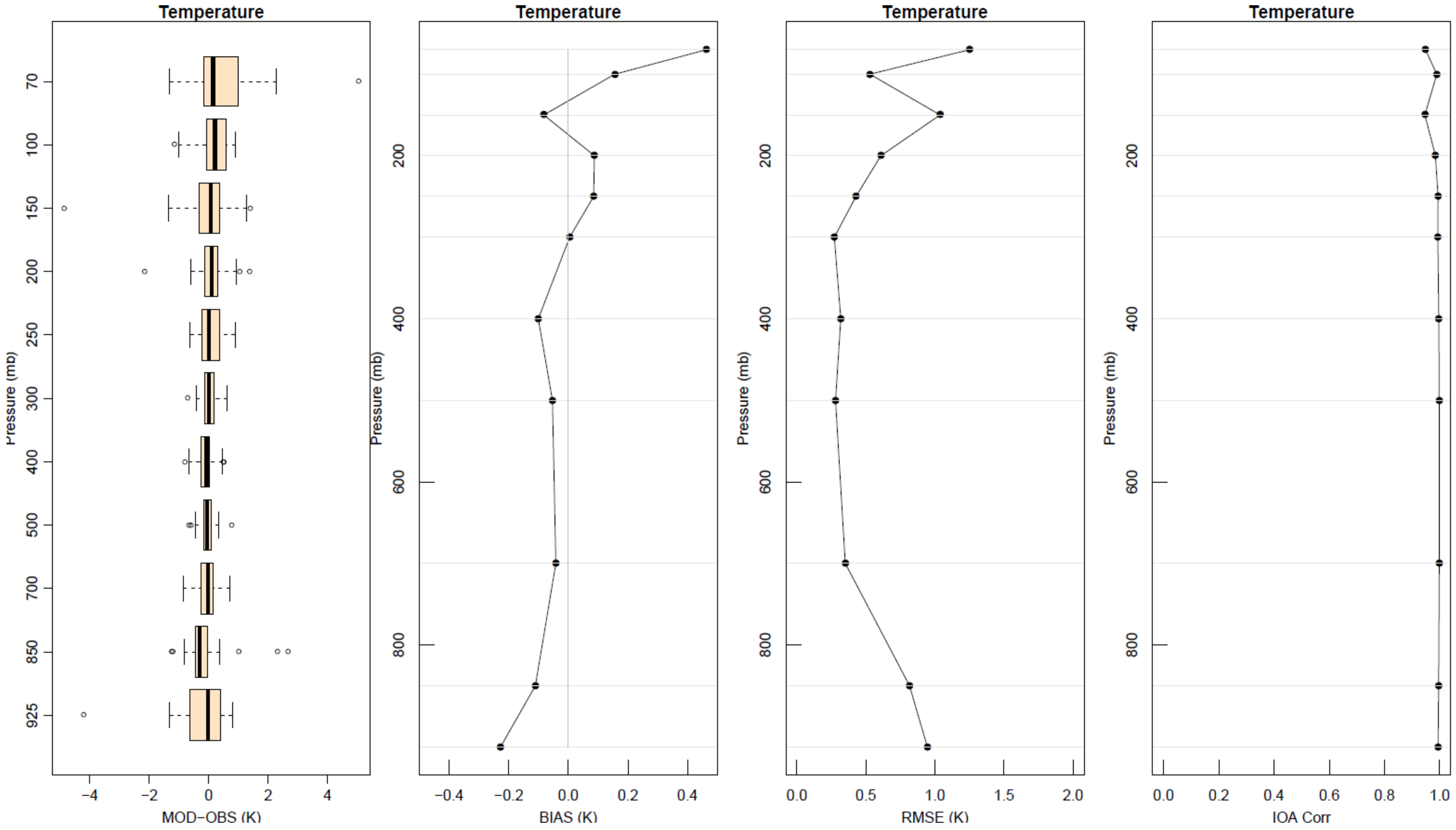
2-m Temp RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
	Dec	Dec	Jan	Jan	Feb	Feb
PAFA	4.38/3.55	2.20	4.70/3.84	2.60	4.41/3.56	2.40
PAFB	2.77/2.41	1.70	3.09/2.56	1.90	2.82/2.73	1.70
PAEI	2.68/2.57	2.40	2.94/2.13	2.20	3.36/3.03	2.70
ASTREET (10m)	1.54	NA/2.54	1.39	2.63	2.15	1.90
NCORE (3/10m)	1.23	1.72/2.09	1.32	2.22/2.69	2.00	1.39
HURST (3/10/23m)	2.34	2.02/1.96/1.96	2.39	1.66/1.52/1.40	2.66	1.65/1.48/1.32
BRHA2	X	1.70	X	1.90	X	2.00
FAEA2	X	2.30	X	2.10	X	1.60
AWCA2*	X	2.80*	X	X	X	X
LTPA2	X	2.10	X	2.10	X	2.30*
F4513	X	1.90	X	2.10	X	1.70
F3318	X	1.90	X	1.90	X	1.60

Final Simulation

Table 2: WRF RMSE of 10-m wind speed and MAE of direction at key observation sites around Fairbanks. Also provided are moisture errors. ADEC values are based on the 2021 Ramboll report. USEPA is the best US EPA WRF simulation with corrections to observation nudging files and updated configuration.

10-m WS RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
	Dec	**Dec**	**Jan**	**Jan**	**Feb**	**Feb**
PAFA*	1.7	1.3	1.8	1.4	1.7	1.2
PAFB*	1.4	1.6	1.6	1.8	1.5	1.9
PAEI*	1.3	1.4	1.2	1.0	1.3	0.7
10-m WD MAE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
PAFA*	X	40	X	52	X	35
PAFB*	X	38	X	57	X	50
PAEI*	X	44	X	50	X	51
2-m RH/Q MAE/RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
PAFA	NA / ~0.4	5 / 0.07	NA / ~0.3	4 / 0.07	NA / ~0.4	5 / 0.23
PAFB	NA / ~0.3	5 / 0.15	NA / ~0.2	4 / 0.06	NA / ~0.3	4 / 0.13
PAEI	NA / ~0.4	5 /0.16	NA / ~0.2	4 /0.06	NA / ~0.4	5 / 0.23

Final Simulation



Temperature profile statistics for the Dec-Feb modeling period at PAFA. Tiles include the distribution of temperature difference (mod-obs), model bias, error (RMSE) and index of agreement.

Notes on Obs Nudging, ETC

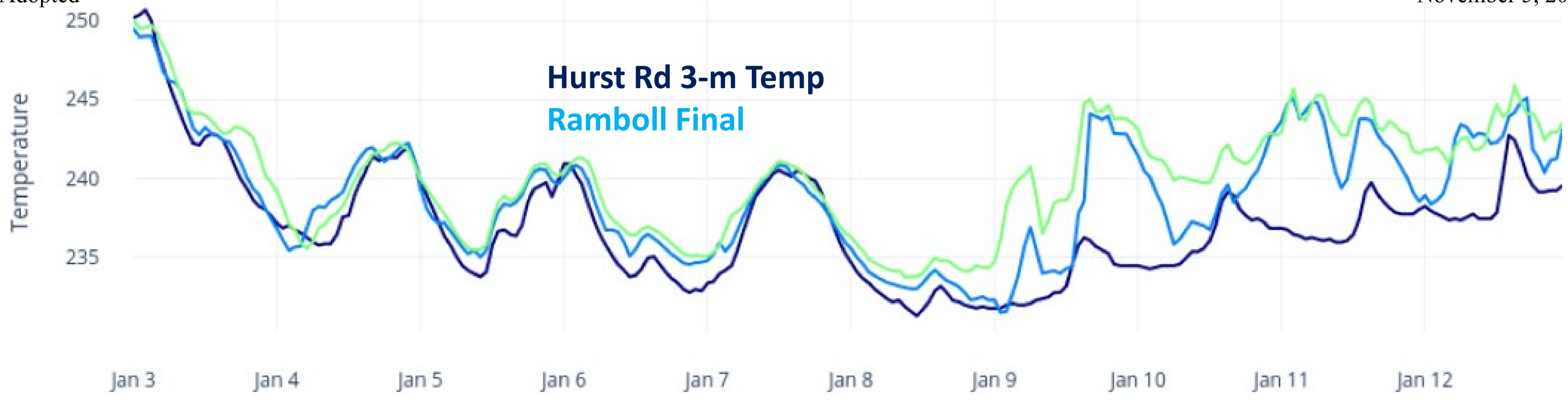
- Observational nudging breaks when WRF is restarted
- Observational nudging files should not have any overlapping times like concatenating 5.5 day Obs nudging files for a long simulation
- Obsgrid only outputs 99 hours of obs nudging files in a single run. So we run daily in a loop over a period.
- Hourly obs are concatenated in a single daily obs nudging file.
- These can be concatenated into a single file for the period of the simulation, but the way Obsgrid runs from 00 UTC to 00 UTC, that last 00 hour for the next day is removed in the daily file.

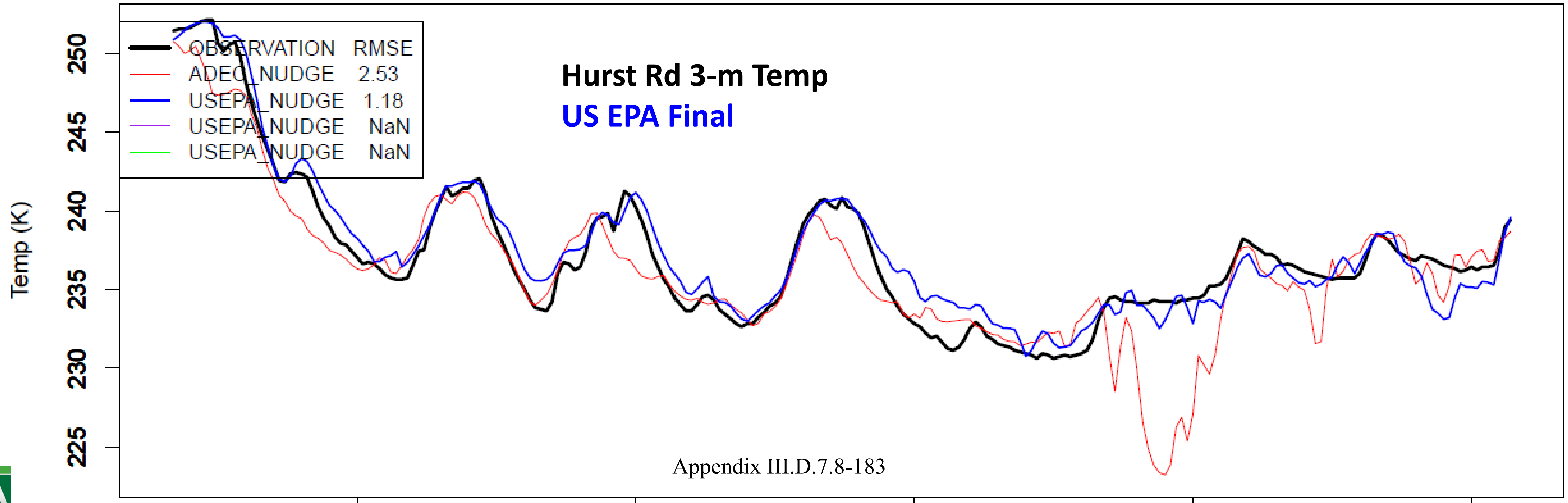
Supplementary Slides

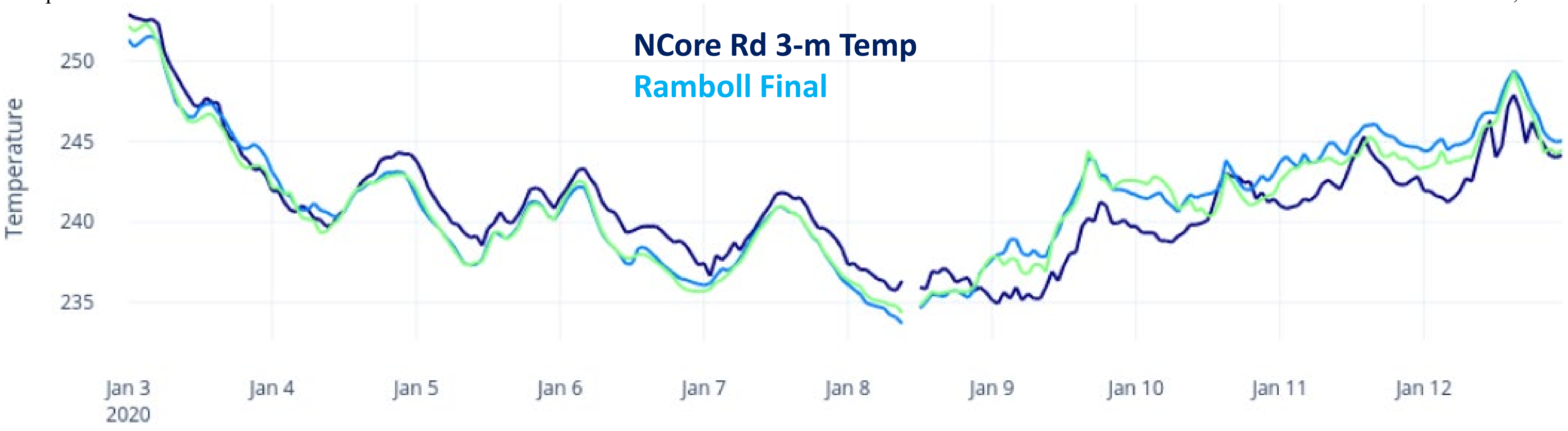
1. The contractors report has timeseries in local time. It appears WRF was adjusted to local time in their figure for Hurst above. ADEC and other observations were not converted to WRF UTC for the evaluation. Per contractor report Fig 6-15, PAFA reaches peak temp at 1200 Local time. So I assume everything in the report (PAFA sounding support this as well) is local time.

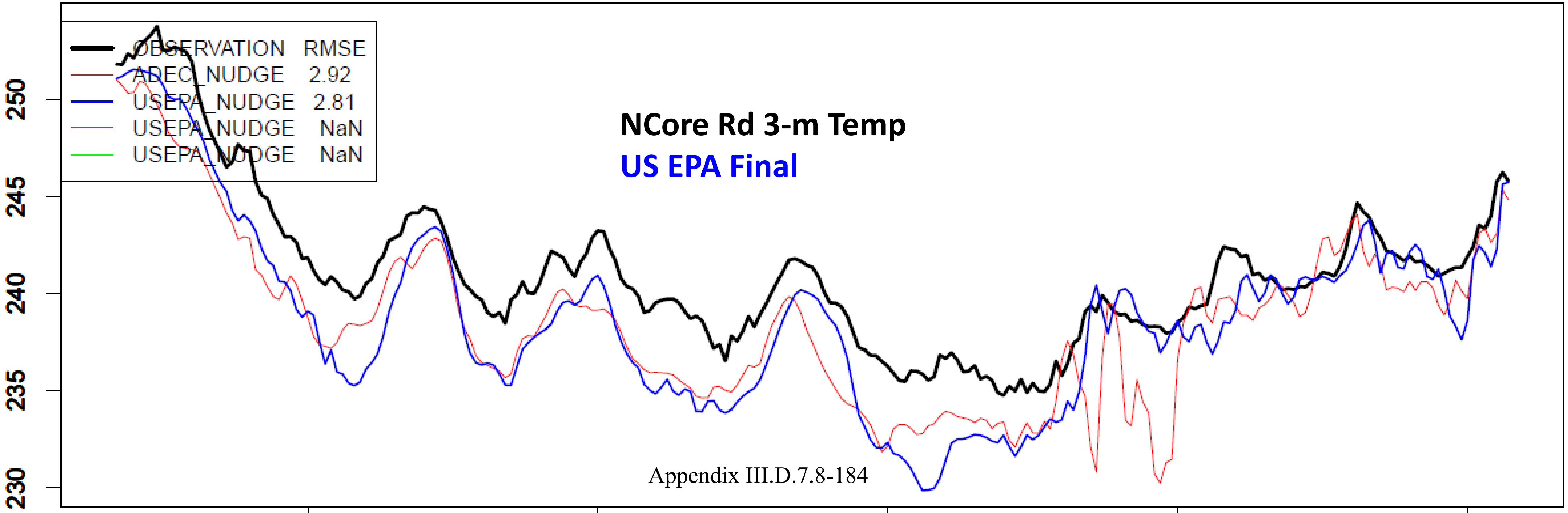
2. We went back and reexamined the observation nudging file provide to the US EPA by ADEC. It is assumed this file was used in The contractors nudging (file directory and name from tarball is 2020-01-04/ALL_OBS_DOMAIN301). We confirm that on Jan 7, the ADEC site Hurst Rd reached peak temperature at about 12 UTC per nudging file date/time. IN the same file the PAFA report reached a peak temperature about 9 hours later… 22-23 UTC. This a clear evidence the ADEC obs had a date/time 9 hours too early in the nudging file.

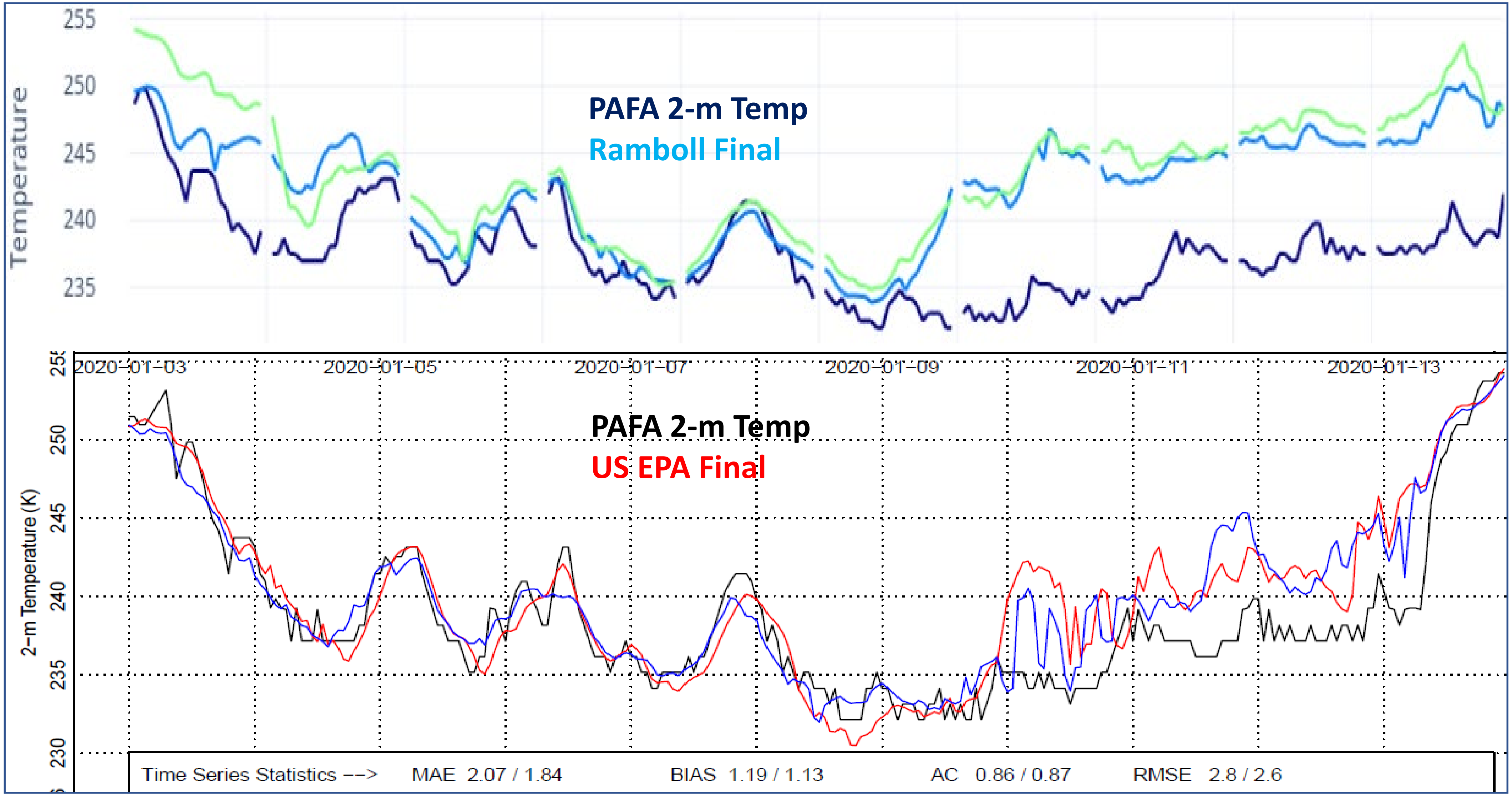
3. The big question in the contractors report is why does WRF agree with ADEC measurements relatively well. And in some cases, the error level lower than we see in almost all of our modeling if there were some flaws in the nudging file. The evidence above suggests that they adjusted WRF to local time. They adjusted NOAA obs like PAFA, PAFB and PAEI to local time for the evaluation. I'm not sure how METSTAT works, but ADEC obs were in local time. So it is theorized that the decent comparison of ADEC with WRF is because WRF was adjusted back to local time which would align WRF with ADEC obs in the nudging file. At PAFA for example, the Obs time and WRF were both moved back 9 hours to local time, so peak on Jan 7 and time series is correct in those figures (Fig 6-15). The problem is in WRF, the nudging of the 3 ADEC sites (Astreet, Ncore and Hurst) is still 9 hours early. One can imagine how it "shakes up" WRF. Midday in WRF for days with solar radiation for example would be warming, but grid cells impact by ADEC obs nudging would be pushed towards cooler temperatures of ADEC obs that have a bad time 9 hour in the future which would be at night in this example. Or, a rapid cool down after a front would be initiated early in WRF where ADEC sites have influence in terms of nudging. But other observations that are accurately represented in time would reflect be pre-frontal, warmer conditions. Essentially a really bad offset to the diurnal and synoptic temperature signal is likely in the Ramboll run near the surface. Aloft the model is not affected, so I suspect there are really poor representations of the temperature profiles of the lower atmosphere. This should have a direct negative impact on dispersion. This does not even get into any obs nudging of wind where transport would be impacted too.


Hurst Rd 3-m Temp
Ramboll Final
Temperature
250
245
240
235
Jan 3
Jan 4
Jan 5
Jan 6
Jan 7
Jan 8
Jan 9
Jan 10
Jan 11
Jan 12

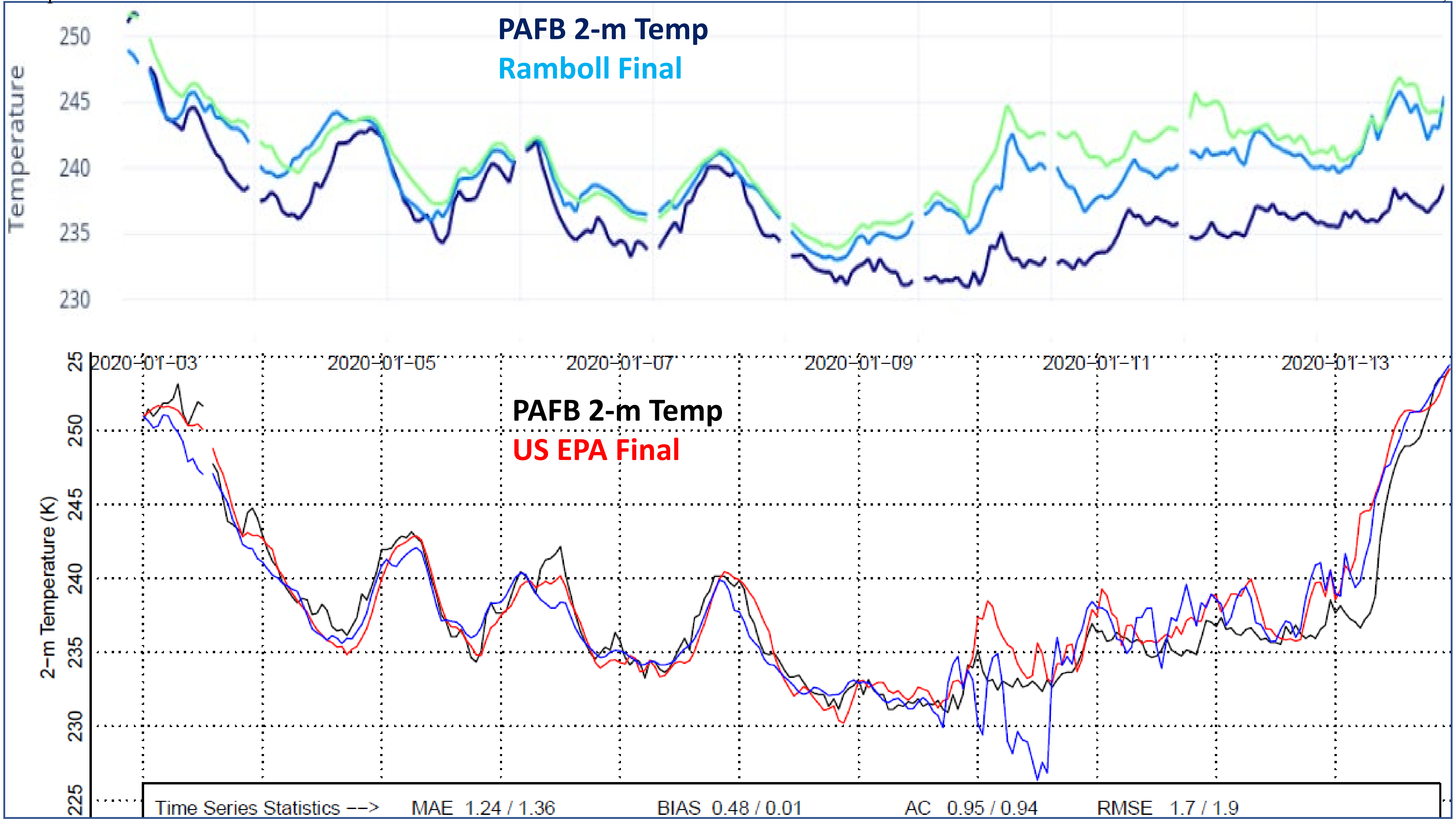

OBSERVATION RMSE
ADEC_NUDGE 2.53
USEPA_NUDGE 1.18
USEPA_NUDGE NaN
USEPA_NUDGE NaN
Hurst Rd 3-m Temp
US EPA Final
Temp (K)
250
245
240
235
230
225

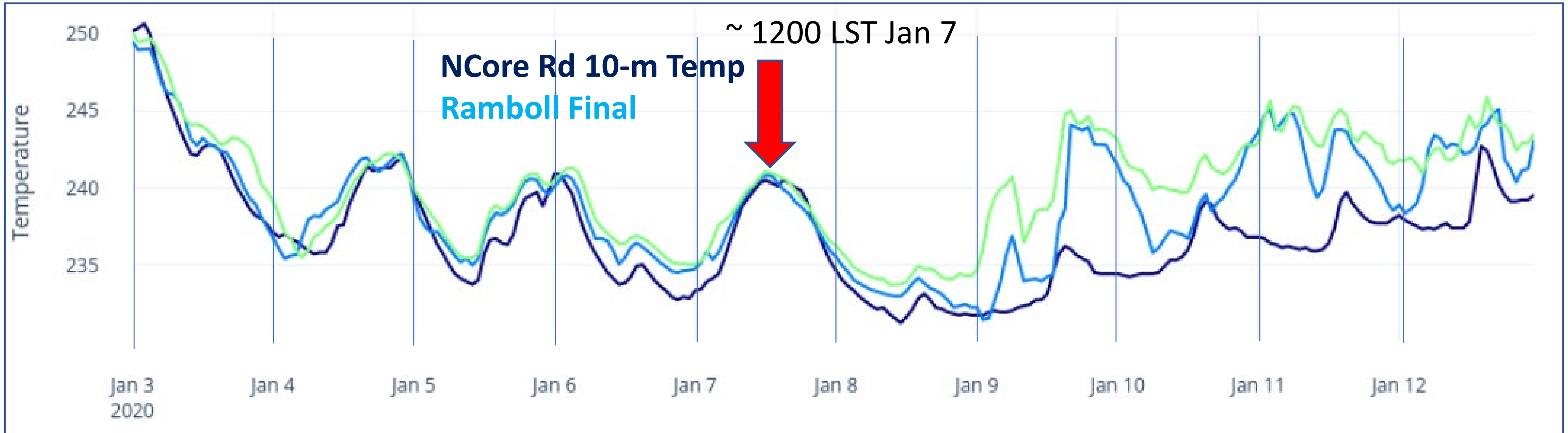

NCore Rd 3-m Temp
Ramboll Final
Temperature
250
245
240
235
Jan 3
2020
Jan 4
Jan 5
Jan 6
Jan 7
Jan 8
Jan 9
Jan 10
Jan 11
Jan 12

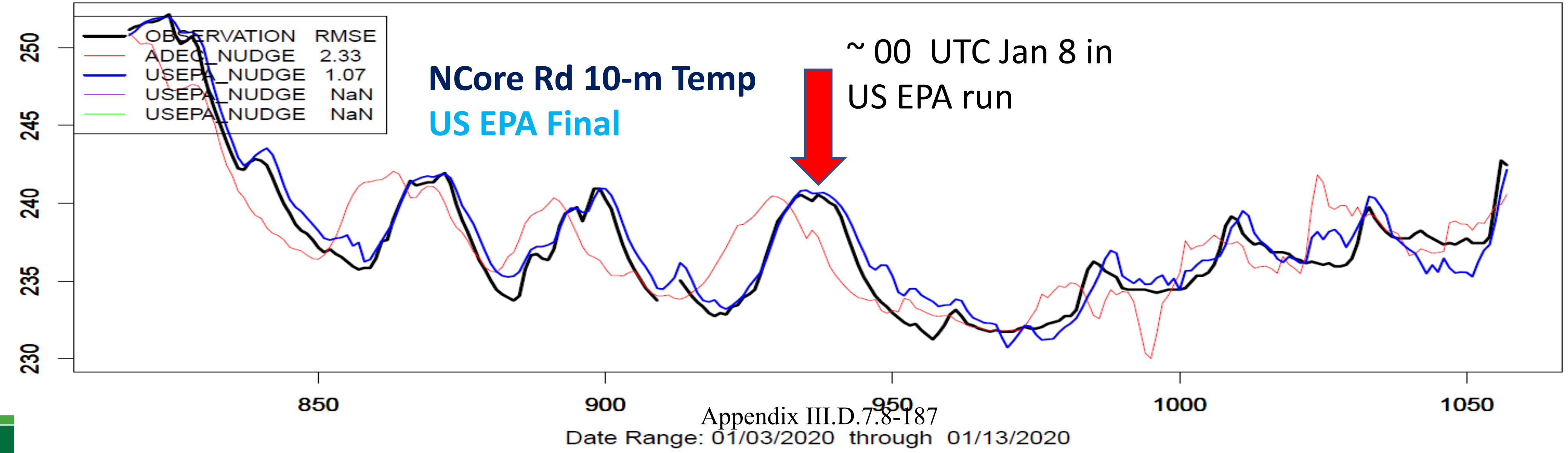

OBSERVATION RMSE
ADEC_NUDGE 2.92
USEPA_NUDGE 2.81
USEPA_NUDGE NaN
USEPA_NUDGE NaN
NCore Rd 3-m Temp
US EPA Final
250
245
240
235
230



255
250
245
240
235
Temperature
PAFA 2-m Temp
Ramboll Final
2020-01-03
2020-01-05
2020-01-07
2020-01-09
2020-01-11
2020-01-13
250
245
240
235
230
2-m Temperature (K)
PAFA 2-m Temp
US EPA Final
Time Series Statistics --> MAE 2.07 / 1.84 BIAS 1.19 / 1.13 AC 0.86 / 0.87 RMSE 2.8 / 2.6


PAFB 2-m Temp
Ramboll Final
Temperature
250
245
240
235
230
PAFB 2-m Temp
US EPA Final
2-m Temperature (K)
225
230
235
240
245
250
255
2020-01-03
2020-01-05
2020-01-07
2020-01-09
2020-01-11
2020-01-13
Time Series Statistics --> MAE 1.24 / 1.36 BIAS 0.48 / 0.01 AC 0.95 / 0.94 RMSE 1.7 / 1.9


~ 1200 LST Jan 7
NCore Rd 10-m Temp
Ramboll Final
Temperature
250
245
240
235
Jan 3 2020
Jan 4
Jan 5
Jan 6
Jan 7
Jan 8
Jan 9
Jan 10
Jan 11
Jan 12


OBSERVATION RMSE
ADEQ_NUDGE 2.33
USEPA_NUDGE 1.07
USEPA_NUDGE NaN
USEPA_NUDGE NaN
NCore Rd 10-m Temp
US EPA Final
~ 00 UTC Jan 8 in
US EPA run
250
245
240
235
230
850
900
950
1000
1050
Date Range: 01/03/2020 through 01/13/2020