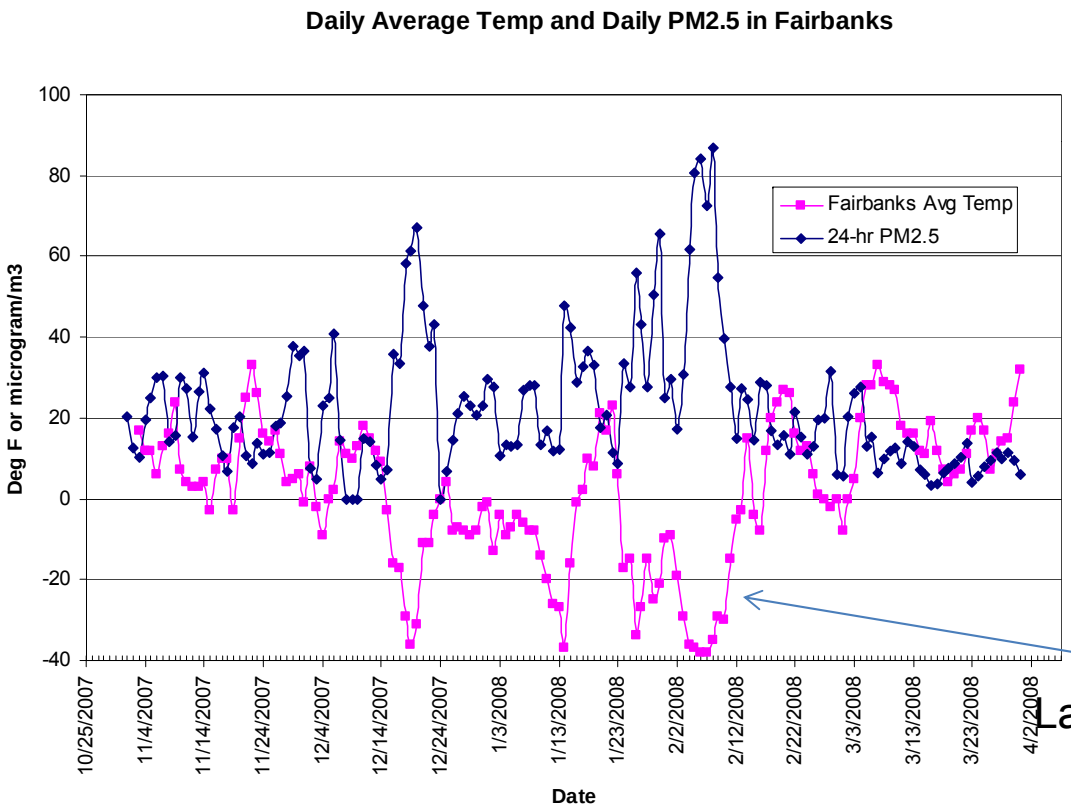
WRF Meteorological Modeling for Elevated PM2.5 Episodes near Fairbanks, Alaska

Project Manager: Barbara Trost
PI: Brian Gaudet
Co-PI: David Stauffer
PSU Participants: Glenn Hunter, Jeffrey Zielonka

Regional Applied Research Effort (RARE) Project (fall 2008 – spring 2010)

Kenneth Schere, EPA / ORD / NERL, Project Manager
(collaborators: Robert Elleman, Jonathan Pleim, Robert Gilliam)

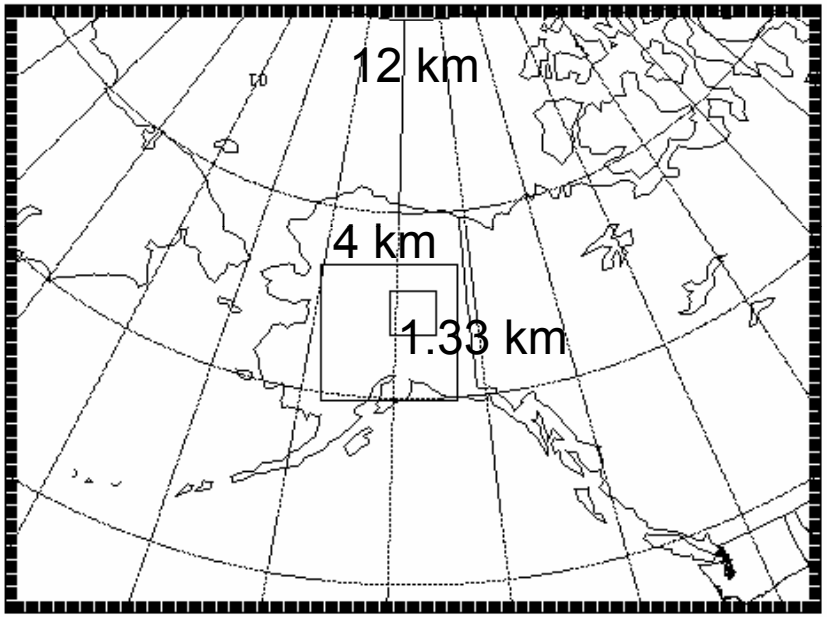
Performed for 2007-2008 Winter Season



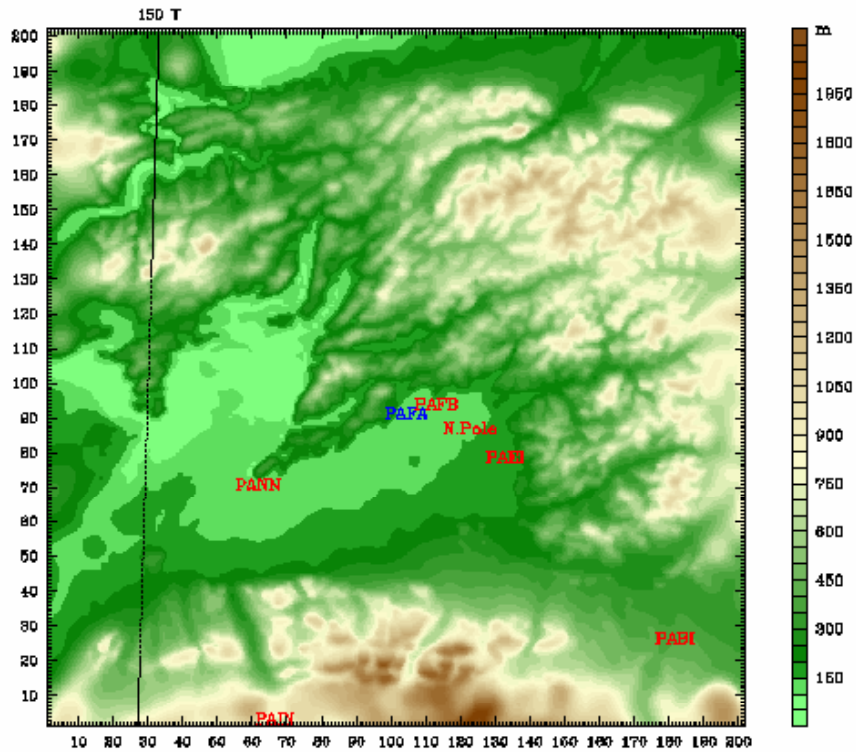
Late Jan – Mid Feb 2008

(courtesy Robert Dulla, Sierra Research)

Domain Configuration



1.33 km Domain



Alaska Domains:

12 km:	Synoptic scale	401 x 301	Δt = 24 s
4 km:	Central AK region	202 x 202	Δt = 8 s
1.33 km:	Tanana Basin	202 x 202	Δt = 4 s

39 vertical levels, to 4 m grid spacing near surface

Grid-independent Parameters

nesting procedure	one-way concurrent
model top (hPa)	50
number of vertical layers	39
eta value of full levels	1.0, 0.9995, 0.999, 0.9984, 0.99705, 0.99415, 0.99155, 0.986, 0.78, 0.966, 0.95, 0.034, 0.918, 0.902, 0.886, 0.866, 0.842, 0.814, 0.78, 0.74, 0.694, 0.648, 0.602, 0.556, 0.51, 0.464, 0.418, 0.372, 0.326, 0.282, 0.24, 0.2, 0.163, 0.128, 0.096, 0.066, 0.04, 0.018, 0
approximate height above ground level of half levels (m)	2.0, 6.0, 10.5, 18.4, 35.5, 57.8, 90.9, 146.2, 228.3, 344.5, 478.7, 614.8, 752.7, 892.5, 1052.3, 1251.1, 1491.2, 1785.4, 2148.4, 2587.7, 3079.8, 3598.2, 4146.0, 4727.3, 5346.7, 6010.4, 6725.8, 7502.6, 8333.4, 9208.6, 10135.5, 11190.6, 12139.8, 13234.2, 14408.4, 15652.1, 16921.7, 18193.7
exclude nudging from the boundary layer	no
G for analysis nudging, when used (s^{-1})	0.0003
G for obs nudging, when used (s^{-1})	0.0004
obs nudging half-time window (hr)	2
specified, relaxed zone width	1, 9

Grid-dependent Parameters

	Grid 1	Grid 2	Grid 3
horizontal extent	401 x 301	202 x 202	202 x 202
horizontal Δx (km)	12	4	1.33
i parent start	-	156	103
j parent start	-	106	106
time step (s)	24	8	4
sound step ratio	8	8	4
dampcoef	0.0	0.0	0.0
analysis nudging	yes	no	no
obs nudging	yes	yes	yes
surface obs nudging xy radius (km)	100	100	75
topographic dataset	USGS	USGS	USGS -- 30 s

Four Dimensional Data Assimilation (FDDA) Strategy

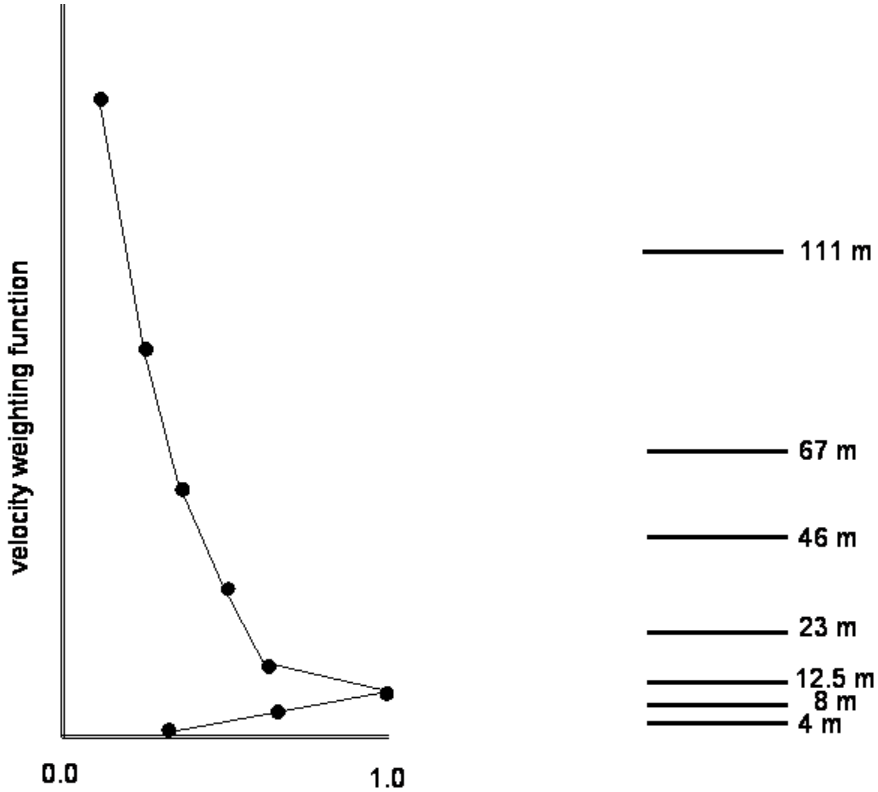
- Multiscale, Multigrid (Stauffer and Seaman 1994)

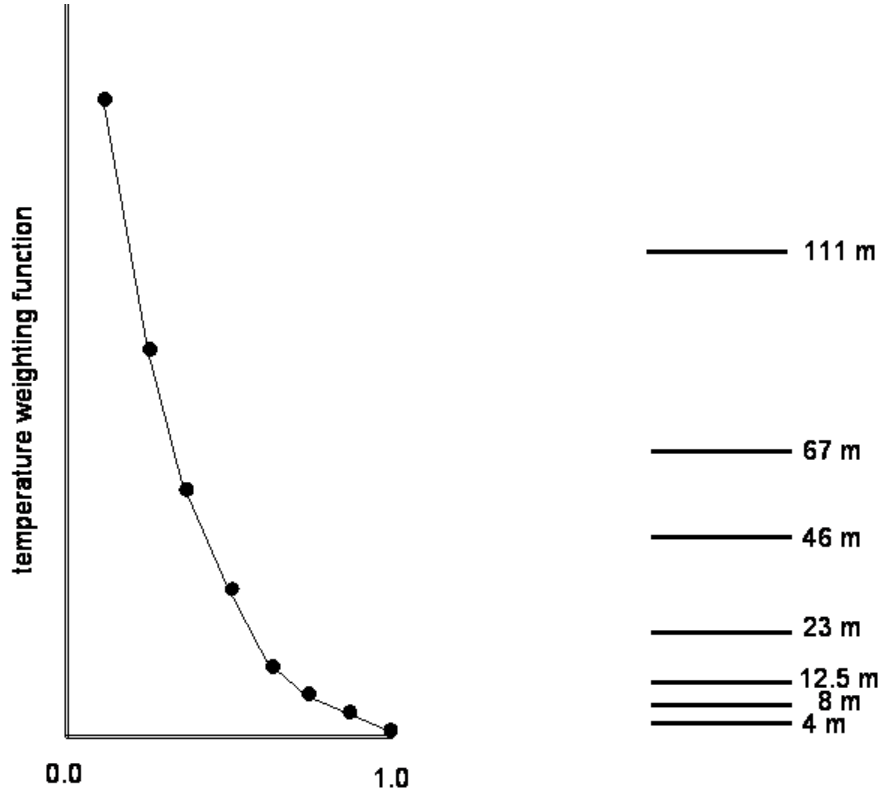
	Grid 1 (12 km)	Grid 2 (4 km)	Grid 3 (1.33 km)
Analysis Nudging (Surface and Upper-Air)	yes	no	no
Observation Nudging	yes	yes	yes (in final dynamic analysis)

EPA RARE Modifications

- 1) Vertical weighting functions for surface observations in FDDA were restricted to approximately 150 m AGL, due to the stable conditions.
- 2) Wind innovations were applied directly at 10 m; no similarity adjustment was performed for either wind or temperature

Modified Vertical Weighting Functions for Surface Observations
EPA RARE Project





(also used for mixing ratio)

EPA RARE Modifications

- 3) The time window for surface observations in observations was multiplied by 0.5 (sfcfact).
- 4) The influence of surface observations was spread along topography according to the MM5 method of Stauffer and Seaman (1994), instead of the default WRF pressure-based method.
- 5) The surface observation of a sounding was treated like a surface ob.

Surface Observation Spreading Functions
(Reduces the Weight Assigned to an Observation at Model Grid Points with Significantly Different Surface Pressures)

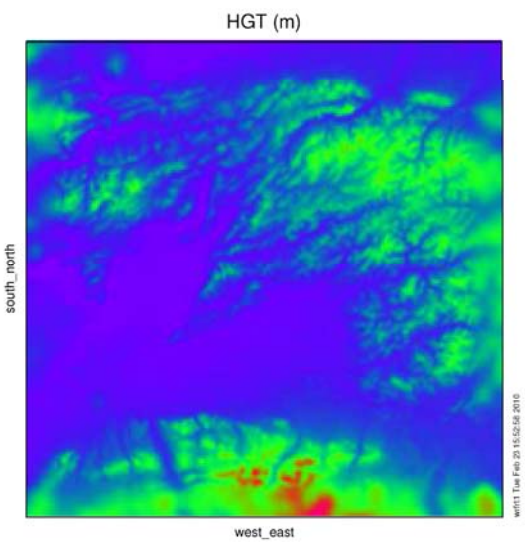
r: distance between grid point and observation
r_0: surface radius of influence parameter
p: model surface pressure at grid point
p_b: model surface pressure at location of observation
Δp_d: surface pressure difference parameter ('dpsmx')

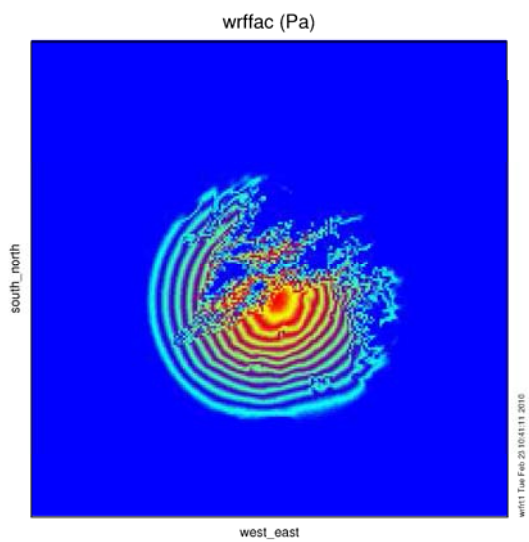
Default WRF

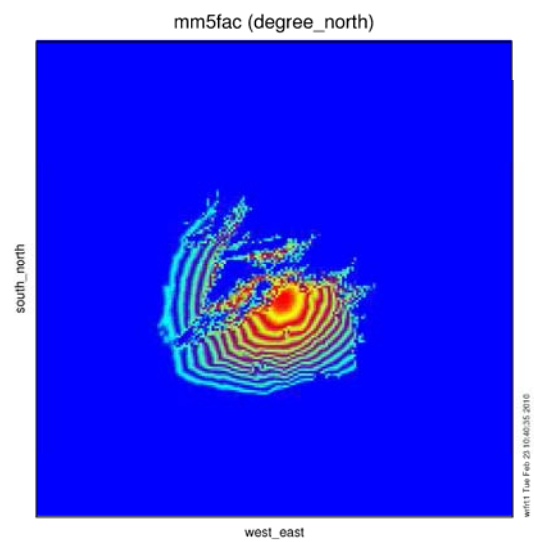
$$w = \max\left[0.0,\ 1.0 - \frac{|p - p_b|}{\Delta p_d}\right]\left[\frac{r_0^2 - r^2}{r_0^2 + r^2}\right]$$

MM5 (Stauffer and Seaman 1994)

$$w = \frac{r_0^2 - \left[r + r_0 \frac{|p - p_b|}{\Delta p_d}\right]^2}{r_0^2 + \left[r + r_0 \frac{|p - p_b|}{\Delta p_d}\right]^2}$$



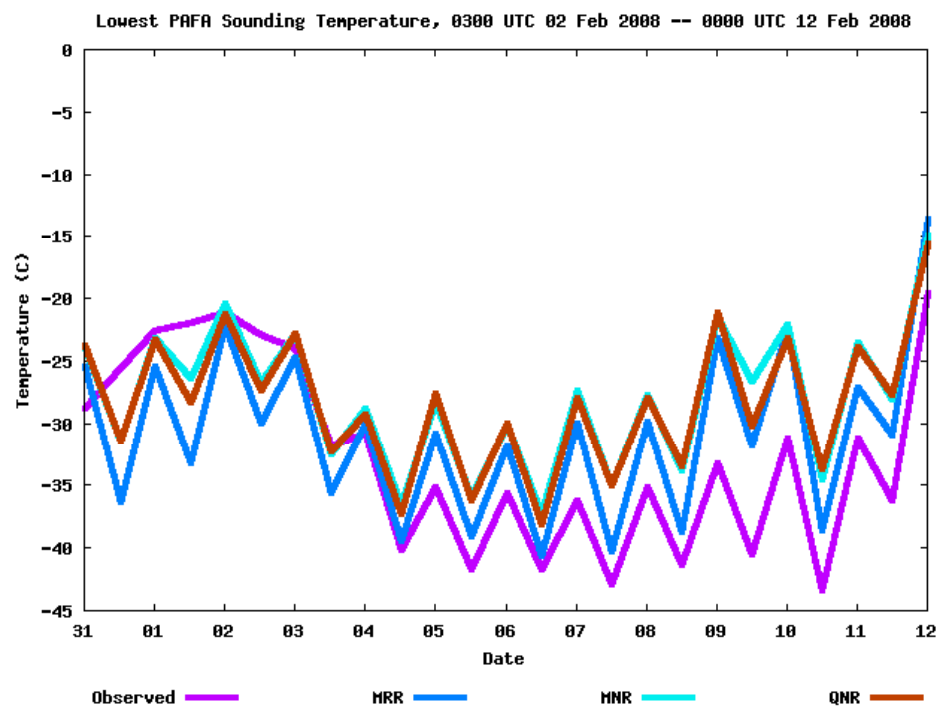




Recommended Physics Suite:
MYJ (modified) PBL scheme
RUC Land Surface Model (LSM)
RRTMG Longwave and Shortwave Radiative Scheme

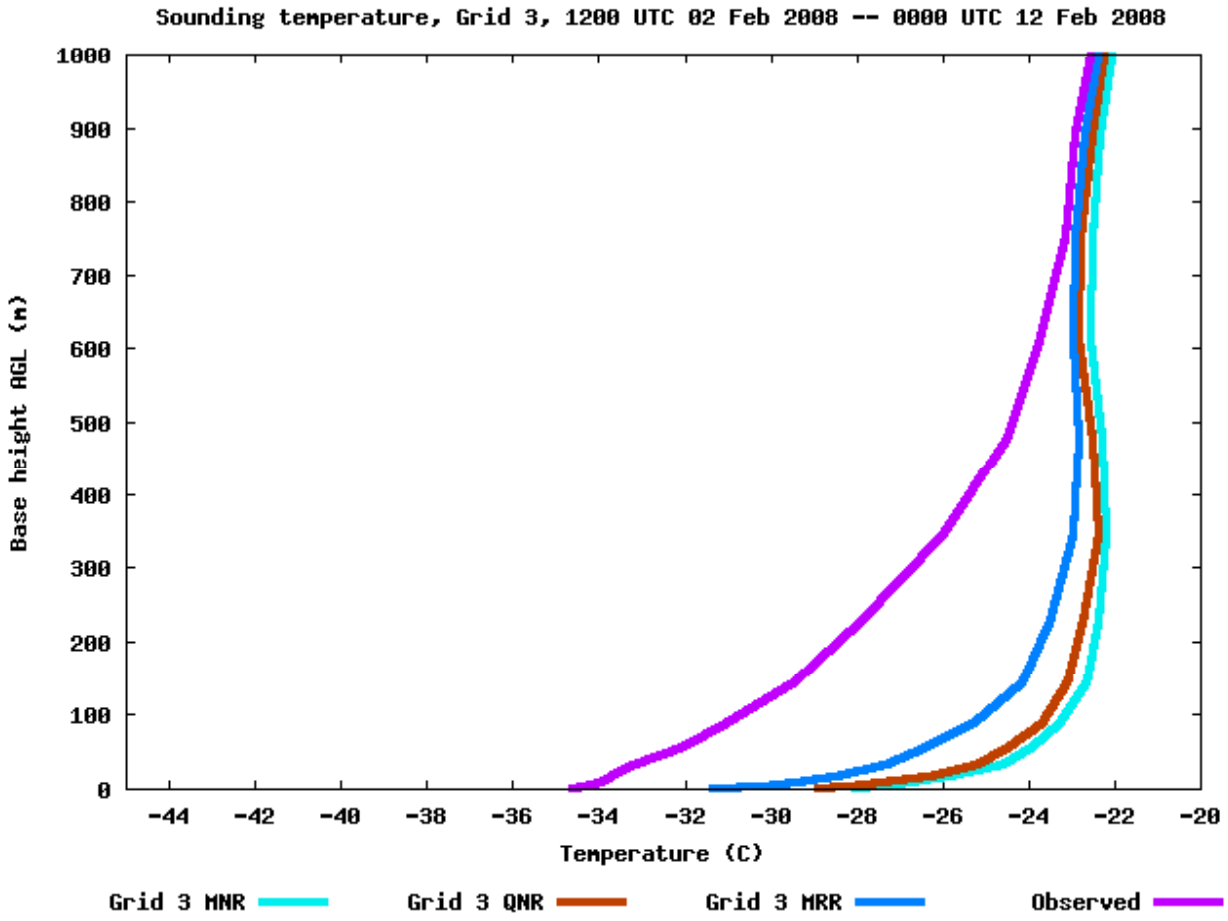
(0300 UTC 02 Feb 2008 – 0000 UTC 12 Feb 2008)

Purple – Observed
Dark Blue – MYJ / RUC / RRTMG
Light Blue – MYJ / Noah / RRTMG
Brown – QNSE/ Noah / RRTMG



(from EPA RARE final report)

(1200 UTC 02 Feb 2008 – 0000 UTC 12 Feb 2008 average sounding)



Purple – Observed
Dark Blue – MYJ / RUC / RRTMG
Light Blue – MYJ / Noah / RRTMG
Brown – QNSE/ Noah / RRTMG

(interpolated to appoximate WRF model levels)

EPA RARE Modifications (for Grid 3 in final dynamic analysis)

- 6) The ‘dpsmx’ parameter was reduced to 37.5 hPa.
- 7) RINXY (obs nudging radius of influence) was set to 75 km on Grid 3 vs. 100 km on Grids 1,2
- 8) Within the vertical weighting function region for surface observations within FDDA, only temperature and mixing ratio were nudged for Grid 3.

ADEC / FNSB Project (spring 2011-spring 2012)

- Supported by the Alaska Department of Environmental Conservation (ADEC) and the Fairbanks / North Star Borough – Program Manager Barbara Trost

- collaborators: Deanna Huff (ADEC), Mark Hixson (Sierra Research), Jim Connor (FNSB), Robert Elleman

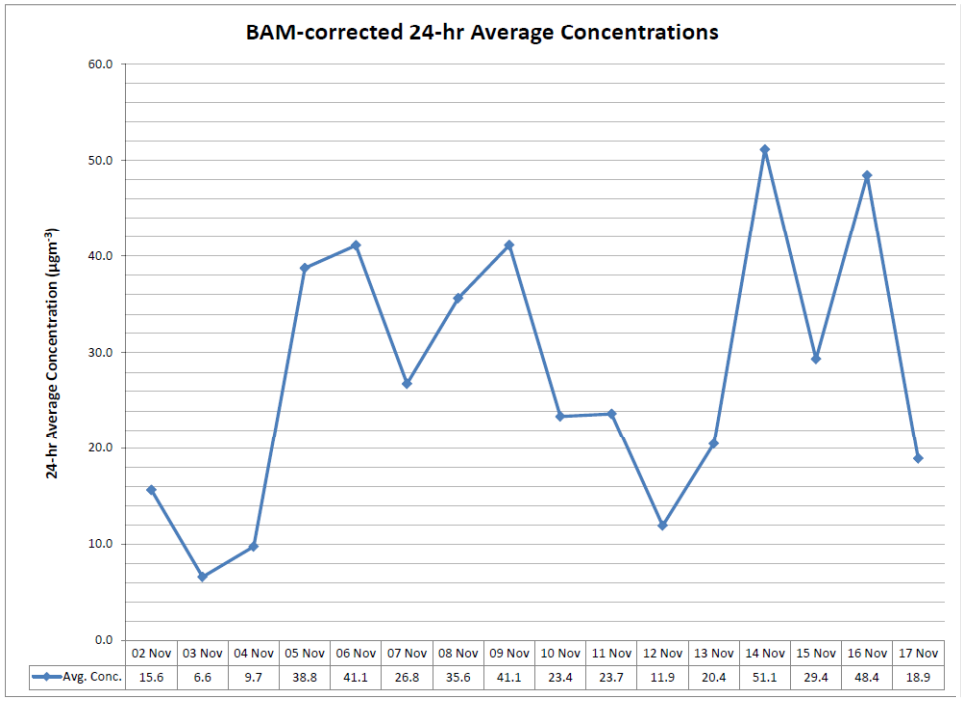
- Purpose: to perform meteorological modeling of the region around Fairbanks and North Pole, AK, as part of the State Implementation Plan for fine particulate matter (PM2.5) analysis of the region.

Desired Modifications to OBSGRID Data Processing

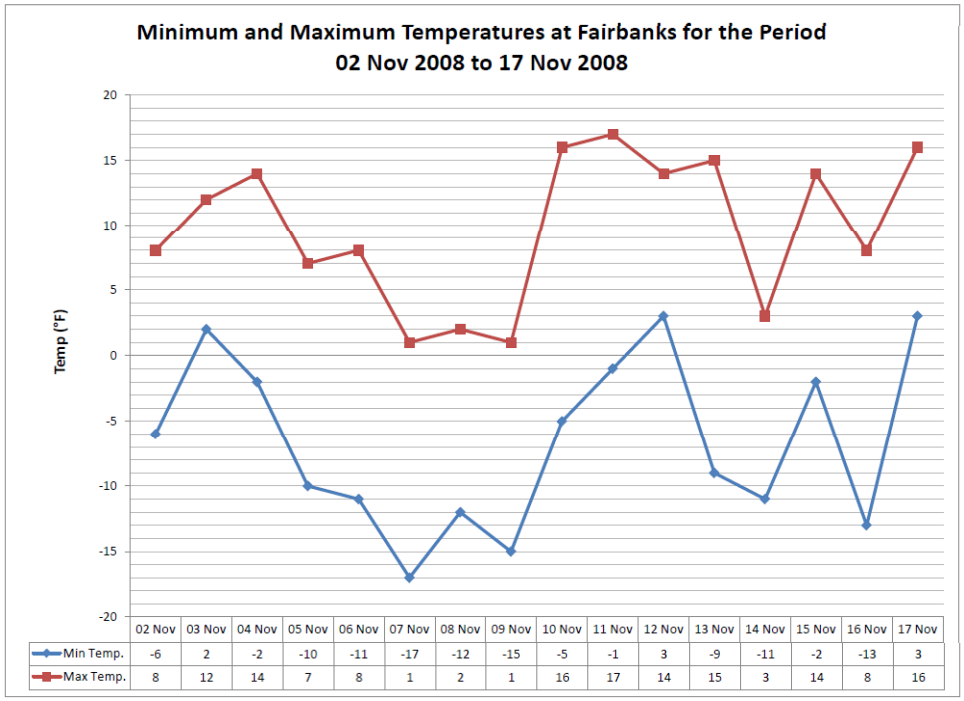
- Use of high-resolution UNGRIB decoder – to allow OBSGRID QC at finer vertical resolution

- Application of Cressman analysis above surface with RAWINS scanning method

New Case – 2-17 Nov. 2008



	02 Nov	03 Nov	04 Nov	05 Nov	06 Nov	07 Nov	08 Nov	09 Nov	10 Nov	11 Nov	12 Nov	13 Nov	14 Nov	15 Nov	16 Nov	17 Nov
Avg. Conc.	15.6	6.6	9.7	38.8	41.1	26.8	35.6	41.1	23.4	23.7	11.9	20.4	51.1	29.4	48.4	18.9



	02 Nov	03 Nov	04 Nov	05 Nov	06 Nov	07 Nov	08 Nov	09 Nov	10 Nov	11 Nov	12 Nov	13 Nov	14 Nov	15 Nov	16 Nov	17 Nov
Min Temp.	-6	2	-2	-10	-11	-17	-12	-15	-5	-1	3	-9	-11	-2	-13	3
Max Temp.	8	12	14	7	8	1	2	1	16	17	14	15	3	14	8	16

Available Data

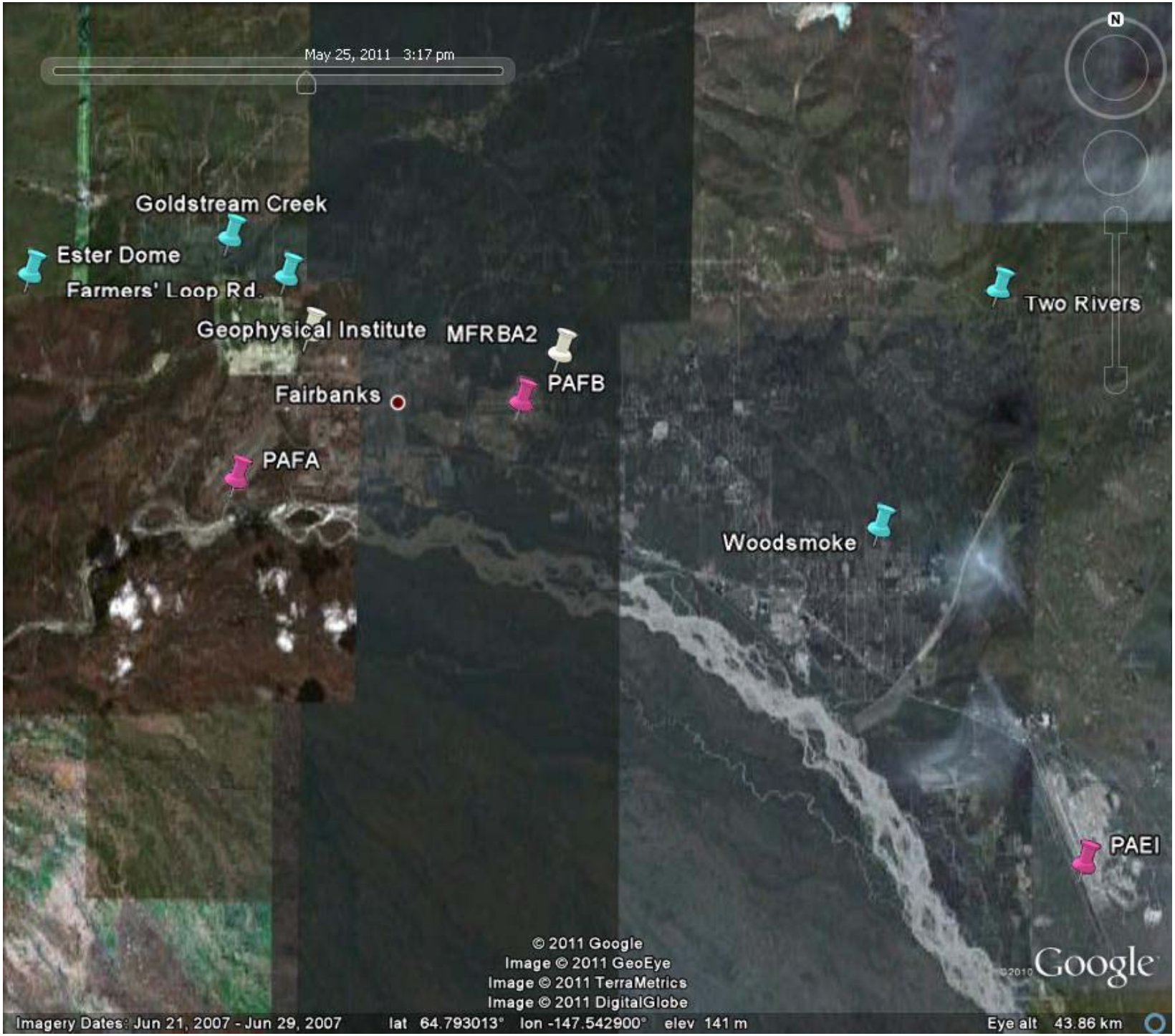
- 0.5-degree GFS (GRIB2) 0-hour forecasts
- Unidata-feed raw obs
- Special data (MADIS stations) *(converted to little_r format)*

APRSWXNET – Automatic Position Reporting System as a WX NETwork; RAWS – Remote Automated Weather Station; AKDOT – AK Department of Transportation; MADIS – Meteorological Assimilation Data Ingest System

Station	Database	Latitude	Longitude	Elevation (m)
Woodsmoke	Other MADIS	64.781	-147.284	145
Goodpasture	RAWS	64.238	-145.267	463
Healy (near Otto Lake Rd.)	APRSWXNET	63.839	-149.068	594
Two Rivers	APRSWXNET	64.873	-147.174	229
Fairbanks, near Farmer's Loop Rd. & Ballaine Rd.	APRSWXNET	64.879	-147.824	152
Goldstream Creek	APRSWXNET	64.894	-147.876	176
Livengood	RAWS	65.424	-148.722	137
Ester Dome	APRSWXNET	64.879	-148.055	708
Parks Hwy at Antler Creek	AKDOT	63.810	-148.965	462

Standard Meteorological Stations

- Surface METARs:
  - Non-attainment: Fairbanks (PAFA), Eielson AFB (PAEI), Ft. Wainwright (PAFB)
  - Other Grid 3: Nenana (PANN), Delta Junction (PABI), Manley Hot Springs (PAML), McKinley Park (PAIN), Healy (PAHV)
- Rawinsonde (sounding):
  - Fairbanks


May 25, 2011 3:17 pm
N
Goldstream Creek
Ester Dome
Farmers' Loop Rd
Geophysical Institute
MFRBA2
PAFB
Fairbanks
PAFA
Two Rivers
Woodsmoke
PAEI
© 2011 Google
Image © 2011 GeoEye
Image © 2011 TerraMetrics
Image © 2011 DigitalGlobe
Google
Imagery Dates: Jun 21, 2007 - Jun 29, 2007
lat 64.793013° lon -147.542900° elev 141 m
Eye alt 43.86 km

Experimental Design

- Simulated using series of segments overlapping by 12 hours:
  - 12 UTC 1 Nov – 00 UTC 5 Nov
  - 12 UTC 4 Nov – 12 UTC 9 Nov
  - 00 UTC 9 Nov – 00 UTC 14 Nov
  - 12 UTC 13 Nov – 12 UTC 18 Nov

- 5-8 Nov used as sensitivity test period (FDDA methodology)

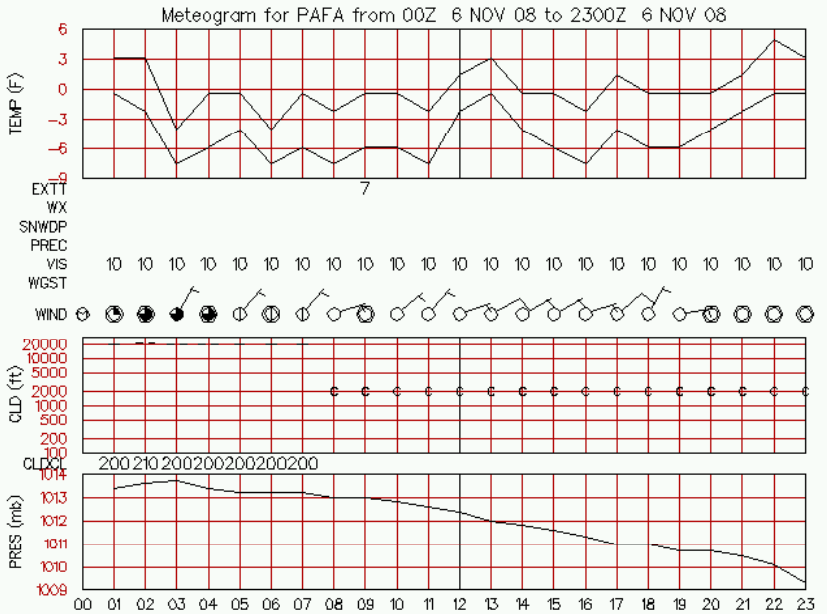
- After initial validation of FDDA with expanded data network and enhanced vertical resolution:

  - Experiment T: on Grid 3 assimilate mass fields (T, q_v) only, as before
  - Experiment TWIND: on Grid 3 assimilate both mass and wind fields

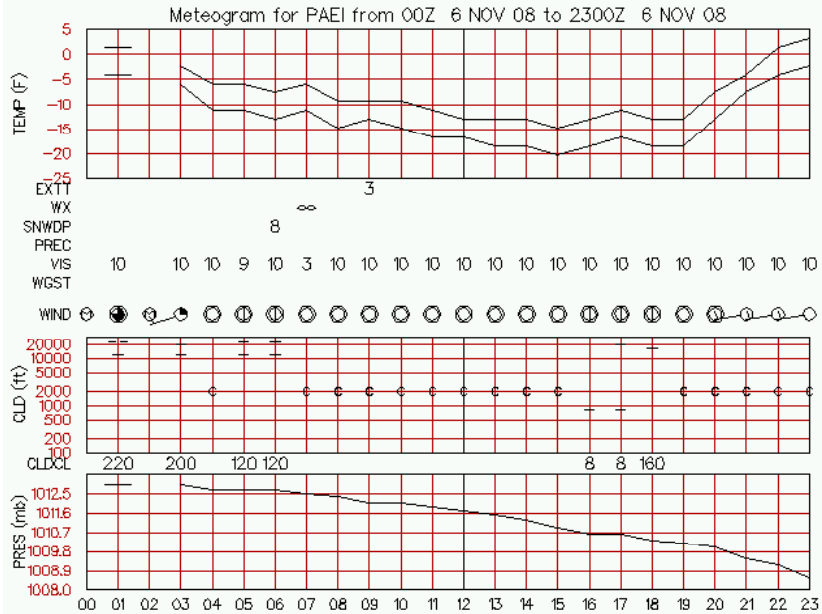
Nov. 5-8 Test Period

Temperature (°C)	T RMSE (MAE for wind direction)	TWIND RMSE (MAE for wind direction)	T Bias	TWIND Bias
Fairbanks	***1.71***	1.72	***-0.07***	-0.15
Eielson AFB	1.83	***1.80***	1.20	***1.18***
Ft. Wainwright	1.36	***1.32***	***0.05***	***-0.05***
Three Stations	1.70	***1.68***	0.42	***0.36***
Relative Humidity (%)				
Fairbanks	***4.21***	4.31	***-0.54***	-0.59
Eielson AFB	***7.39***	7.50	***3.59***	3.70
Ft. Wainwright	***17.55***	17.89	***-16.59***	-16.96
Three Stations	***9.31***	9.49	***-2.06***	-2.11
Wind Speed (m s^{-1})				
Fairbanks	0.98	***0.95***	0.54	***0.16***
Eielson AFB	1.20	***1.16***	0.71	***0.70***
Ft. Wainwright	0.82	***0.75***	***0.18***	0.53
Three Stations	1.05	***1.01***	0.54	***0.53***
Wind Direction (degrees)				
Fairbanks	49.1	***32.6***	26.2	***22.4***
Eielson AFB	66.2	***37.6***	42.0	***16.7***
Ft. Wainwright	93.1	***74.2***	***35.8***	36.2
Three Stations	73.1	***53.8***	33.2	***28.4***

Plymouth State Weather Center



Plymouth State Weather Center



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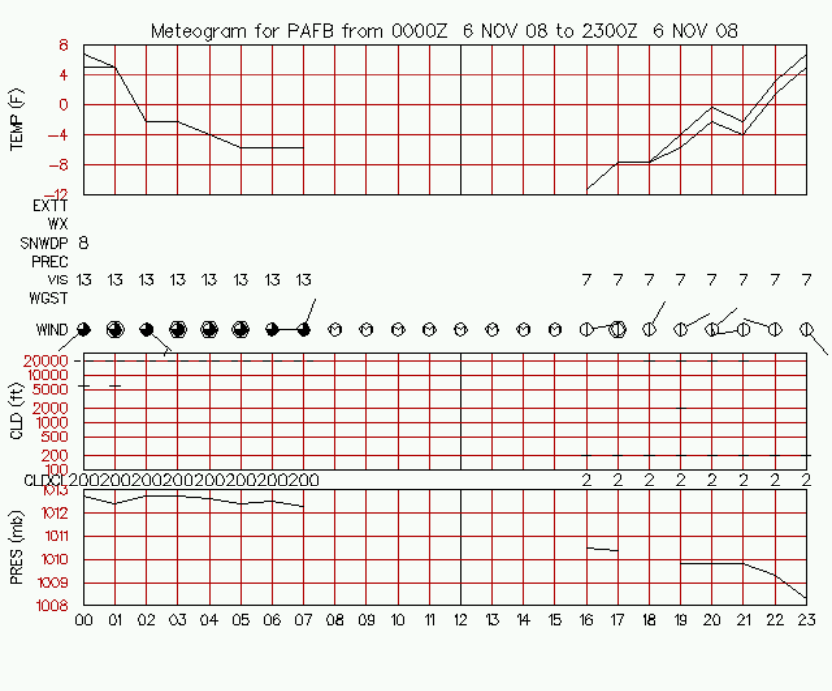

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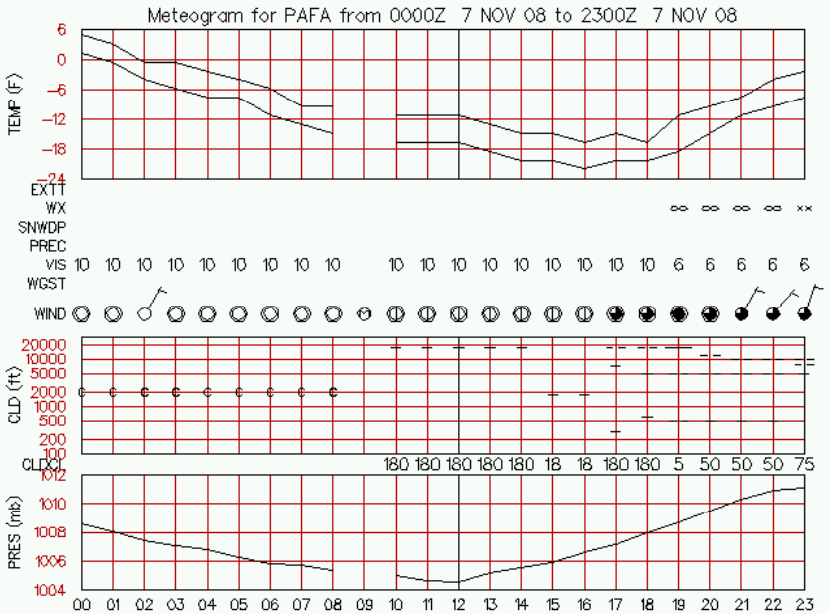
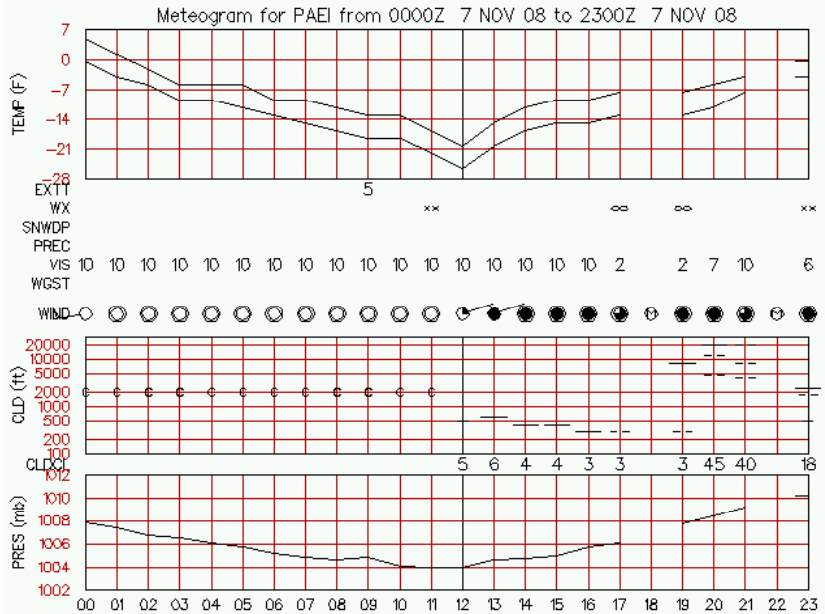
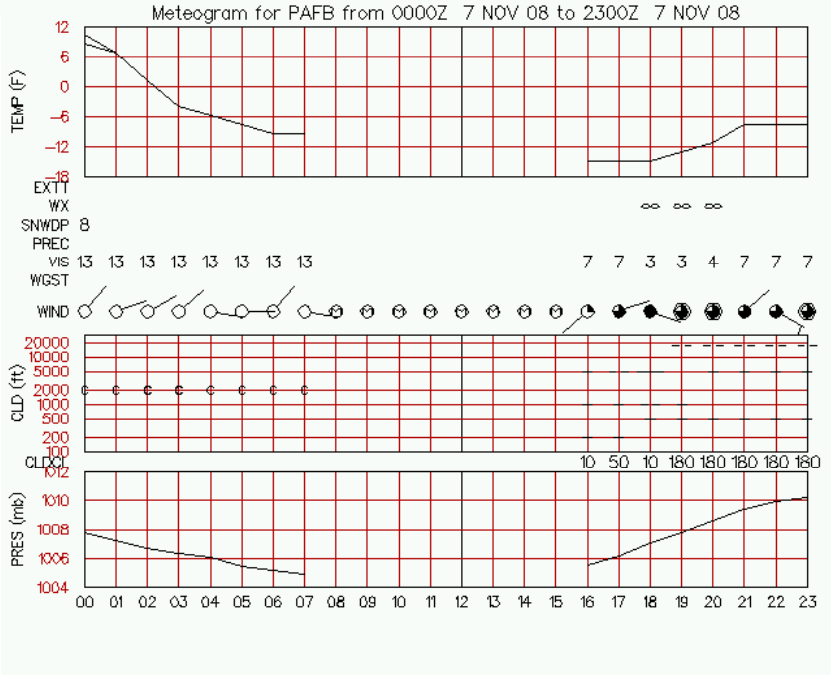
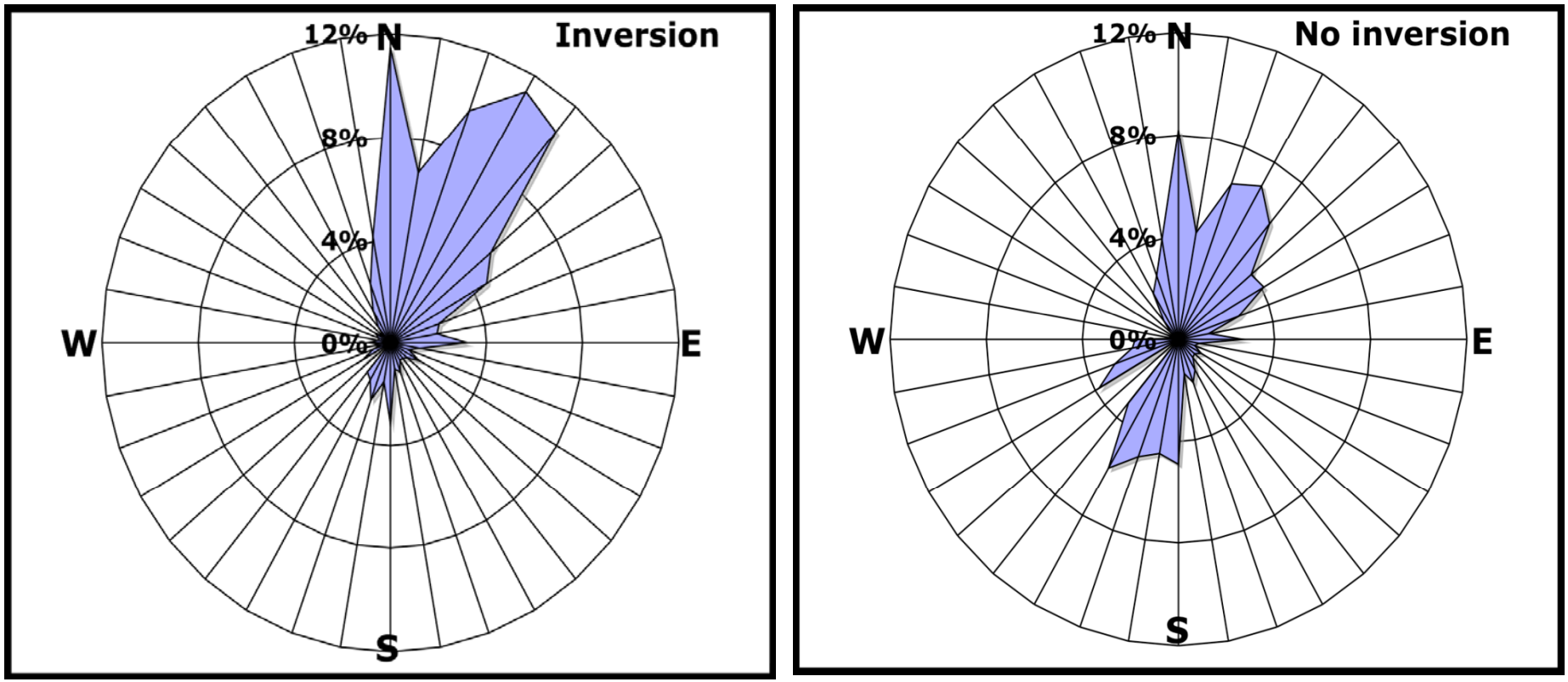


Plymouth State Weather Center



Plymouth State Weather Center



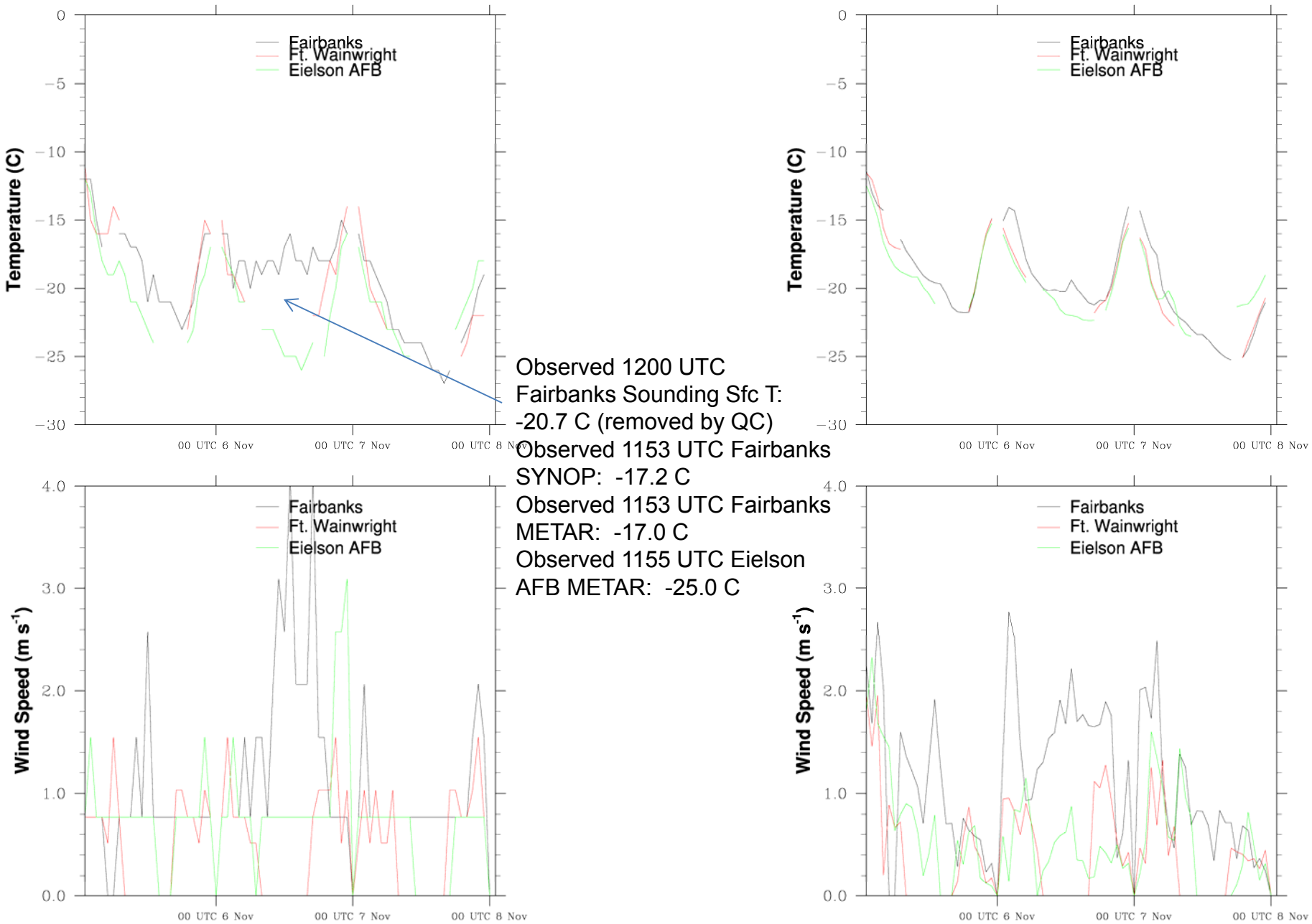


(from Hartmann and Wendler 2005)

METAR Stations

Observations

TWIND Model



Observed 1200 UTC Fairbanks Sounding Sfc T: -20.7 C (removed by QC)

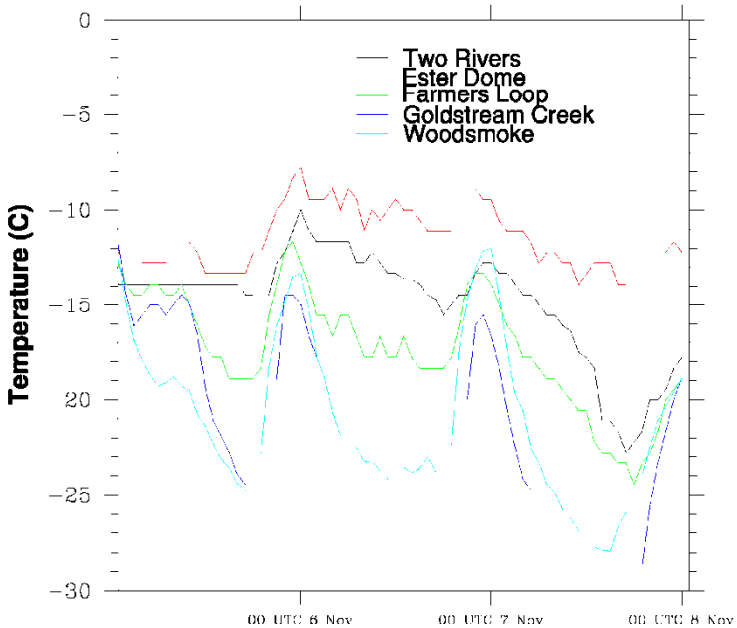
Observed 1153 UTC Fairbanks SYNOP: -17.2 C

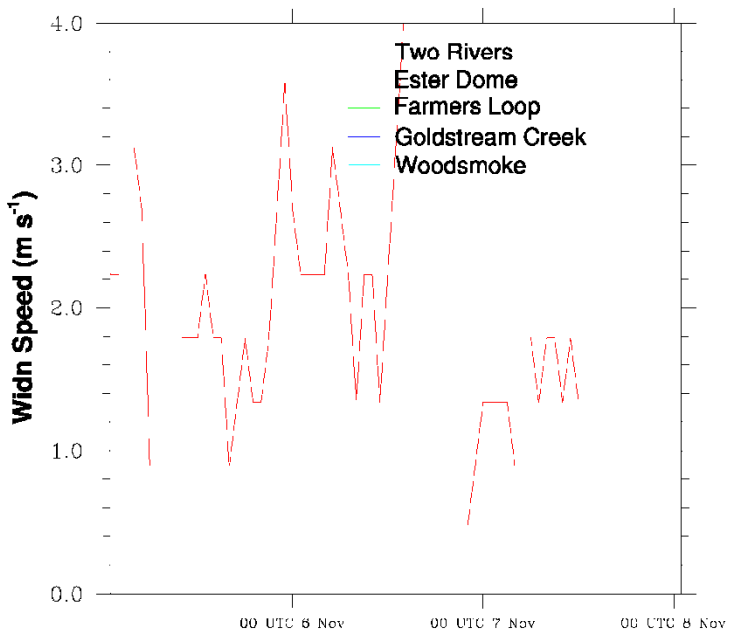
Observed 1153 UTC Fairbanks METAR: -17.0 C

Observed 1155 UTC Eielson AFB METAR: -25.0 C

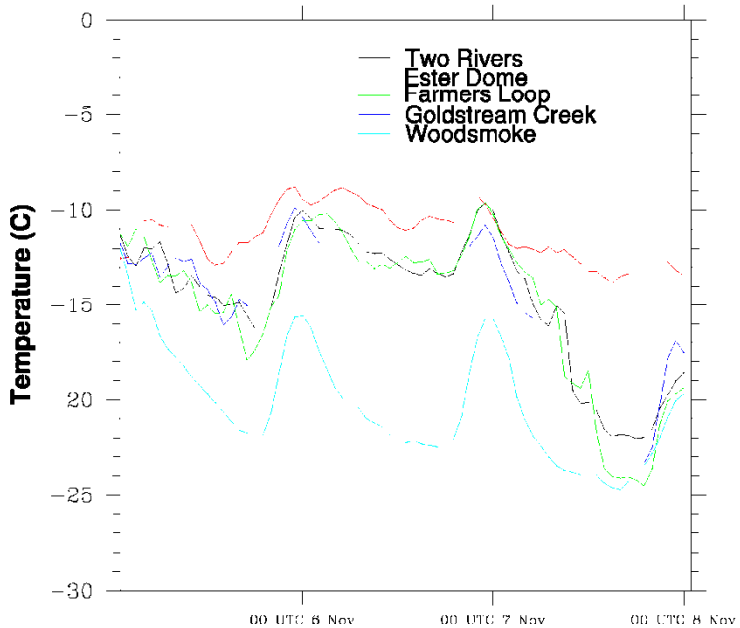
Non-METAR Stations

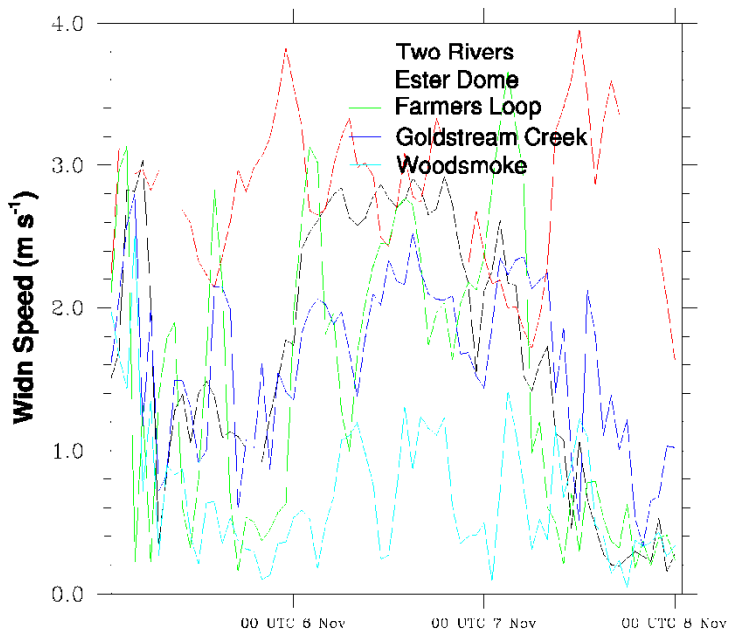
Observations





TWIND Model





Nov. 5-8 Test Period

Temperature (°C)	TWIND RMSE (MAE for wind direction)	TWIND2X30 RMSE (MAE for wind direction)	TWIND Bias	TWIND2X30 Bias
Fairbanks	1.72	***1.68***	***-0.15***	0.33
Eielson AFB	1.80	***1.45***	1.18	***0.95***
Ft. Wainwright	***1.32***	1.43	***-0.05***	0.63
Three Stations	1.68	***1.55***	***0.36***	0.62
Relative Humidity (%)				
Fairbanks	***4.31***	4.46	***-0.59***	-0.61
Eielson AFB	7.50	***5.43***	3.70	***2.49***
Ft .Wainwright	17.89	***16.22***	-16.96	***-15.33***
Three Stations	9.49	***8.36***	***-2.11***	-2.26
Wind Speed (m s^{-1})				
Fairbanks	***0.95***	1.01	***0.16***	0.60
Eielson AFB	***1.16***	1.24	***0.70***	0.82
Ft. Wainwright	***0.75***	0.91	0.53	***0.27***
Three Stations	***1.01***	1.10	***0.53***	0.63
Wind Direction (degrees)				
Fairbanks	32.6	***21.0***	22.4	***9.5***
Eielson AFB	37.6	***19.3***	16.7	***3.1***
Ft. Wainwright	74.2	***48.9***	36.2	***10.7***
Three Stations	53.8	***34.5***	28.4	***9.2***

TWIND2X30 Experiment

- Double observation nudging strength (from 3 x 10^{-4} to 6 x 10^{-4}) for wind components

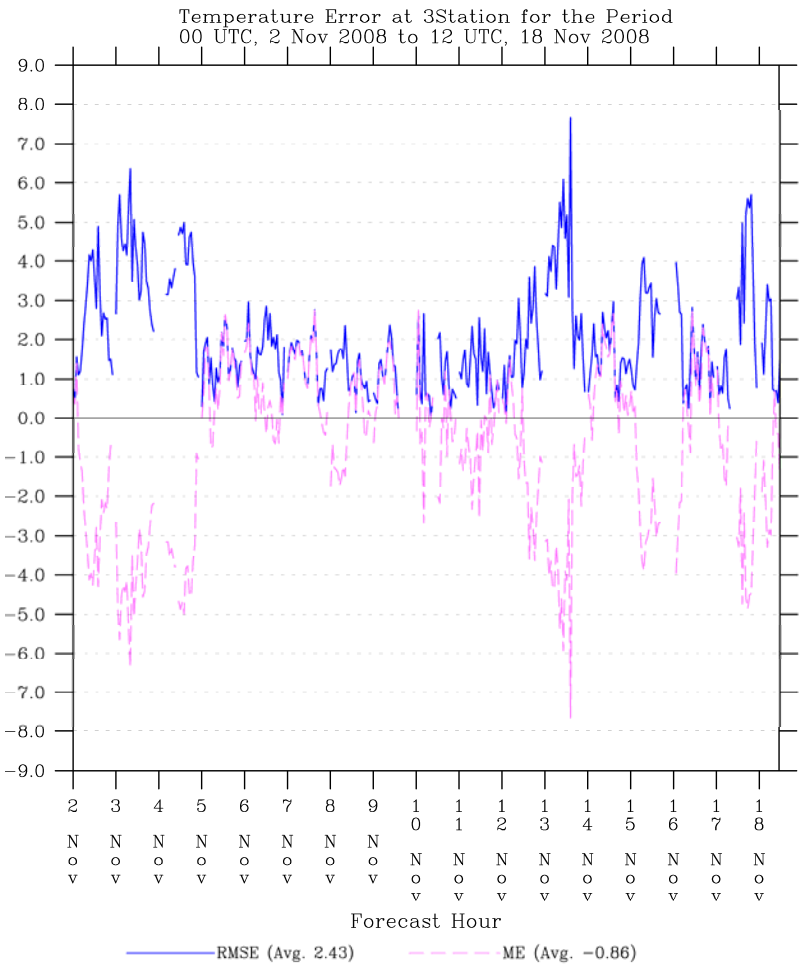
- Reduce radius of influence for observation nudging from 75 km to 30 km (based on result from spatial correlation analysis on free-forecast 1.33-km domain)

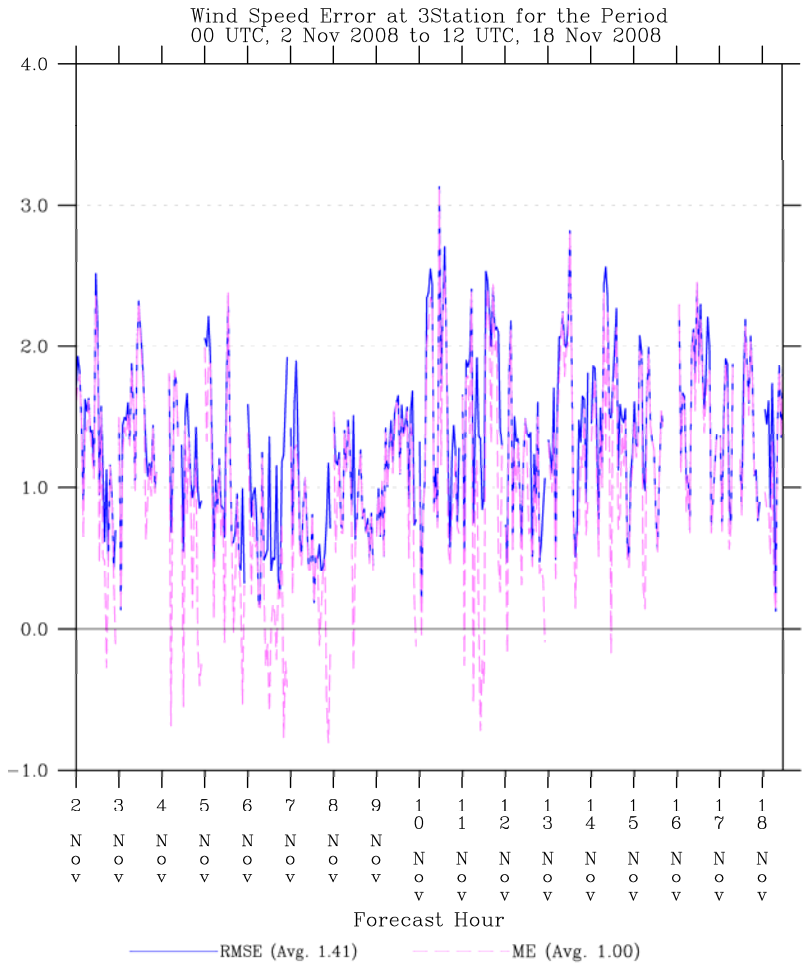
Considerations with Calm Winds

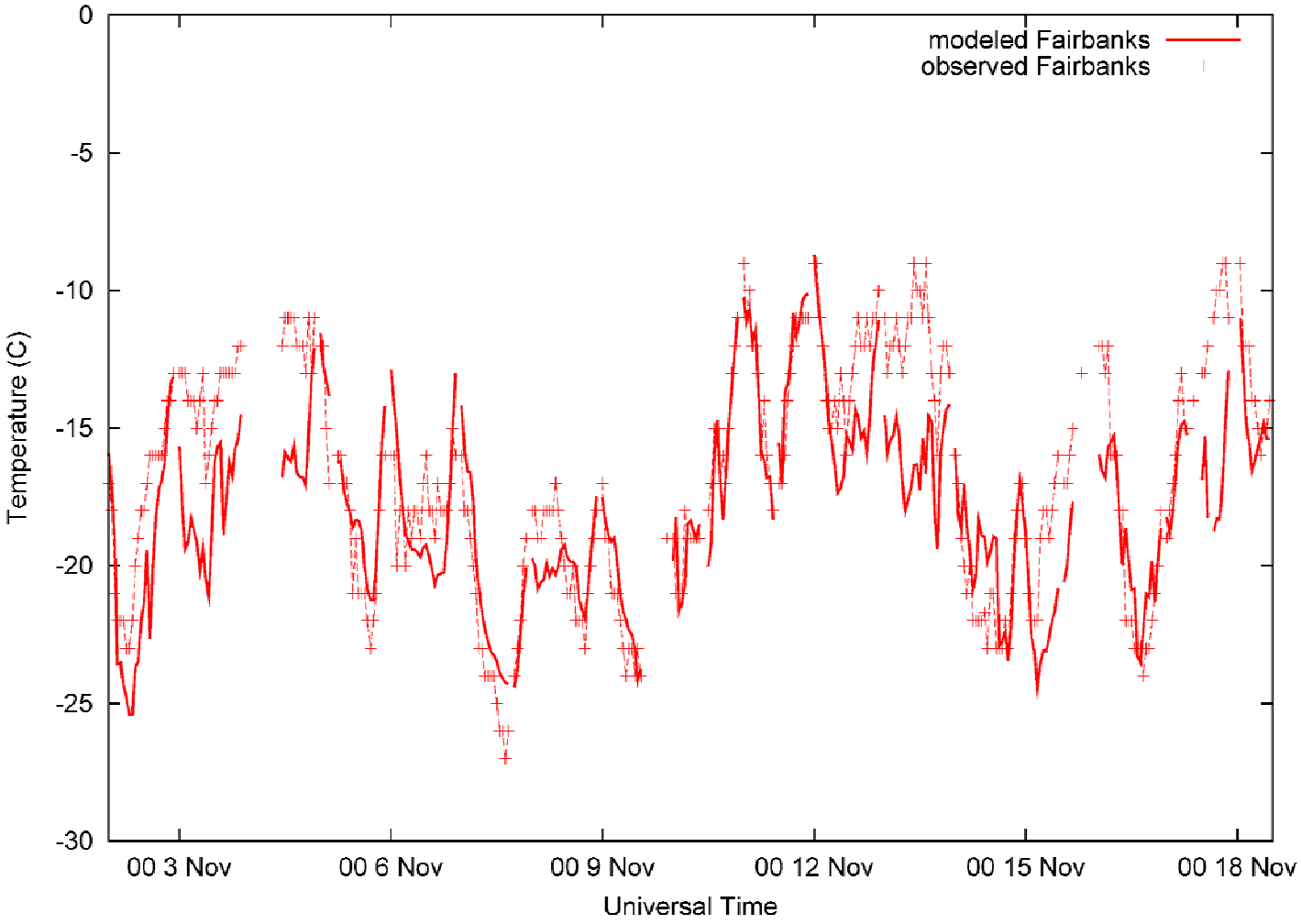
- Can’t verify wind direction when wind is calm
- Observations of calm may be calm, or may be missing, or may be below the instrument and/or reporting threshold (e.g., 3 knots).
- Observation nudging of winds is applied to u,v components separately

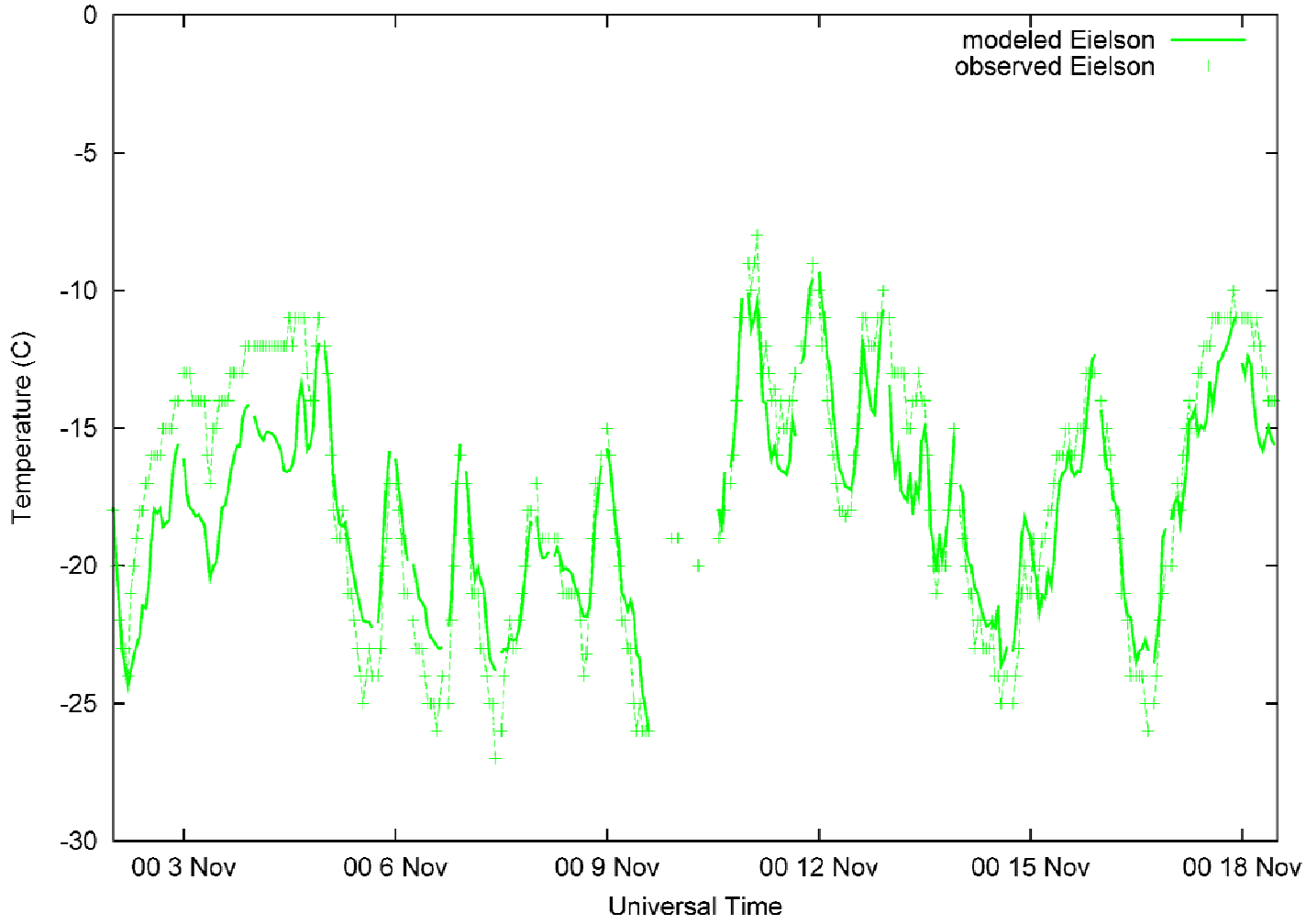
Whole Nov. 2-18 Episode

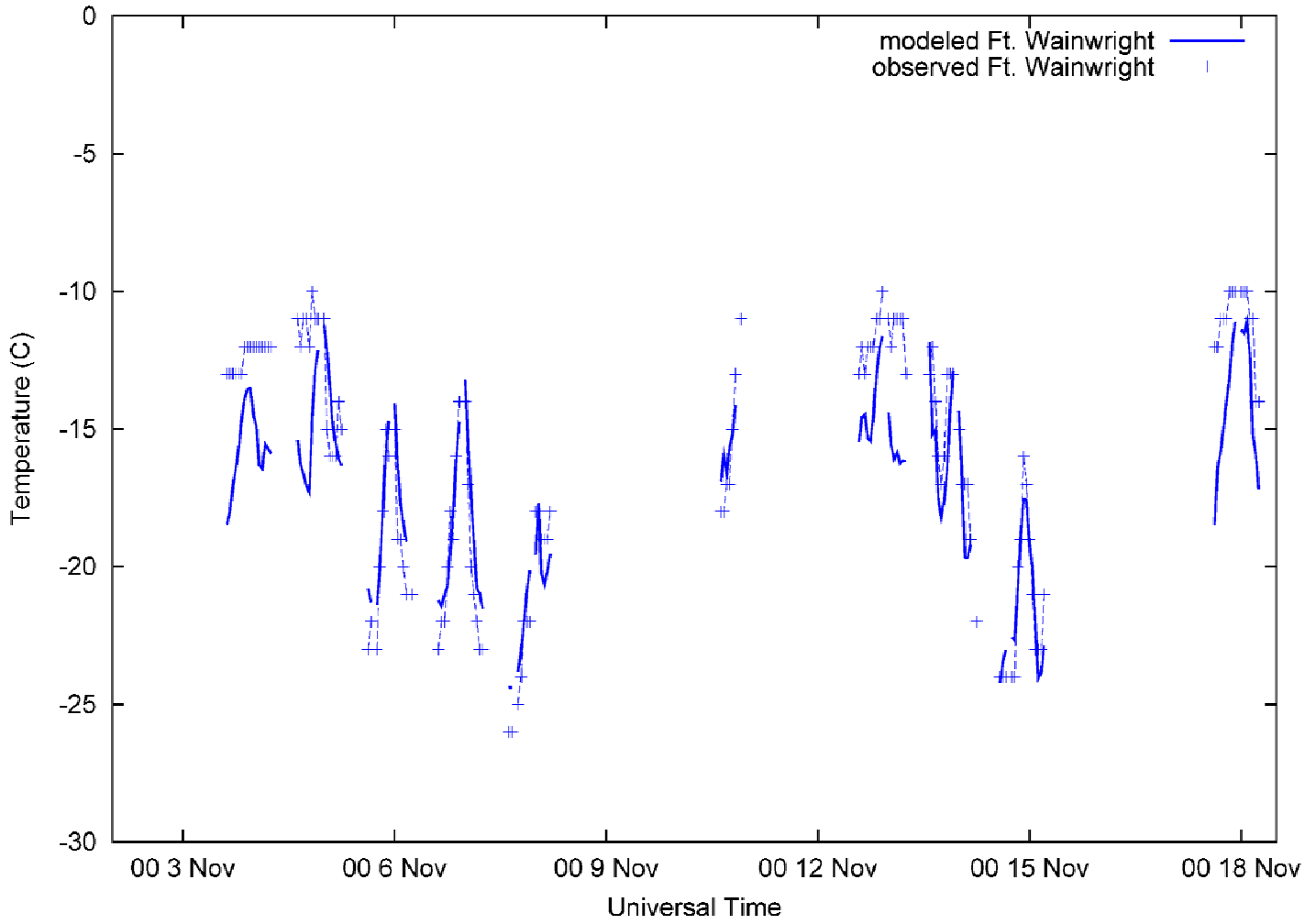
Temperature (°C)	TWIND2X30CALM RMSE (MAE for wind direction)	TWIND2X30 RMSE (MAE for wind direction)	TWIND2X30CALM Bias	TWIND2X30 Bias
Fairbanks	***1.51***	1.68	***0.22***	0.33
Eielson AFB	***1.43***	1.45	***0.93***	0.95
Ft. Wainwright	1.50	***1.43***	0.70	***0.63***
Three Stations	***1.48***	1.55	***0.57***	0.62
Relative Humidity (%)				
Fairbanks	4.55	***4.46***	-0.87	***-0.61***
Eielson AFB	5.44	***5.43***	***2.46***	2.49
Ft. Wainwright	***16.21***	16.22	***-15.30***	-15.33
Three Stations	8.37	***8.36***	-2.38	***-2.26***
Wind Speed (m s^{-1})				
Fairbanks	***0.97***	1.01	***0.54***	0.60
Eielson AFB	***1.18***	1.24	***0.72***	0.82
Ft. Wainwright	0.96	***0.91***	0.29	***0.27***
Three Stations	***1.07***	1.10	***0.57***	0.63
Wind Direction (degrees)				
Fairbanks	31.4	***21.0***	20.9	***9.5***
Eielson AFB	31.0	***19.3***	4.97	***3.1***
Ft. Wainwright	83.7	***48.9***	***5.9***	10.7
Three Stations	57.1	***34.5***	11.3	***9.2***

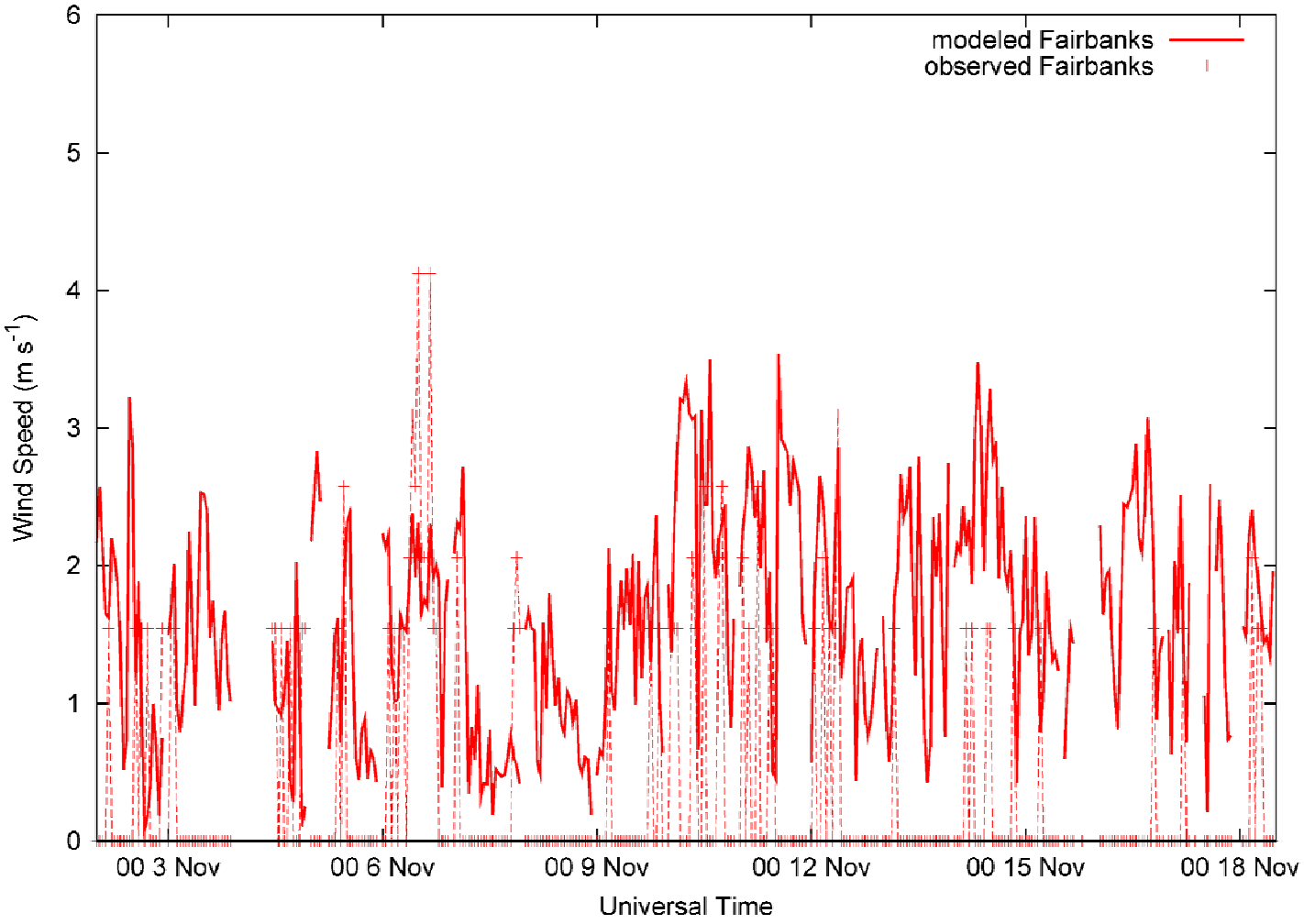

Temperature Error at 3Station for the Period
00 UTC, 2 Nov 2008 to 12 UTC, 18 Nov 2008
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
−5.0
−6.0
−7.0
−8.0
−9.0
2 Nov
3 Nov
4 Nov
5 Nov
6 Nov
7 Nov
8 Nov
9 Nov
10 Nov
11 Nov
12 Nov
13 Nov
14 Nov
15 Nov
16 Nov
17 Nov
18 Nov
Forecast Hour
RMSE (Avg. 2.43)
ME (Avg. −0.86)

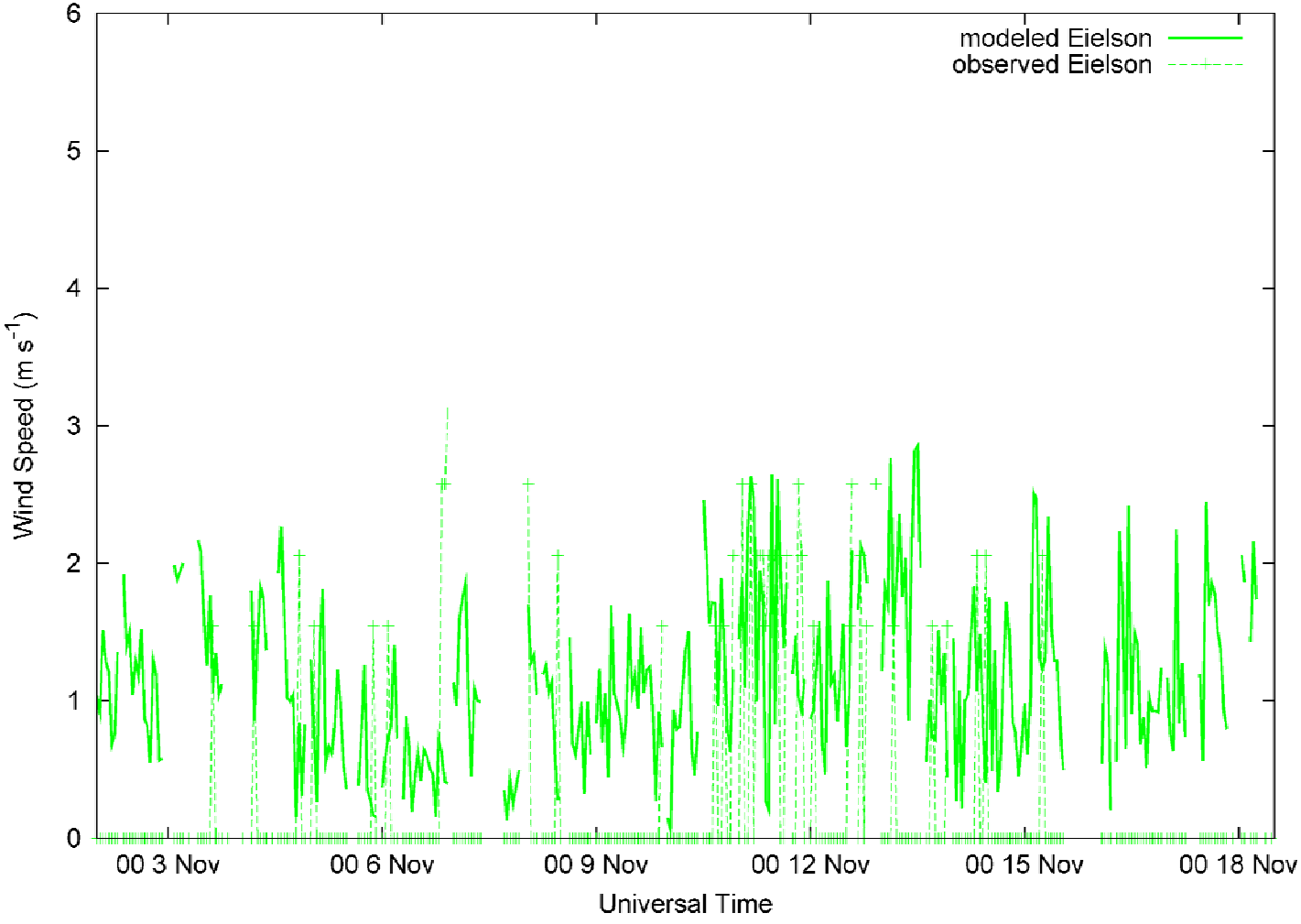

Wind Speed Error at 3Station for the Period
00 UTC, 2 Nov 2008 to 12 UTC, 18 Nov 2008
4.0
3.0
2.0
1.0
0.0
−1.0
2 Nov
3 Nov
4 Nov
5 Nov
6 Nov
7 Nov
8 Nov
9 Nov
10 Nov
11 Nov
12 Nov
13 Nov
14 Nov
15 Nov
16 Nov
17 Nov
18 Nov
Forecast Hour
RMSE (Avg. 1.41)
ME (Avg. 1.00)

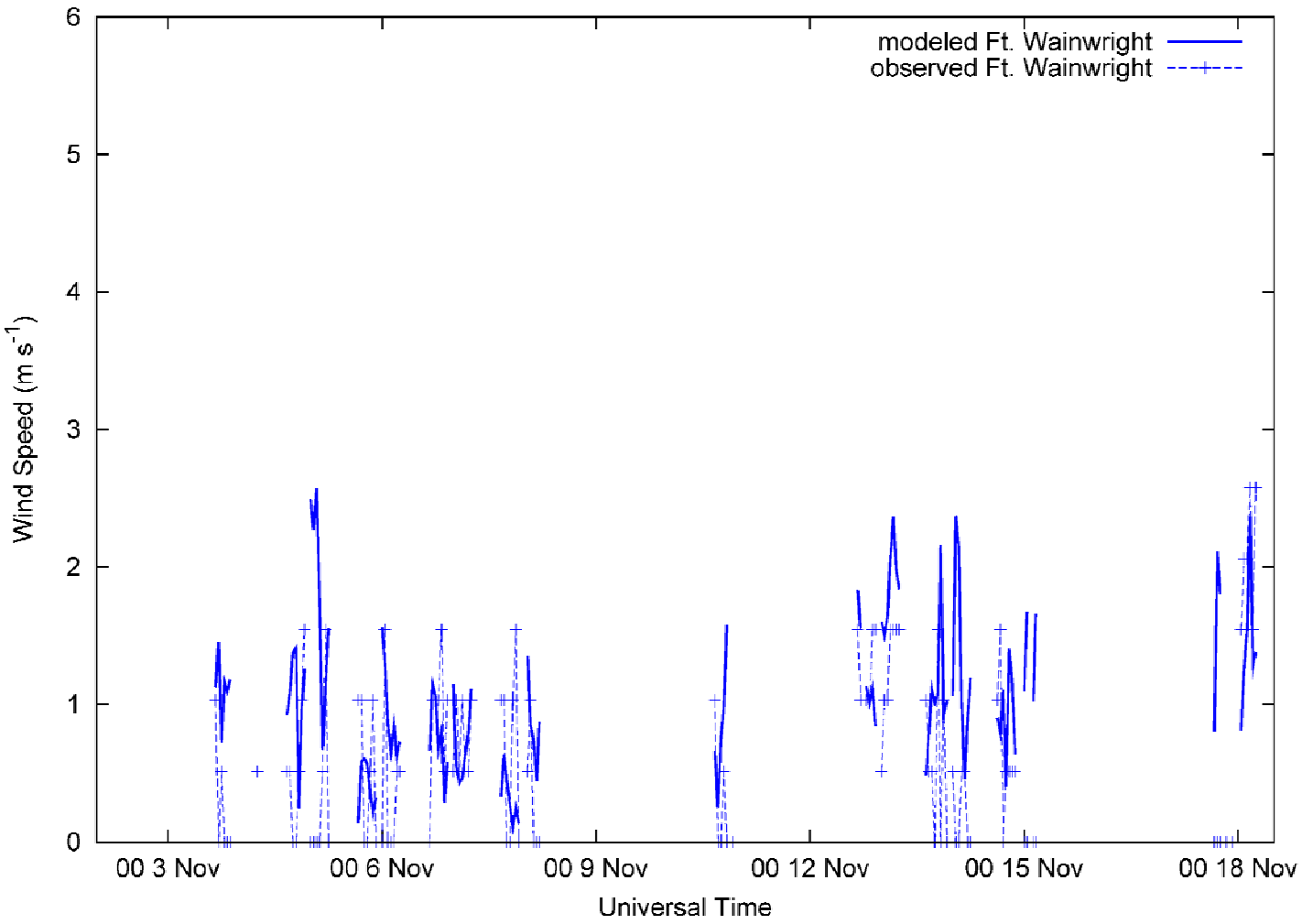

modeled Fairbanks
observed Fairbanks
Temperature (C)
0
-5
-10
-15
-20
-25
-30
00 3 Nov
00 6 Nov
00 9 Nov
00 12 Nov
00 15 Nov
00 18 Nov
Universal Time


modeled Eielson
observed Eielson
Temperature (C)
0
-5
-10
-15
-20
-25
-30
00 3 Nov
00 6 Nov
00 9 Nov
00 12 Nov
00 15 Nov
00 18 Nov
Universal Time


modeled Ft. Wainwright
observed Ft. Wainwright
Temperature (C)
0
-5
-10
-15
-20
-25
-30
00 3 Nov
00 6 Nov
00 9 Nov
00 12 Nov
00 15 Nov
00 18 Nov
Universal Time

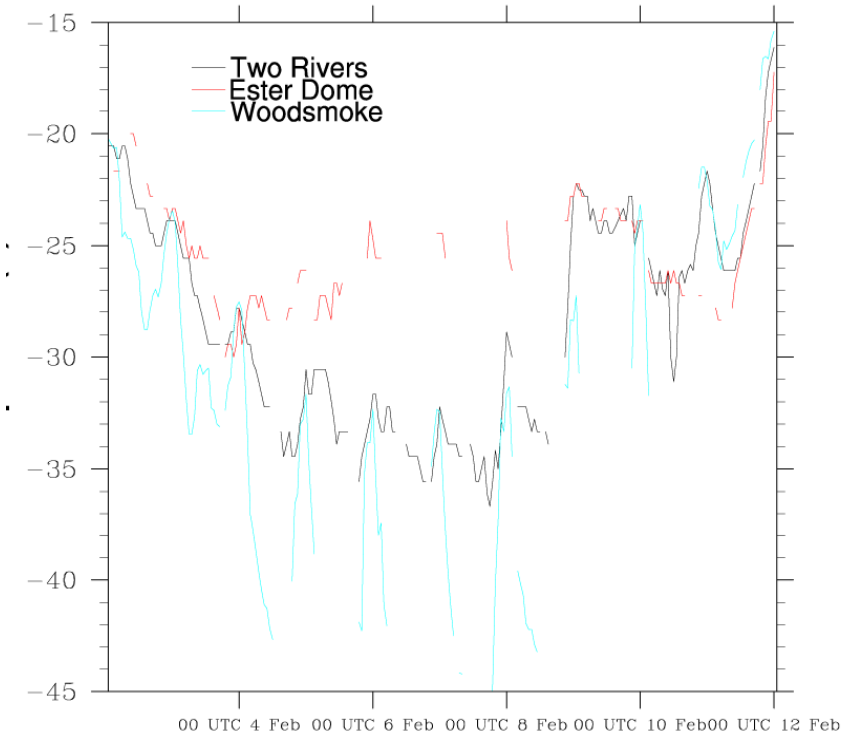

modeled Fairbanks
observed Fairbanks
Wind Speed (m s-1)
0
1
2
3
4
5
6
00 3 Nov
00 6 Nov
00 9 Nov
00 12 Nov
00 15 Nov
00 18 Nov
Universal Time


modeled Eielson
observed Eielson
Wind Speed (m s-1)
0
1
2
3
4
5
6
00 3 Nov
00 6 Nov
00 9 Nov
00 12 Nov
00 15 Nov
00 18 Nov
Universal Time

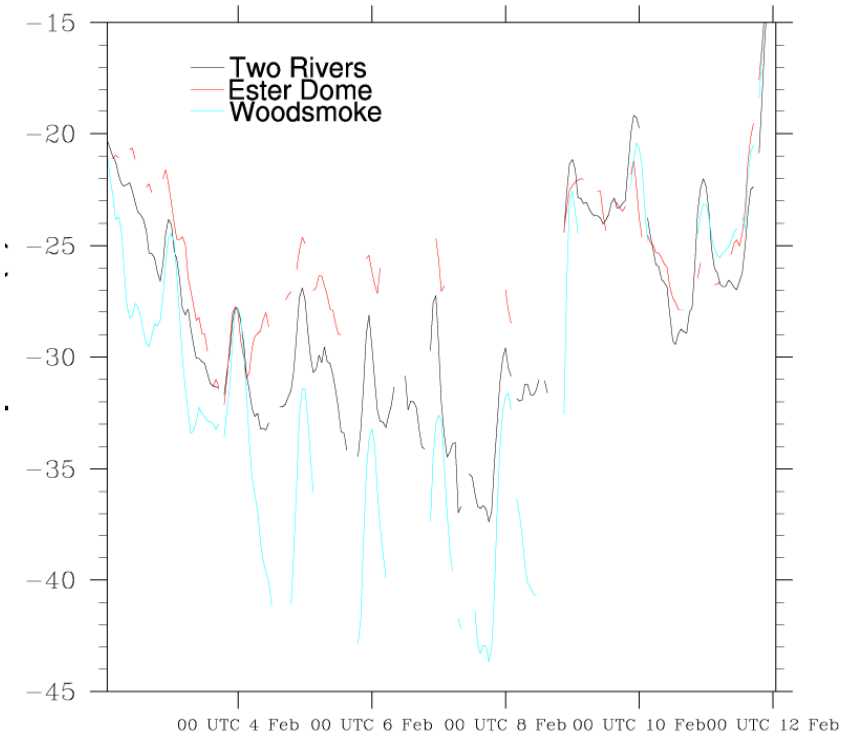

modeled Ft. Wainwright
observed Ft. Wainwright
Wind Speed (m s-1)
0
1
2
3
4
5
6
00 3 Nov
00 6 Nov
00 9 Nov
00 12 Nov
00 15 Nov
00 18 Nov
Universal Time

TWIND2X30 Applied to Jan – Feb 2008 RARE Case

Observed

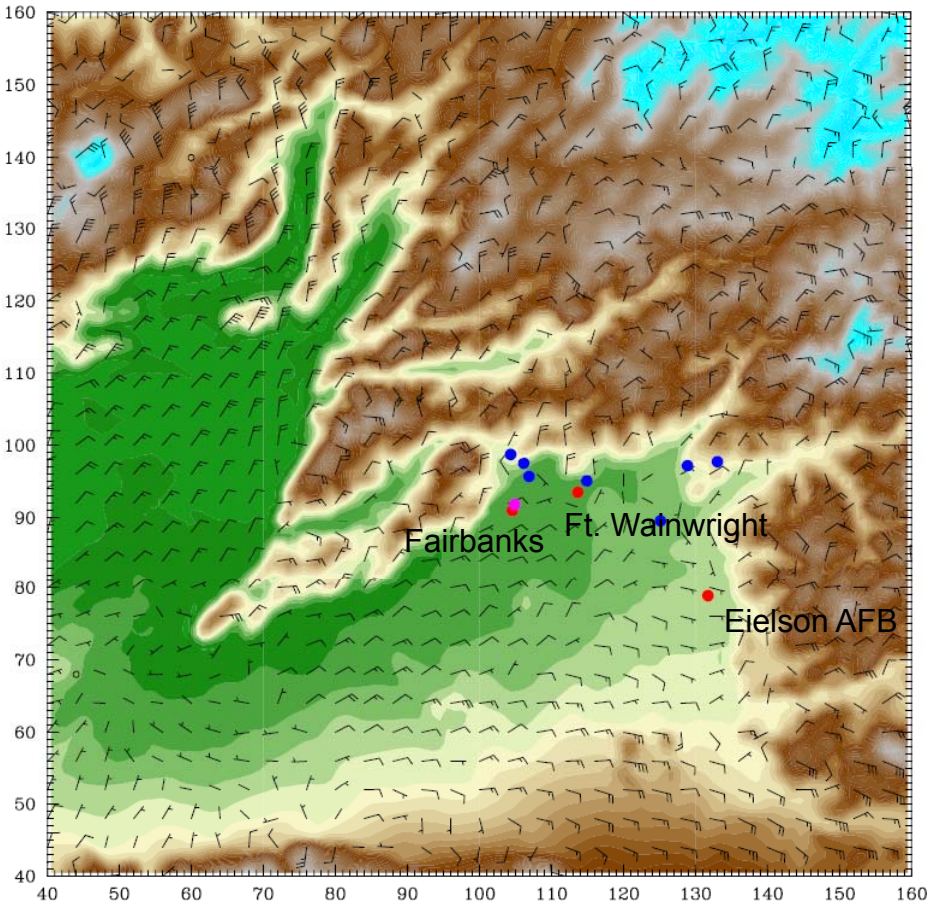


Model

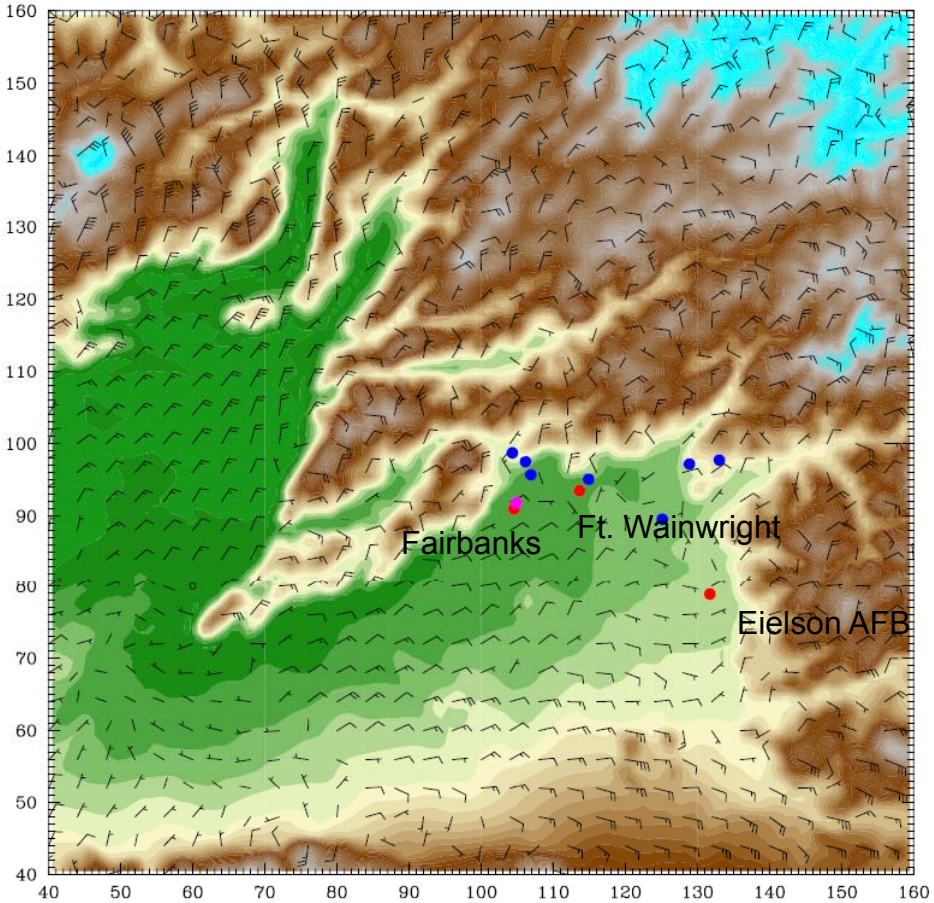


12 UTC 6 Nov 2008

OFDDA

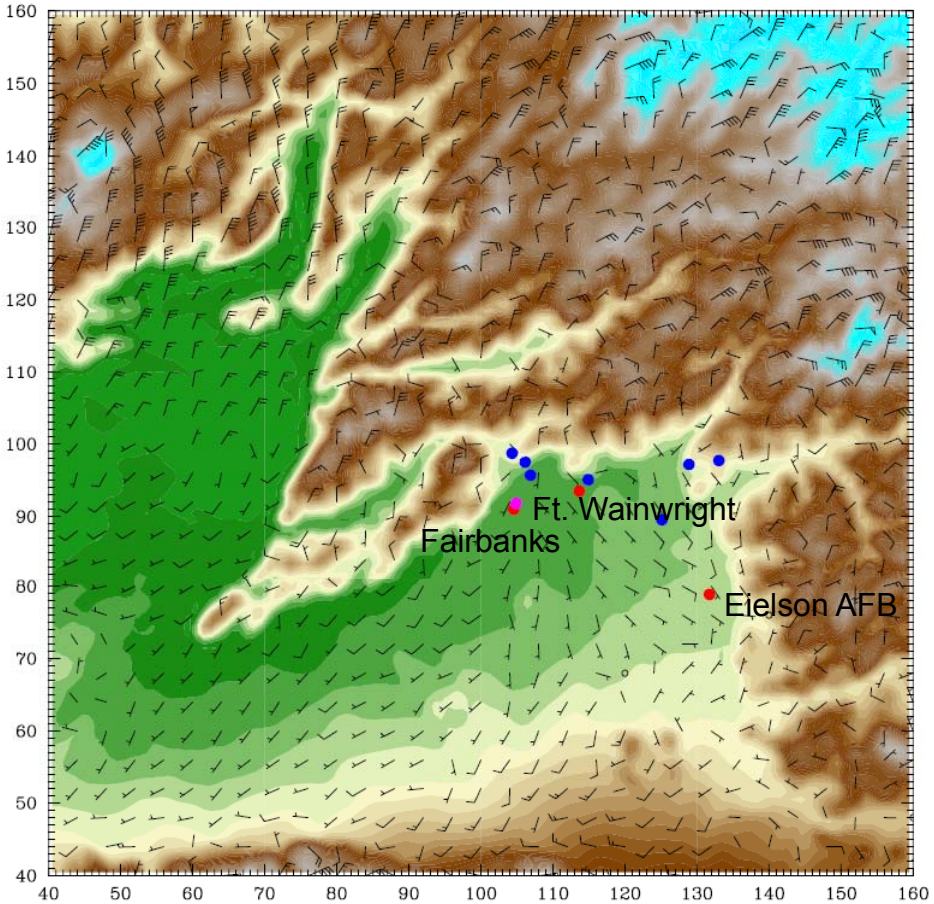


OFDDAWIND

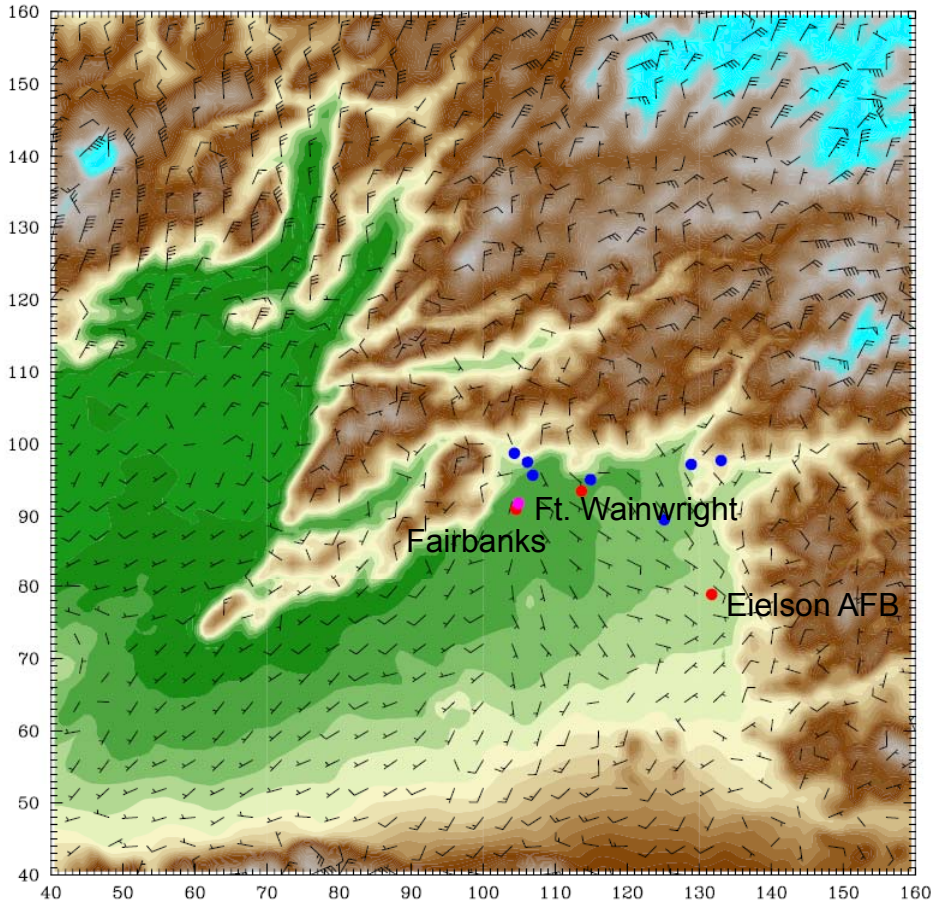


12 UTC 7 Nov 2008

OFDDA

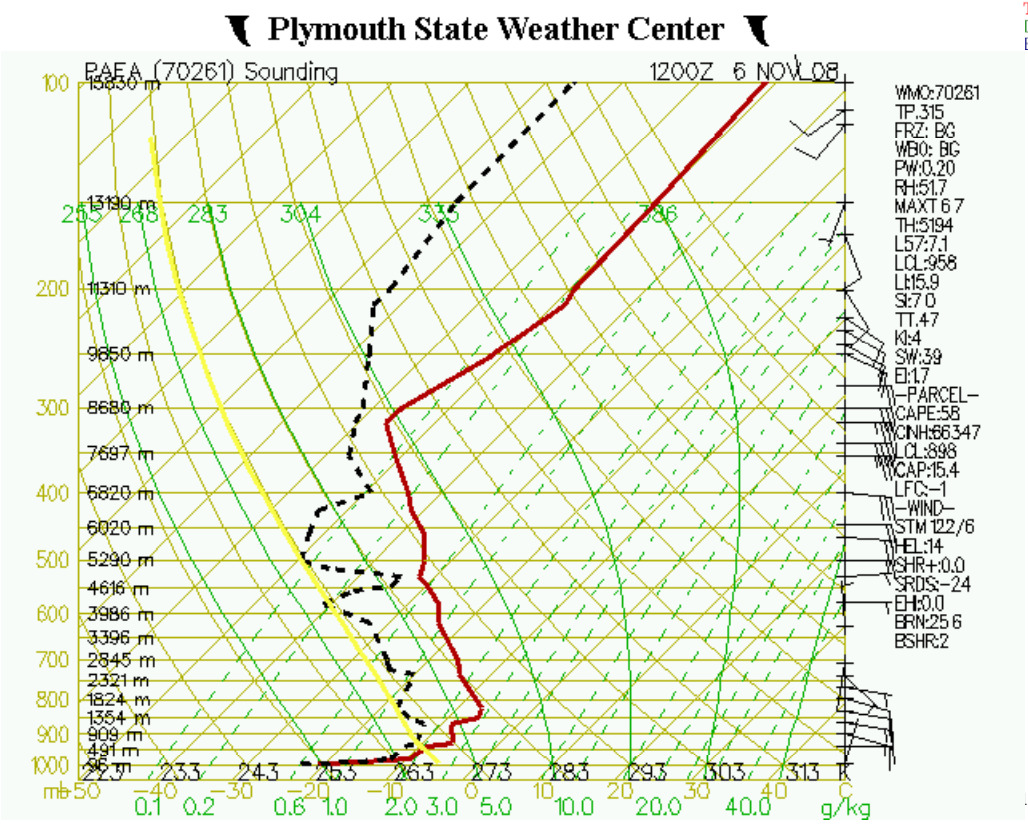


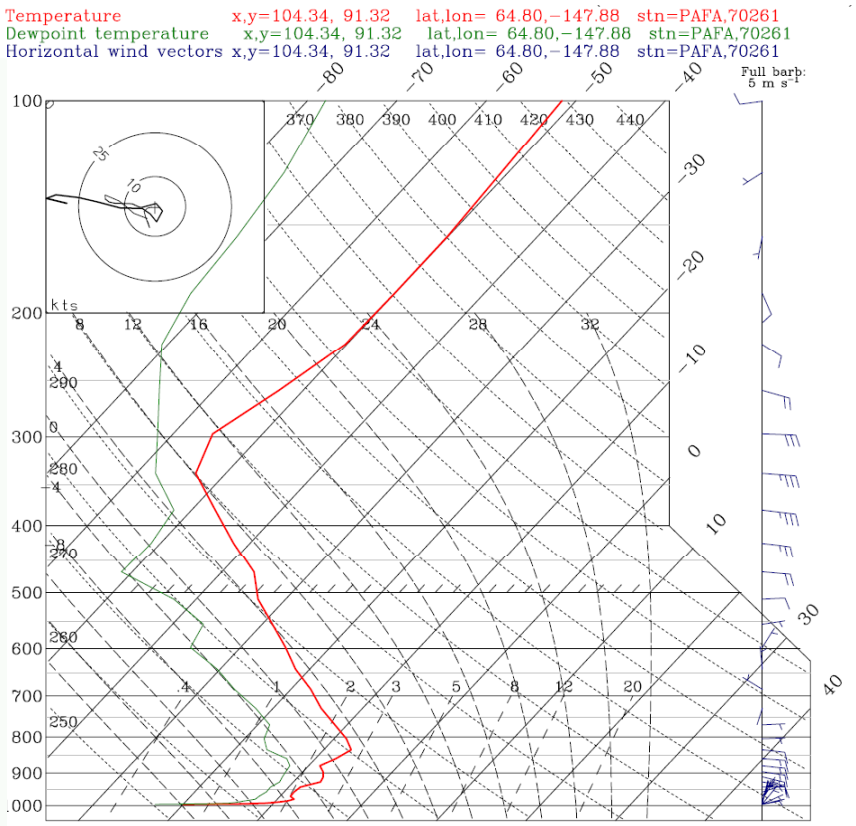
OFDDAWIND



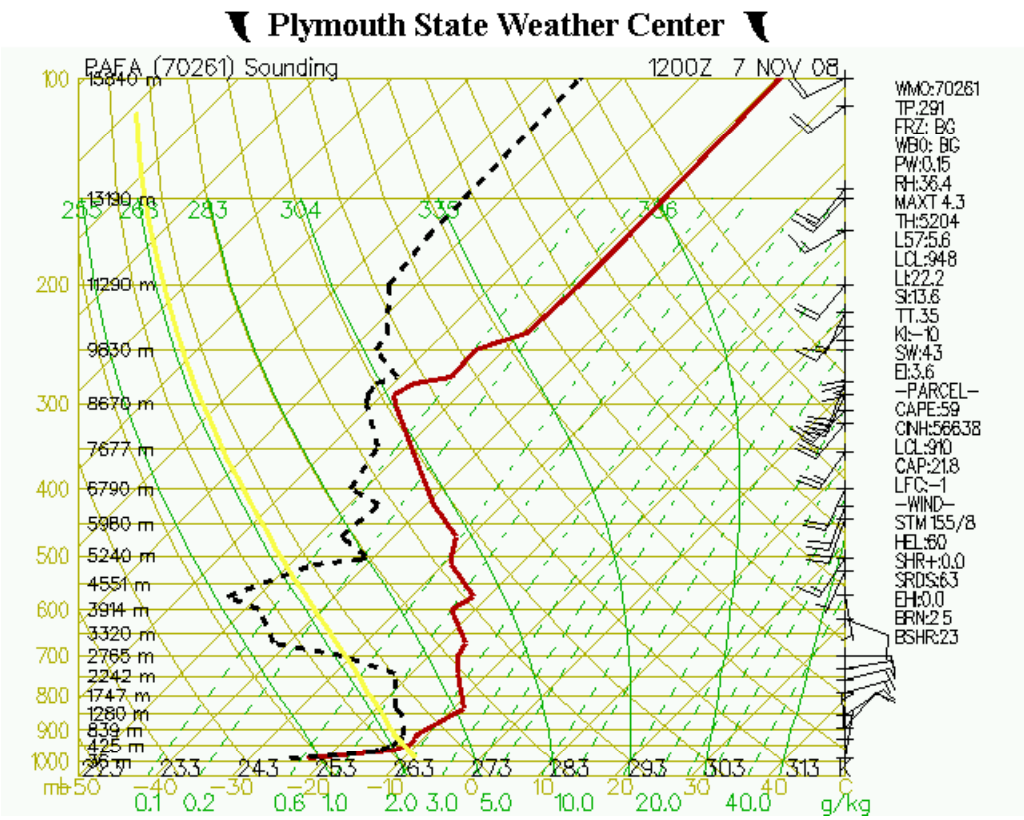
BARB VECTORS: FULL BARB = 2 m s^{-1}

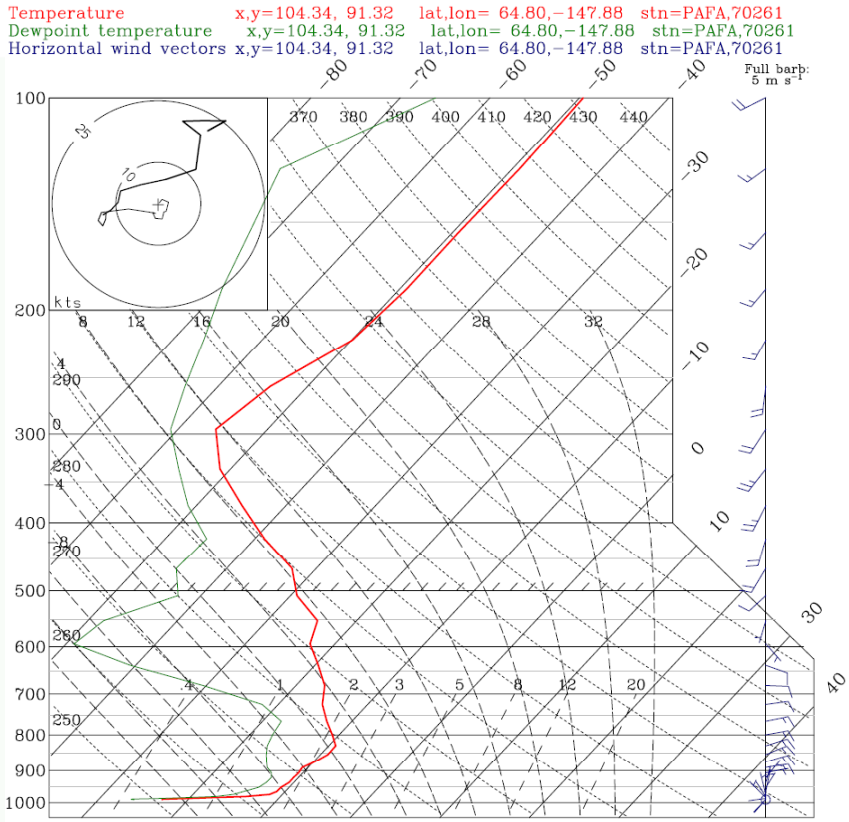
12 UTC 6 Nov 2008





12 UTC 7 Nov 2008





Major Findings

- The use of near-surface winds in data assimilation led to an improvement of 20° in wind direction MAE, and modest improvements in other variables.

- Doubling (u,v) nudging weights and reducing the radius of influence from 75 km to 30 km led to a further improvement of 19° in wind direction MAE, and slightly better temperature statistics. This configuration was used to simulate the whole 2-17 Nov. 2008 episode.

Major Findings (cont.)

- Including calm wind reports in data assimilation for the entire 2-17 Nov. 2008 episode reduced the positive model wind speed bias by about 0.1 m s^{-1} , but made wind direction MAE 14° worse.

- Qualitatively, the meteorological analysis produce realistic topographical flows, and was capable of reproducing -40° temperatures in locations such as Woodsmoke. However, the model tended to have a positive near-surface temperature bias during cold episodes at poorly-resolved valley locations (e.g., Goldstream Creek).

Major Findings (cont.)

- The subperiods of largest temperature RMSE error at the METAR stations were generally characterized by a negative temperature bias, and were characterized meteorologically by extensive cloudiness and frequent reports of snow. The cold episodes adjacent to these events had positive temperature biases, but usually these were 2° C or less. Overall temperature bias was less than a degree Celsius.

- The overall METAR wind speed bias for the 2-17 Nov 2008 episode was approximately 1.0 m s^{-1} ; the overall wind direction MAE was approximately 40°.