EPA "RARE" Project:
Testing CMAQ air quality model for wintertime Fairbanks episodes

Source: Javier Fochesatto

Fairbanks "RARE" Project

- **RARE = Regional Applied Research Effort**
  - Internal EPA program to match ORD scientists to Regional needs
  - Collaboration between EPA-R10, EPA-ORD, ADEC, and Fairbanks North Star Borough

- **Model meteorological inversions and PM$_{2.5}$**
  - Develop emission inventory ← Sierra Research
  - Test WRF options ← Penn State
  - Test aerosol chemistry ← EPA-R10 and EPA-ORD

- **Rely on field measurements by FNSB and ADEC**

Emissions Inventory (Sierra)

- **Update and refine point, area, and mobile sources**

- **Residential home heating**

- **Mobile emissions**

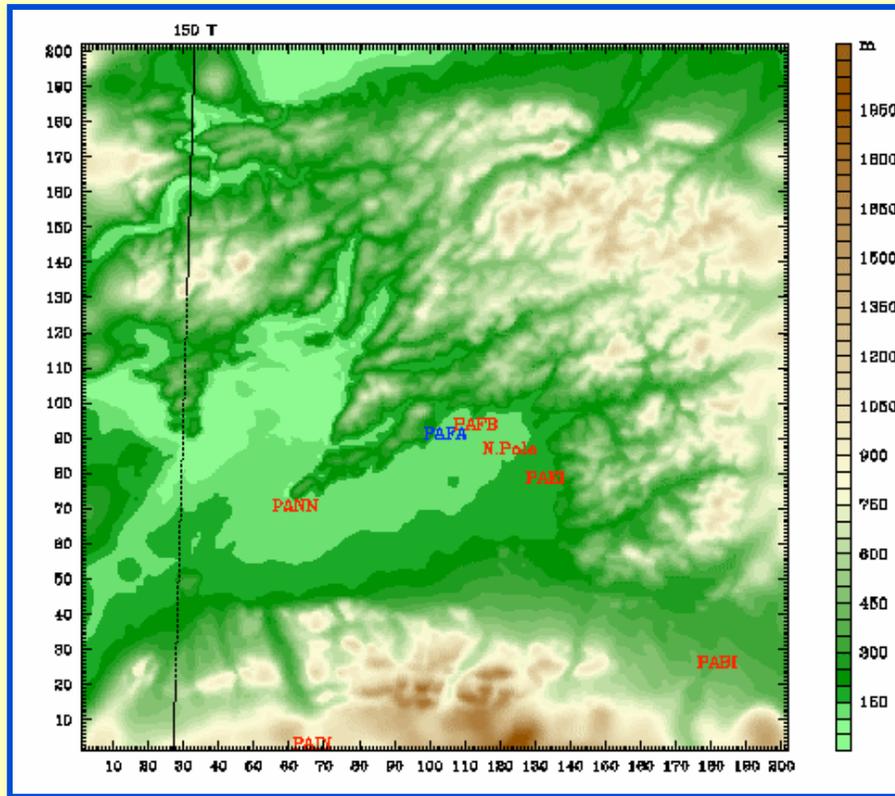- **Results to come after SMOKE processing**
  - **Next few months**

Table III.C.3-1
Base Fairbanks CO Emissions Inventory: Nonattainment Area Totals by Year

Table III.C.3-1
...s Inventory: Nonattainment Area Totals by Year (cont.)

	CO (tpd)													
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad Sources														
Aircraft, excluding Ground Support Equipment								1.470					1.565	1.584
Airport Ground Support Equipment	1.912	1.927	1.886	1.95?	1.978	1.999	2.020	2.042					2.154	2.177
Aerial Lifts	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001
Air Compressors	0.013	0.013	0.014	0.014	0.015	0.015	0.016	0.016	0.016	0.017	0.017	0.018	0.018	0.019
Forklifts	0.034	0.034	0.035	0.035	0.036	0.036	0.036	0.037	0.037	0.038	0.038	0.038	0.039	0.039
Gas Compressors	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.007
Other General Industrial Equipment	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.001	0.001
Other Material Handling Equipment	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Railroad Operations (Locomotives)	0.044	0.044	0.044	0.045	0.045	0.045	0.046	0.046	0.046	0.046	0.047	0.047	0.047	0.048
Railway Maintenance*											0.004	0.004	0.004	0.004
Snowmobiles	0.276	0.278	0.280	0.282	0.284	0.286	0.288	0.290	0.293	0.295	0.297	0.299	0.301	0.303
Sweepers/Scrubbers	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Terminal Tractors	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL	3.66	3.69	3.59	3.75	3.79	3.83	3.87	3.92	3.96	4.00	4.05	4.09	4.14	4.18
Area Sources														
Residential Wood Burning	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77
Fuel Oil	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Propane							0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Coal	0.003	0.003	0.003	0.003	0.003		0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Natural Gas	0.02	0.05	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Structural Fires	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
TOTAL	1.03	1.05	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Point Sources														
MAPCO (Williams)					0.44	0.44	0.45	0.45	0.45	0.46	0.46	0.46	0.47	0.47
Eielson														
Fort Wainwright	1.73	1.75	1.76	1.77	1.78	1.80	1.81	1.82	1.83	1.84	1.86	1.87	1.88	1.90
GVEA/North Pole	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
GVEA/Fairbanks (Illinois St.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
University of Alaska - Fairbanks	0.53	0.53	0.53					0.55	0.56	0.56	0.56	0.57	0.57	0.58
Petro - Star											0.01	0.01	0.01	0.01
Fairbanks MUS (Aurora)	1.64	1.65	1.67	1.68	1.69	1.70	1.71	1.72	1.74	1.75	1.76	1.77	1.78	1.80
Alyeska Pump Station 8														
TOTAL				4.46	4.49	4.52	4.55	4.58	4.61	4.64	4.67	4.71	4.74	4.77
Mobile Sources														
Initial Idle Emissions	8.17	7.46	7.10	6.97	6.17	5.61	5.40	5.15	4.93	4.70	4.59	4.52	4.46	4.38
Traveling Emissions	21.00	20.37	19.66	19.27	16.48	15.17	14.28	13.51	12.98	12.41	12.06	11.80	11.61	11.39
TOTAL	29.17	27.83	26.77	26.24	22.65	20.77	19.68	18.66	17.91	17.11	16.65	16.32	16.07	15.77
GRAND TOTAL	38.21	36.96	35.87	35.54	32.02	30.22	29.19	28.25	27.57	26.85	26.47	26.22	26.05	25.82

WRF Domains (Penn State)

12 km

WRF Domains

WRF 1.3 km Domain

WRF Vertical Levels

67 m

46 m

23 m

12.5 m

10 m → 8 m

6 m → 4 m

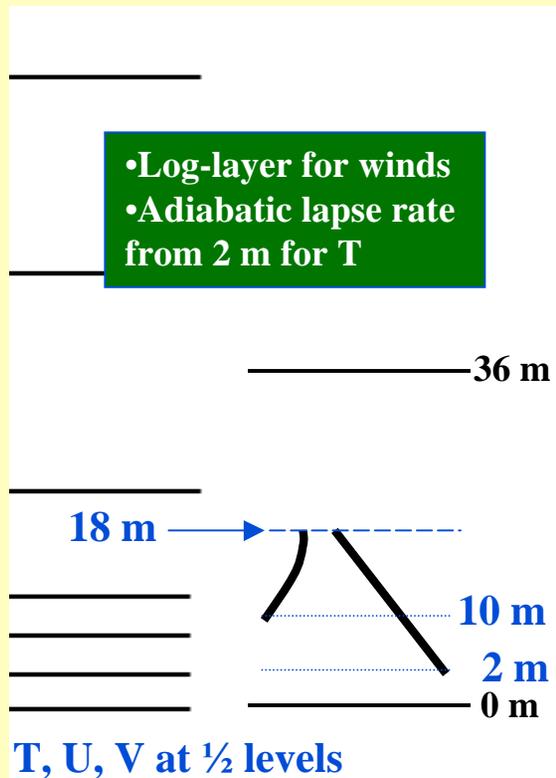2 m →

T, U, V at ½ levels

- **Lowest ½-level for temperature, humidity and winds at 2 meters**
- **Third ½-level at 10 meters**

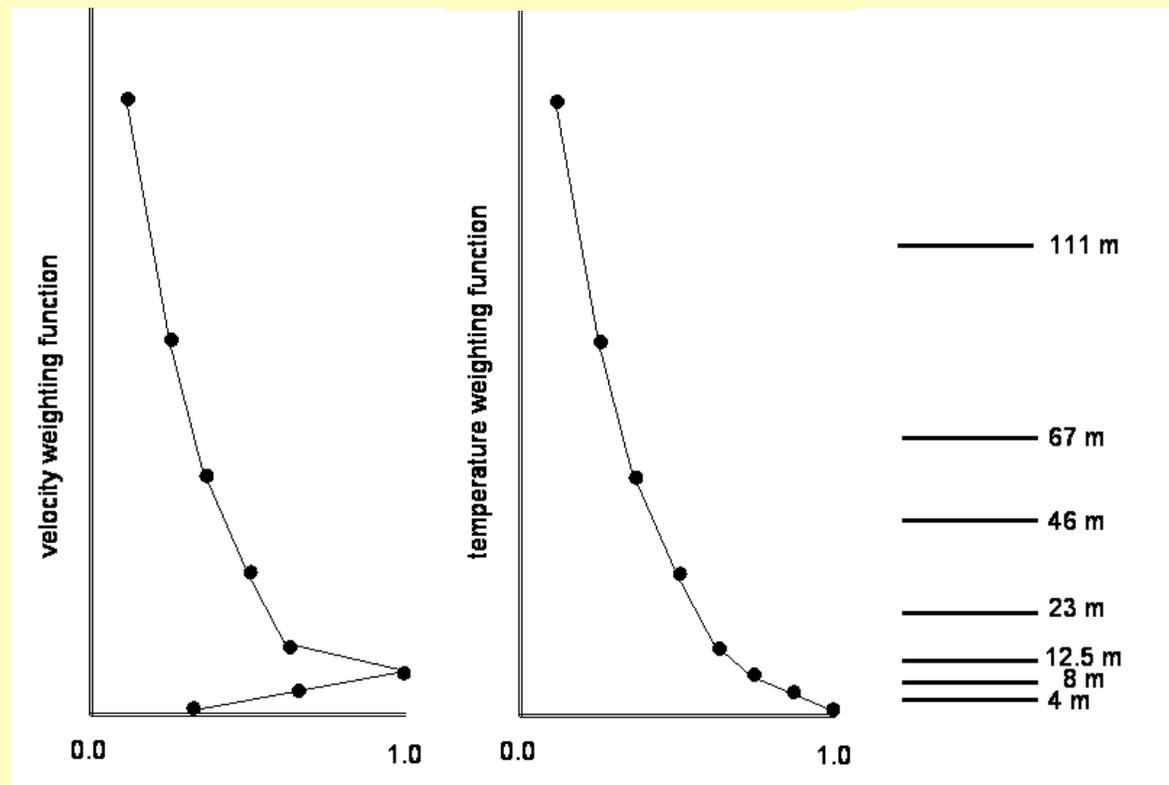# High Vertical Resolution Presents Challenges to Modeling

- **WRF**
  - **Nudging**
  - **Comparison to observations**

- **Pollutant emissions into CMAQ**

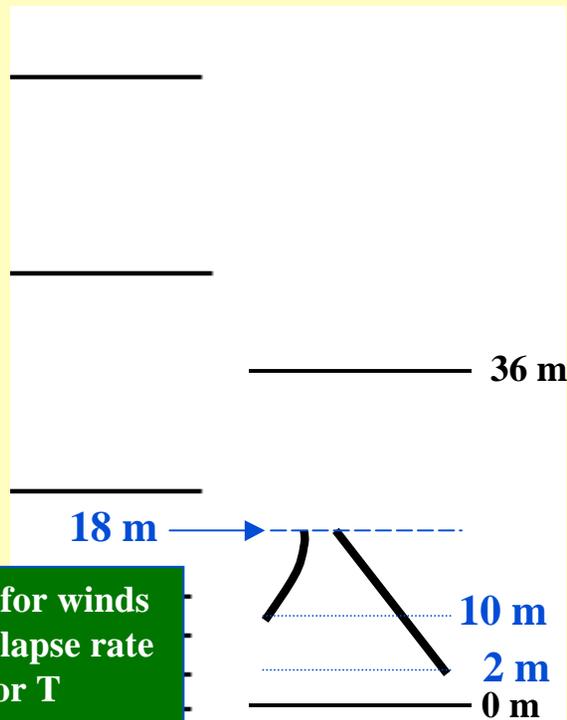# High Vertical Resolution and Nudging

Normal Scenario

- Log-layer for winds
- Adiabatic lapse rate from 2 m for T

36 m

18 m

10 m

2 m

0 m

T, U, V at ½ levels

High Vertical Resolution

velocity weighting function

temperature weighting function

111 m

67 m

46 m

23 m

12.5 m
8 m
4 m

0.0   1.0   0.0   1.0

- Normally use neutral log layer to extrapolate from 10 and 2 meters
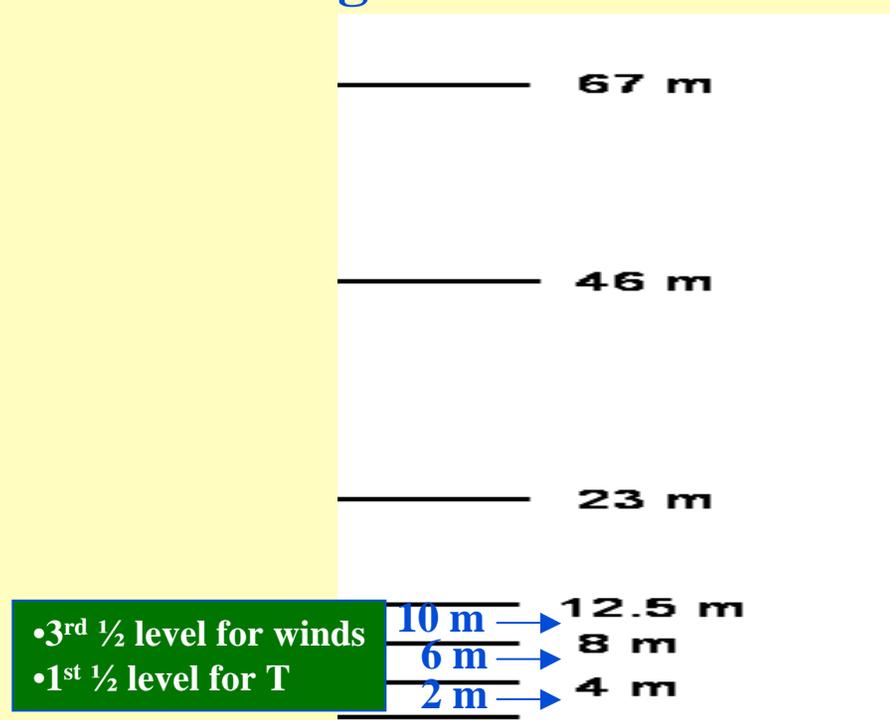- Need to change nudging and verification to use explicit WRF levels

High Vertical Resolution and Comparison to Observations

Normal Scenario

18 m

•Log-layer for winds
•Adiabatic lapse rate from 2 m for T

36 m

10 m

2 m

0 m

T, U, V at ½ levels

High Vertical Resolution

67 m

46 m

23 m

•3rd ½ level for winds
•1st ½ level for T

10 m

6 m

2 m

12.5 m

8 m

4 m

T, U, V at ½ levels

- Normally use neutral log layer to extrapolate from 10 and 2 meters
- Need to change nudging and verification to use explicit WRF levels

High Vertical Resolution and Pollutant Emissions

Normal Scenario

36 m

Chimney   Tailpipe

0 m

High Vertical Resolution

67 m

46 m

23 m

Chimney   Tailpipe

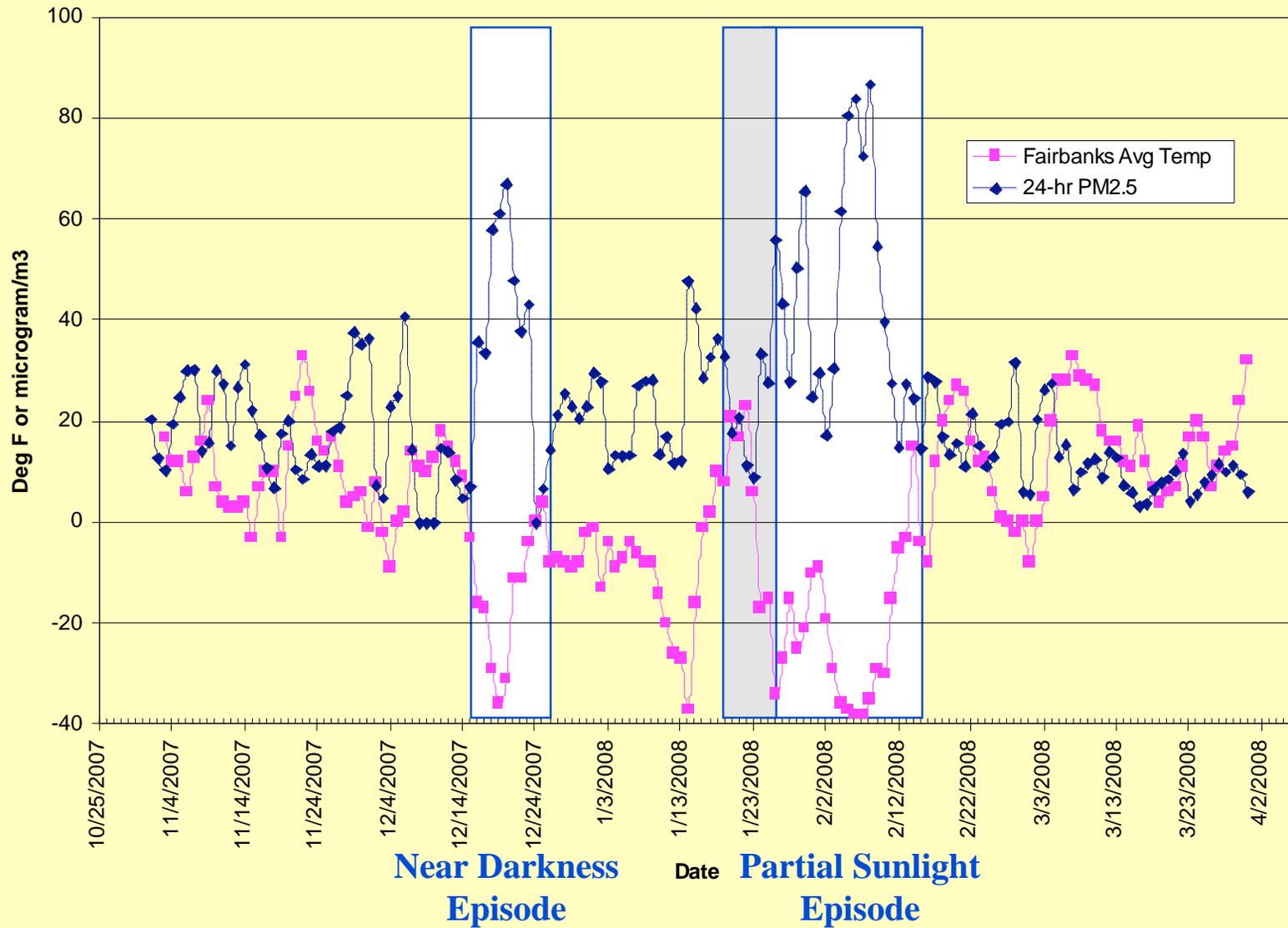10 m →
6 m →
2 m →

T, U, V at ½ levels
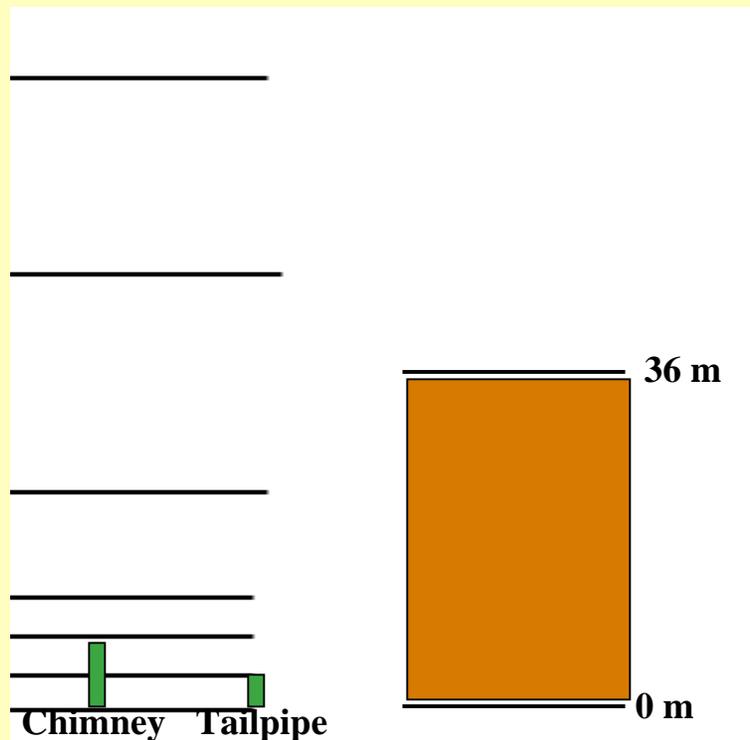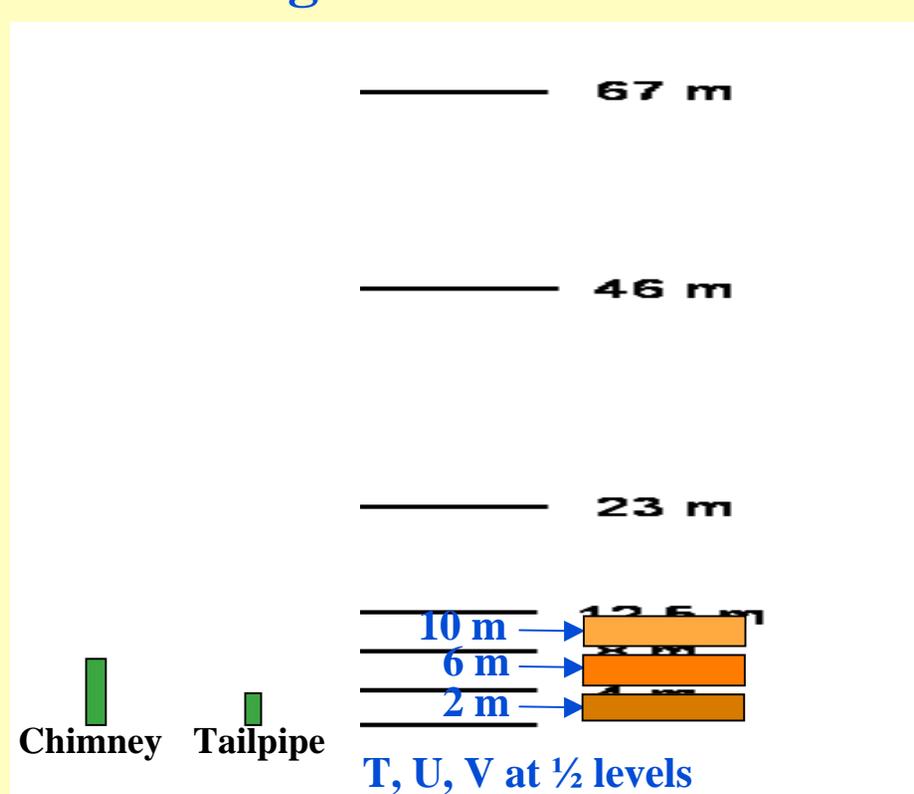
- **Emissions are now in the 2nd or 3rd layer of CMAQ**
- **Roadway turbulence must be parameterized**

High Vertical Resolution Presents Challenges to Modeling

- **WRF**
  - **Nudging** ⟵ **Penn State**
  - **Comparison to observations** ⟵ **Penn State**

- **Pollutant emissions into CMAQ** ⟵ **EPA-ORD**

Time Periods

Daily Average Temp and Daily PM2.5 in Fairbanks

WRF Configurations

Experiment Name	Planetary Boundary Layer (PBL)	Land Surface Model (LSM)	Radiation
MND (Baseline)	Mellor -Yamada -Janji _ (MYJ)	Noah	Dudhia Shortwave / RRTM Longwave
MNR	Mellor -Yamada -Janji _ (MYJ)	Noah	RRTMG Shortwave / RRTMG Longwave
QNR	Quasi -Normal Scale Elimination (QNSE)	Noah	RRTMG Shortwave / RRTMG Longwave
MRR	Mellor -Yamada -Janji _ (MYJ)	Rapid Update Cycle (RUC)	RRTMG Shortwave / RRTMG Longwave

New Baseline

PBL Schemes

- **Mellor-Yamada-Janjić**
  - Janjić, 2002, NCEP Office Note
  - Turbulent Kinetic Energy (TKE) 2.5 order closure
  - Penn State decreased the minimum TKE by order of magnitude ($0.1 \Rightarrow 0.01$ m^{2}s^{-2})

- **Quasi-Normal Scale Elimination**
  - Sukoriansky and Galperin, 2008, Phys. Scr., vol T132
  - Turbulence becomes anisotropic as stability increases
 - No critical Ri (can get more realistic transition to stable)
  - Includes gravity waves

Land Surface Models

- **Noah**
  - Typical LSM in WRF studies
  - 4 soil levels
  - Dynamic land surface based on simulation rain/snow

- **Rapid-Update Cycle (RUC)**
  - Similar idea as Noah
  - Allows for multiple snow layers
  - Therefore better characterization of unique snow radiation characteristics
  - More LW cooling and thus stronger inversion
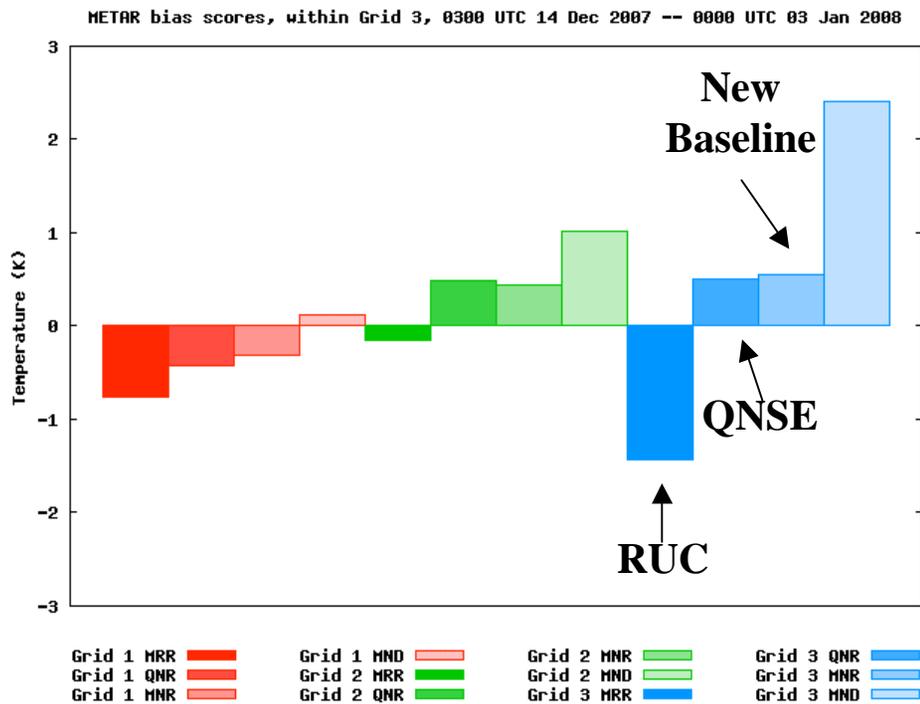
Wind Speed Bias

Near Darkness Episode
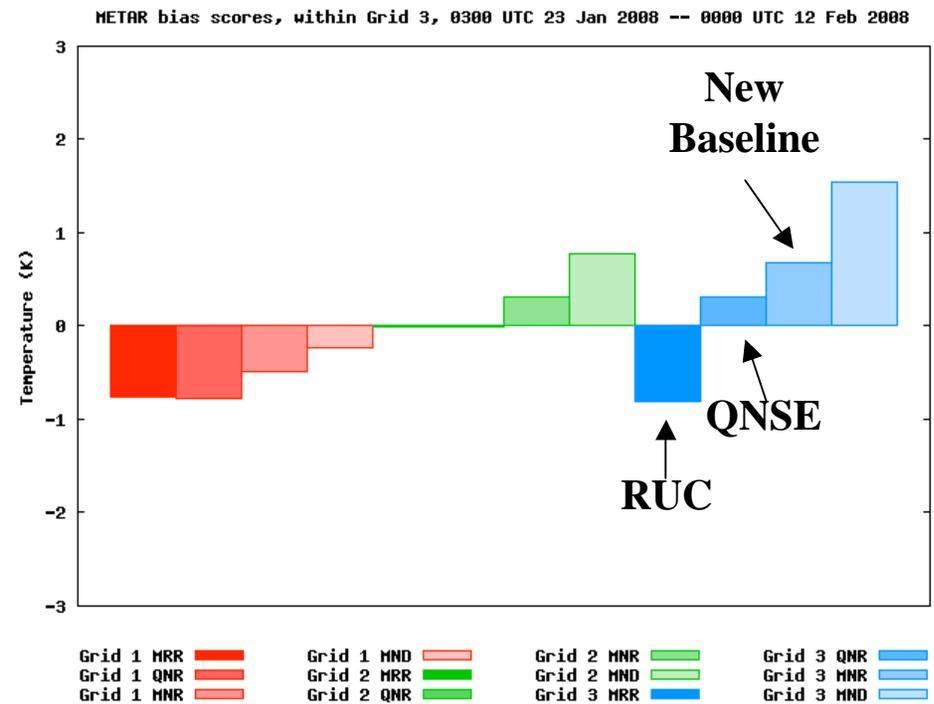
Partial Sunlight Episode
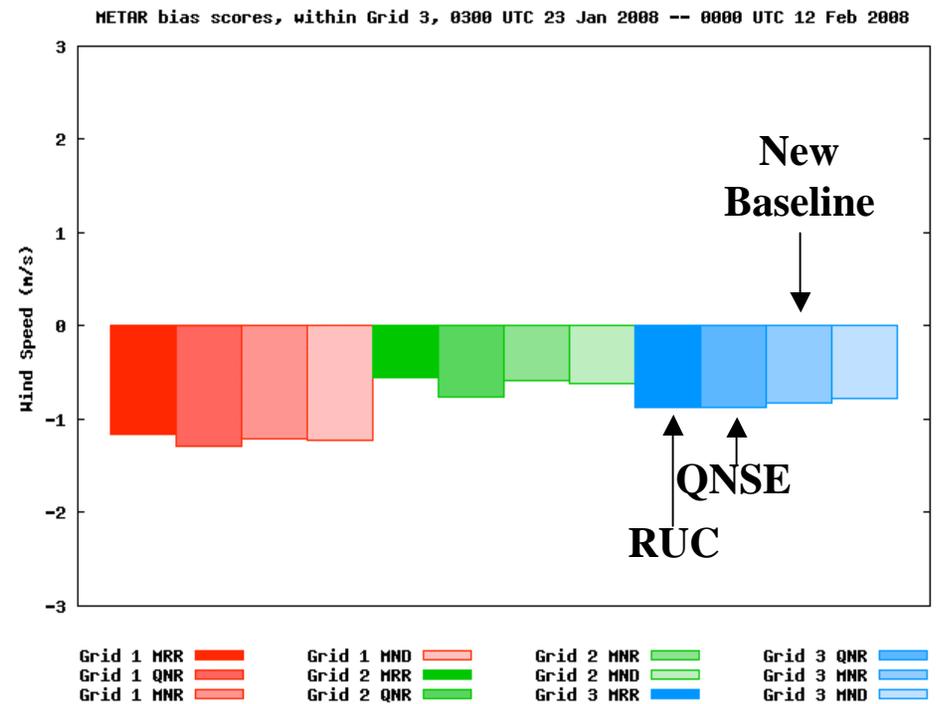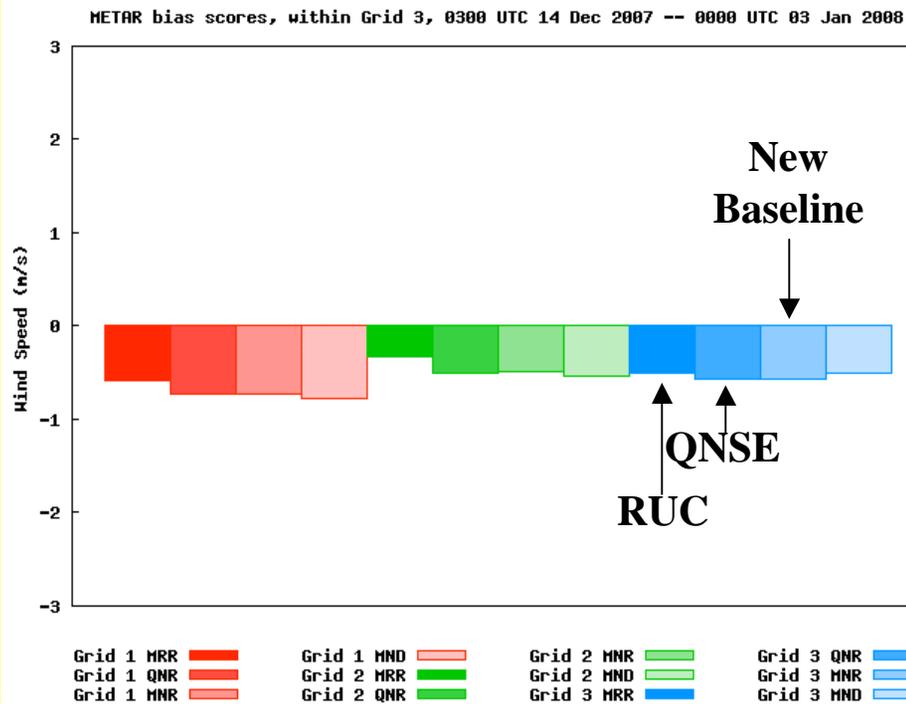
- **No major difference between all simulations at a given resolution**

Temperature Bias
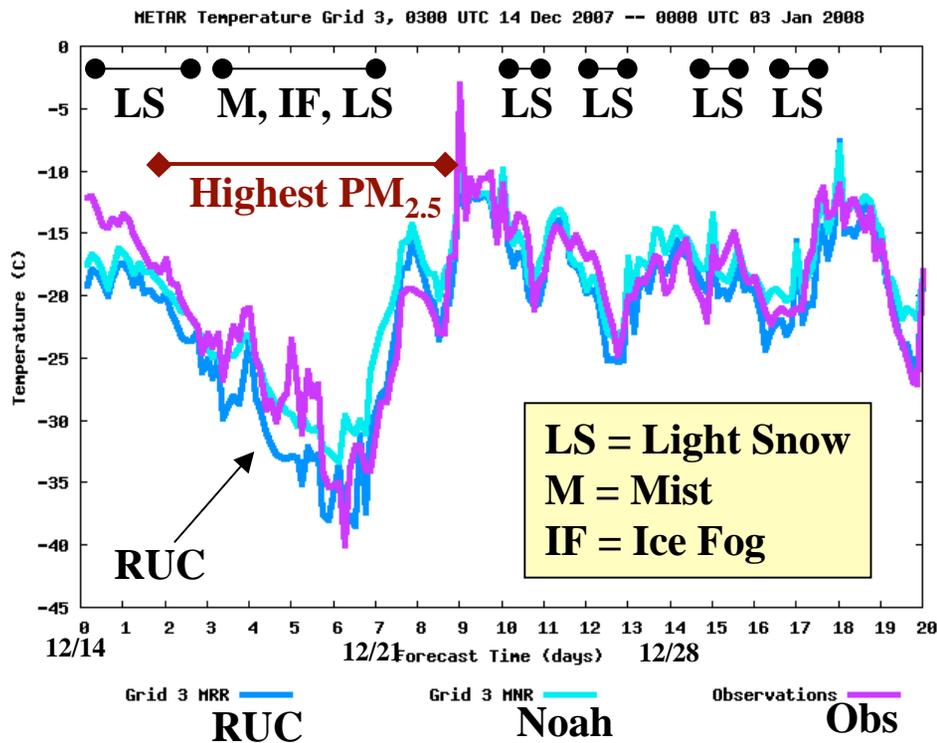

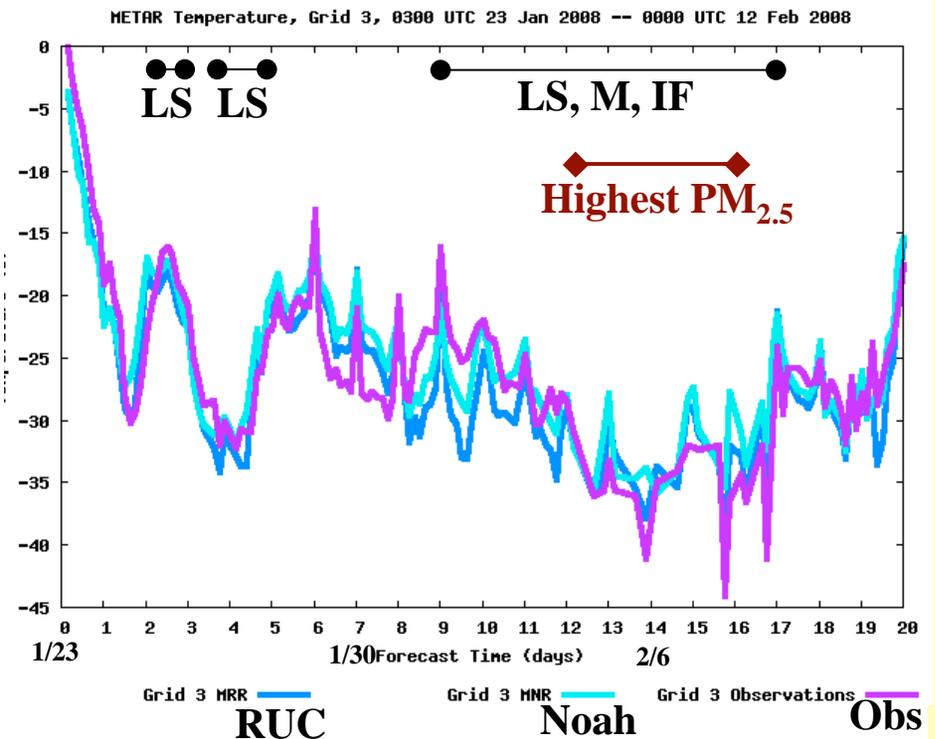
Near Darkness Episode

Partial Sunlight Episode

- **QNSE slightly less warm-biased than MYJ***
- **RUC has cold bias**
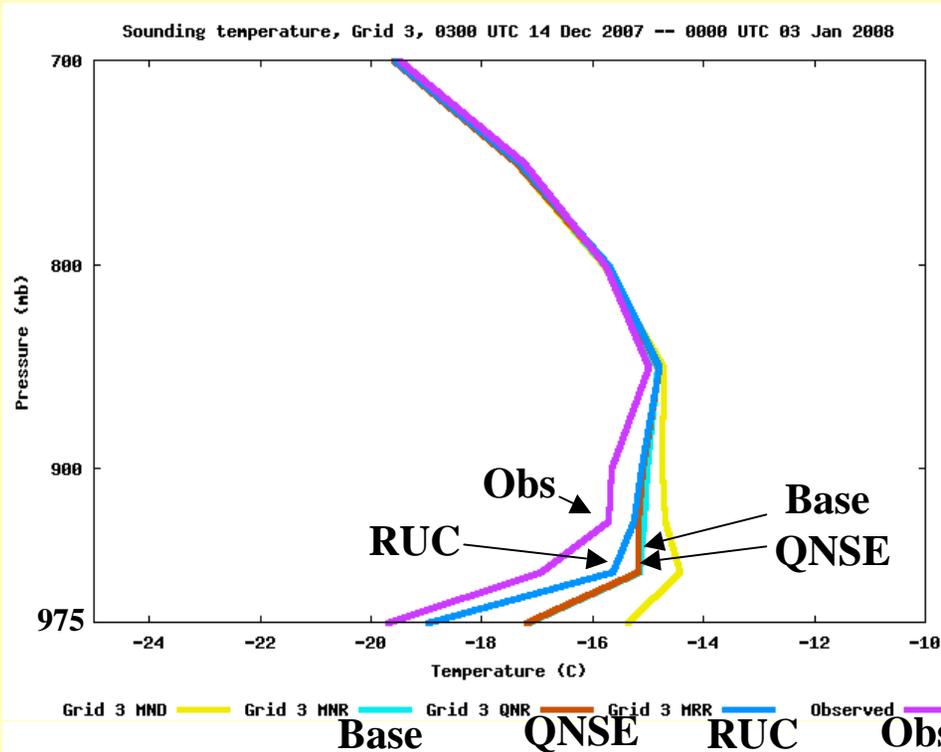
Temperature Bias

Near Darkness Episode

Partial Sunlight Episode

METAR Temperature Grid 3, 0300 UTC 14 Dec 2007 -- 0000 UTC 03 Jan 2008

- LS
- M, IF, LS
- LS LS LS LS

Highest PM$_{2.5}$

RUC

LS = Light Snow
M = Mist
IF = Ice Fog

RUC   Noah   Obs

METAR Temperature, Grid 3, 0300 UTC 23 Jan 2008 -- 0000 UTC 12 Feb 2008

- LS LS
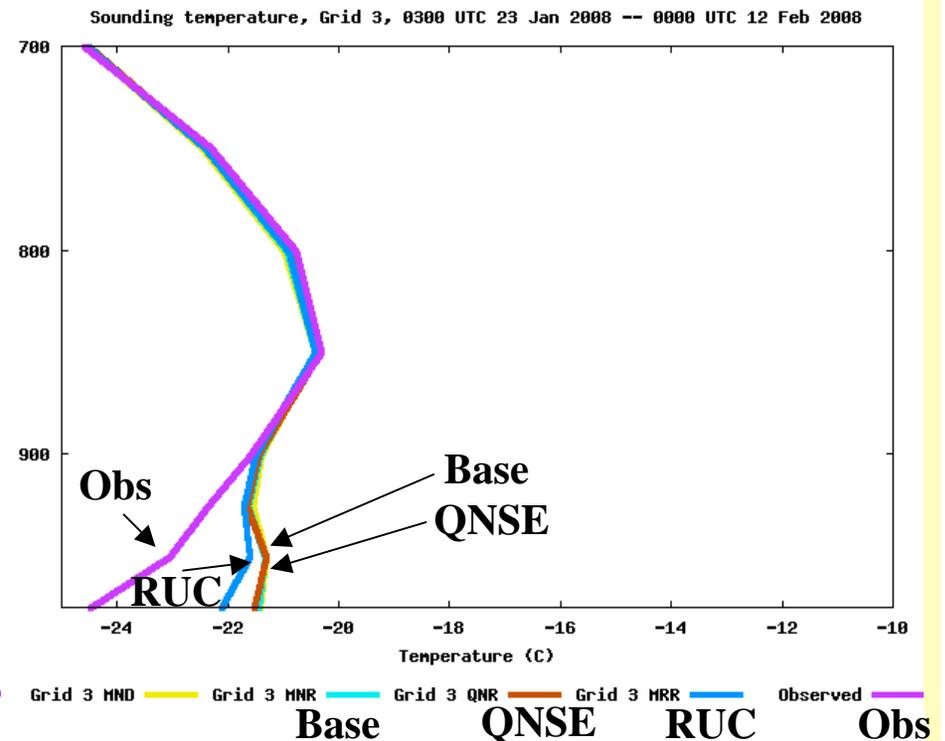- LS, M, IF

Highest PM$_{2.5}$

RUC   Noah   Obs

- **RUC's cold bias occurs during cooling periods with light snow and ice fog**
- **During coldest periods, RUC performs the best because it has the least positive bias**
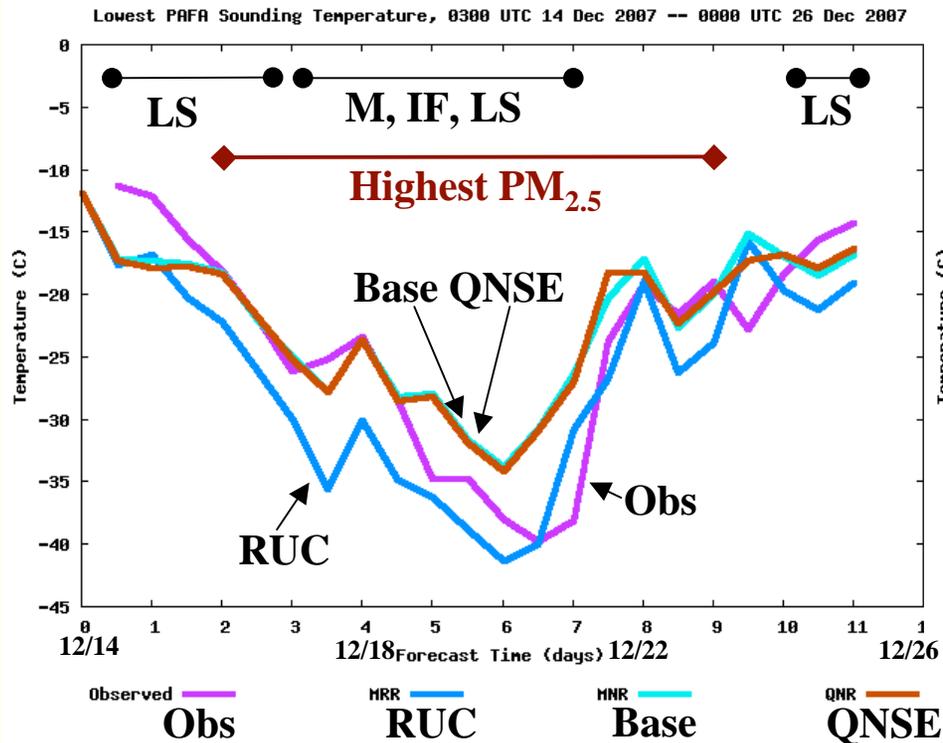
Vertical Temperature Sounding

Near Darkness Episode
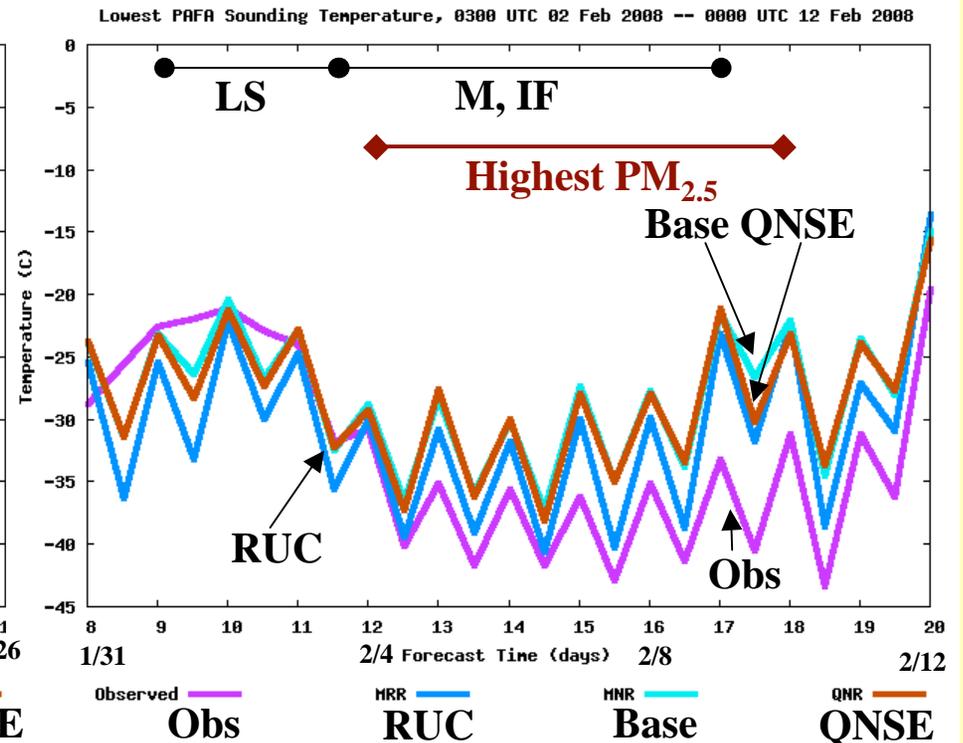
Partial Sunlight Episode

- **RUC is closest to observed Fairbanks airport sounding**
- **RUC is still warm in lowest layers, as an average**
- **QNSE is not much different than MYJ***

975 mb Sounding Temperature

Near Darkness Episode

Partial Sunlight Episode

- *Near Darkness*:
  - RUC develops cold bias during light snow (microphysics?)
  - RUC is best during coldest period
- *Partial Sunlight*:
  - Base and QNSE have best diurnal range but 7 °C warm
  - RUC too cold when snowy (microphysics?)
  - RUC is best at night but too much diurnal range (radiation)

Nudging on 1 km Domain:
Sounding Temperature RMSE

Fairbanks temperature RMSE, 0300 UTC 14 Dec 2007 -- 0000 UTC 20 Dec 2007

Near Darkness Episode

Nudged 1 km

RUC

Base
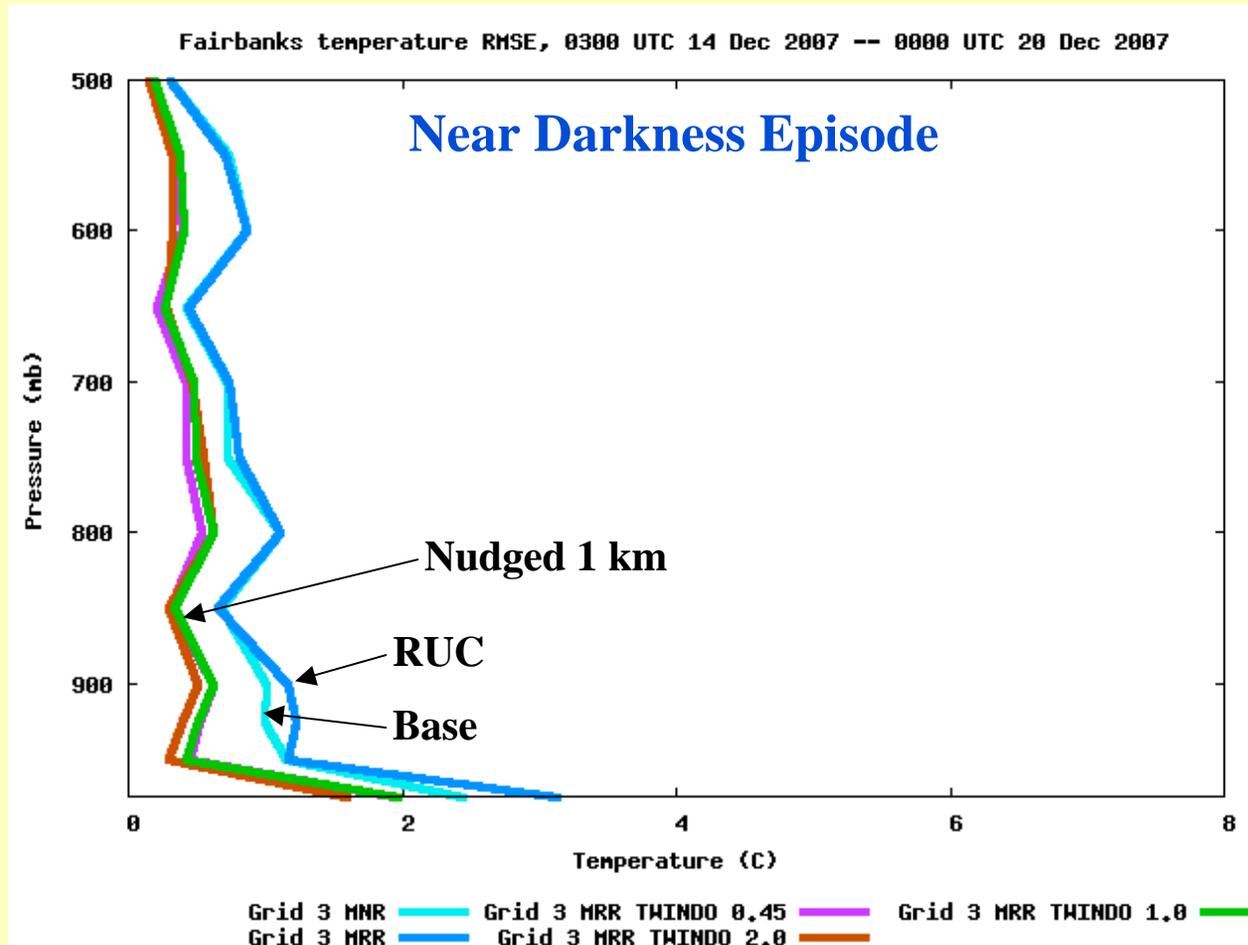
Nudging on 1 km has large effect

Summary

- **WRF can model strong Fairbanks inversions**

- **High vertical resolution requires modifications**
  - **Nudging Methodology, verification routines, CMAQ emissions**

- **QNSE PBL is not much different than MYJ***

- **RUC LSM is better overall than Noah for the coldest periods of this case study**
  - **Cold bias during period of cooling temps and light snow possibly due to microphysics**
  - **Strong diurnal cycle in Feb. and coldest inversions possibly a result of better resolved snow radiation flux**

- **Nudging at 1 km is still useful and perhaps necessary**