Air Quality Screening Modeling

2007 Meteorology Simulation with WRF

OTC Modeling Committee Meeting

September 16, 2010

Baltimore, MD

Presentation is based upon the following technical reports available from the OTC

Sensitivity testing of WRF Physics parameterizations and protocol for meteorological modeling in support of Regional SIP air quality modeling in the Ozone Transport Region (OTR)

Assessment of 2007 WRF meteorological modeling in support of regional air quality modeling in the Ozone Transport Region (OTR)

Design Approach and Conclusions

Collaborative process with other RPOs, with assistance from University of Maryland

Participant States were GA, IA, MD, NC, NY, and VA

Setup benchmark and sensitivity simulations to develop a common configuration

Simulated WRF meteorological fields were found to be acceptable, based on performance metrics for surface-level temperature, wind speed and direction, water vapor, precipitation, wind profilers, cloud cover, and planetary boundary layer height (PBL)

Initial Work

- Goal was to ensure that WRF simulation performed by each State modeling center would yield no differences in the simulated meteorological fields by the use of a common set of input data prepared by UMD for a 20 day period in summer and winter of 2007 with an agreed upon vertical and horizontal framework for WRF simulation

- This benchmark effort however showed significant differences between the state simulations , suggesting the need for a common configuration of hardware/software system

- Using a static compiled executable WRF code with 8 CPUs and a common operating system (OS), the numerical differences between the state modeling centers were found to be minimal

WRF Sensitivity Comparison

- Goal: To determine a suitable configuration for annual simulation

- Selection:

  - Planetary Boundary Layer (PBL) Schemes: ACM2, MYJ, YSU, and modified Blackadar
  - Microphysics: WSM5 and WSM6
  - Land Surface: NOAH and PX
  - Time Periods: Summer and Winter Periods

- Comparison Analysis:

  - Techniques Development Laboratory (TDL) data – wind speed (with/without calms), temperature and humidity from National Weather Service (NWS)
  - Clean Air Status and Trends Network (CASTNet) data – wind speed and temperature
  - Wind profiler data from NWS
  - Satellite cloud cover data from UMD
  - Precipitation data from NWS

Selected Configuration for 2007 OTC WRF Annual Modeling

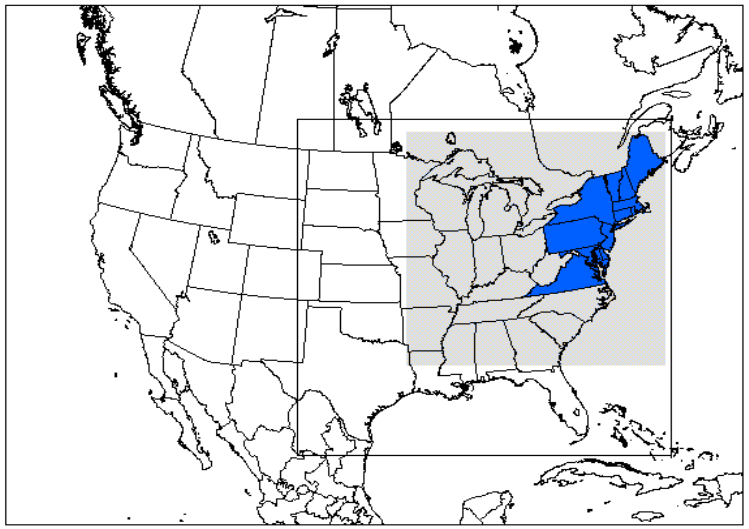
WRF version 3.1

- North American Mesoscale model (NAM) analyses fields as input to 36 km, and 12 km domains in a 2-way nested mode
- OBSGRID for enhance nudging with observed data
- Model runs were at five and half days block with 12 hours overlap

Model Options

- WSM6 microphysics
- RRTM long and shortwave radiation
- Pleim-Xiu land-surface and surface layer models
- Modified-Blackadar planetary boundary layer (PBL) scheme
- Kain-Fritsch cumulus parameterization
- Applied analysis nudging for winds above and below PBL
- Applied analysis nudging for temperature and moisture above PBL only

WRF Modeling domains at 36 and 12 km, and the 12 km Air Quality Modeling domain shown shaded, and the MANE-VU domain shown in blue



WRF simulation Assessment
TDL Data – Monthly Statistics

- Wind Speed: WRF over-predicted (positive bias) in winter months, and negative bias in summer months. The normalized bias is higher in summer due to observed low wind speeds
- Temperature: WRF predictions exhibit positive bias in winter and negative bias in summer
- Humidity: WRF overestimated observed humidity
- Overall: WRF Performance is in-line with acceptable range of bias reported for meteorological modeling systems

An Example

Over the 12 km domain wind speed monthly statistics comparing simulation against TDL data

Wind Speed	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Sample_Size	600076	541340	601626	582365	597352	574771	592688	590041	576115	599801	582704	606478
Mean_Obs	3.61	3.84	3.73	3.82	3.04	2.62	2.34	2.26	2.53	2.90	3.23	3.12
Mean_Model	3.71	3.97	3.67	3.73	2.89	2.45	2.18	2.10	2.55	2.98	3.37	3.21
STD_Obs	2.57	2.74	2.72	2.78	2.38	2.21	1.97	1.97	2.21	2.43	2.58	2.64
STD_Model	2.11	2.38	2.26	2.42	1.92	1.79	1.55	1.52	1.84	2.04	2.20	2.30
Mean_Bias	0.11	0.13	-0.06	-0.09	-0.15	-0.18	-0.16	-0.16	0.03	0.07	0.14	0.09
STD_bias	1.77	1.84	1.82	1.77	1.67	1.62	1.53	1.57	1.59	1.64	1.69	1.73
RMSE	1.78	1.84	1.82	1.78	1.68	1.63	1.54	1.57	1.59	1.64	1.70	1.74
Normalized_Mean_Bias (%)	3.03	3.27	-1.52	-2.27	-4.95	-6.73	-6.69	-7.20	1.04	2.54	4.22	2.81
Mean_Fractional_Bias (%)	24.57	22.68	20.08	17.98	22.31	25.04	28.19	30.11	35.60	33.06	31.91	30.95
Mean_Error	1.29	1.34	1.34	1.34	1.27	1.22	1.17	1.18	1.19	1.21	1.24	1.25
Normalized_Mean_Error (%)	35.72	35.01	35.84	35.02	41.61	46.34	50.05	52.29	46.95	41.87	38.52	40.01
Mean-Fractional_Error (%)	58.24	57.29	60.84	61.61	74.43	83.54	88.52	92.07	84.48	75.07	67.76	70.97
Correlation_Coefficient	0.73	0.75	0.75	0.78	0.72	0.69	0.65	0.63	0.71	0.74	0.76	0.76

Similarly for temperature comparison monthly statistics over 12 km domain

Temperature	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Sample_Size	615669	555571	618981	598522	618278	596032	613847	612687	595867	615711	595098	617887
Mean_Obs	272.98	268.91	279.09	282.37	290.24	294.48	295.42	296.54	292.54	288.08	278.59	273.56
Mean_Model	273.50	269.17	278.59	281.98	289.48	293.64	294.82	296.20	292.58	288.38	279.22	273.93
STD_Obs	9.03	9.38	10.00	8.48	6.91	5.89	5.29	6.14	6.60	7.06	7.04	8.32
STD_Model	8.02	8.63	9.23	7.82	6.44	5.68	5.10	5.66	5.75	6.21	6.31	7.67
Mean_Bias	0.52	0.25	-0.50	-0.39	-0.77	-0.84	-0.61	-0.34	0.04	0.30	0.63	0.37
STD_bias	2.22	2.22	2.43	2.32	2.39	2.19	2.05	2.08	2.11	2.16	2.10	2.24
RMSE	2.27	2.24	2.48	2.35	2.52	2.35	2.13	2.10	2.11	2.18	2.20	2.27
Normalized_Mean_Bias (%)	0.19	0.09	-0.18	-0.14	-0.26	-0.29	-0.20	-0.11	0.01	0.10	0.23	0.14
Mean_Fractional_Bias (%)	0.20	0.10	-0.17	-0.13	-0.26	-0.28	-0.20	-0.11	0.02	0.11	0.23	0.14
Mean_Error	1.64	1.64	1.84	1.75	1.89	1.78	1.61	1.60	1.61	1.63	1.62	1.64
Normalized_Mean_Error (%)	0.60	0.61	0.66	0.62	0.65	0.61	0.55	0.54	0.55	0.57	0.58	0.60
Mean-Fractional_Error (%)	0.61	0.61	0.66	0.62	0.65	0.61	0.55	0.54	0.55	0.57	0.58	0.60
Correlation_Coefficient	0.97	0.97	0.97	0.96	0.94	0.93	0.92	0.94	0.95	0.96	0.96	0.96

An Example Over the **MANEVU** region at 12 km grid spacing

Wind Speed monthly statistics comparing **WRF** simulation against TDL data

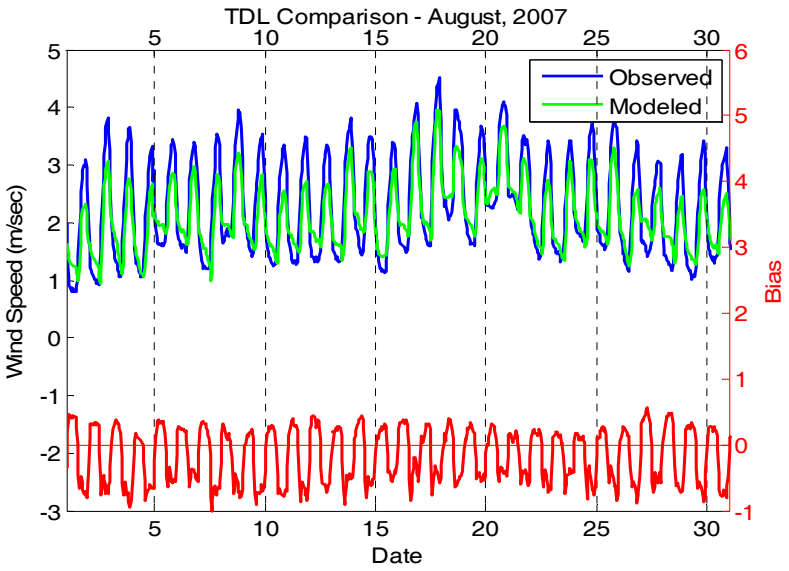
Wind Speed	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Sample_Size	124364	112077	124880	121021	123017	117069	121552	120333	118168	124638	121222	126654
Mean_Obs	3.71	4.21	4.03	3.92	3.02	2.82	2.51	2.36	2.47	2.73	3.21	3.31
Mean_Model	3.64	4.11	3.81	3.67	2.72	2.54	2.26	2.09	2.33	2.60	3.16	3.24
STD_Obs	3.05	3.19	3.11	2.91	2.47	2.36	2.15	2.16	2.35	2.55	2.80	3.03
STD_Model	2.22	2.56	2.32	2.39	1.73	1.67	1.56	1.49	1.60	1.81	2.08	2.39
Mean_Bias	-0.08	-0.10	-0.23	-0.25	-0.30	-0.27	-0.25	-0.28	-0.14	-0.13	-0.05	-0.07
STD_bias	2.30	2.31	2.29	2.03	1.90	1.85	1.69	1.75	1.82	1.95	2.05	2.16
RMSE	2.30	2.31	2.30	2.05	1.92	1.87	1.71	1.77	1.83	1.95	2.05	2.16
Normalized_Mean_Bias (%)	-2.05	-2.37	-5.59	-6.40	-10.01	-9.69	-9.89	-11.67	-5.61	-4.74	-1.61	-2.22
Mean_Fractional_Bias (%)	26.53	21.28	18.74	16.86	22.27	24.22	29.25	30.88	37.92	35.05	32.46	31.34
Mean_Error	1.48	1.54	1.55	1.46	1.38	1.32	1.26	1.26	1.26	1.32	1.38	1.42
Normalized_Mean_Error (%)	39.99	36.66	38.44	37.30	45.52	46.96	50.10	53.44	51.20	48.18	42.83	42.70
Mean-Fractional_Error (%)	66.45	61.60	63.16	64.41	79.43	82.50	90.62	94.92	91.57	86.37	74.66	75.68
Correlation_Coefficient	0.66	0.70	0.68	0.72	0.64	0.62	0.63	0.60	0.63	0.65	0.68	0.71

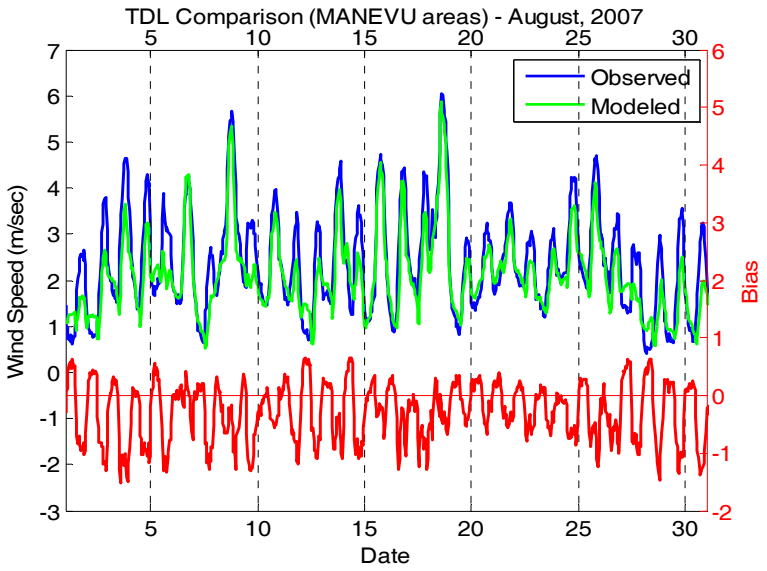
An Example Over the **MANEVU** region at 12 km grid spacing

Temperature monthly statistics comparing **WRF** simulation against TDL data

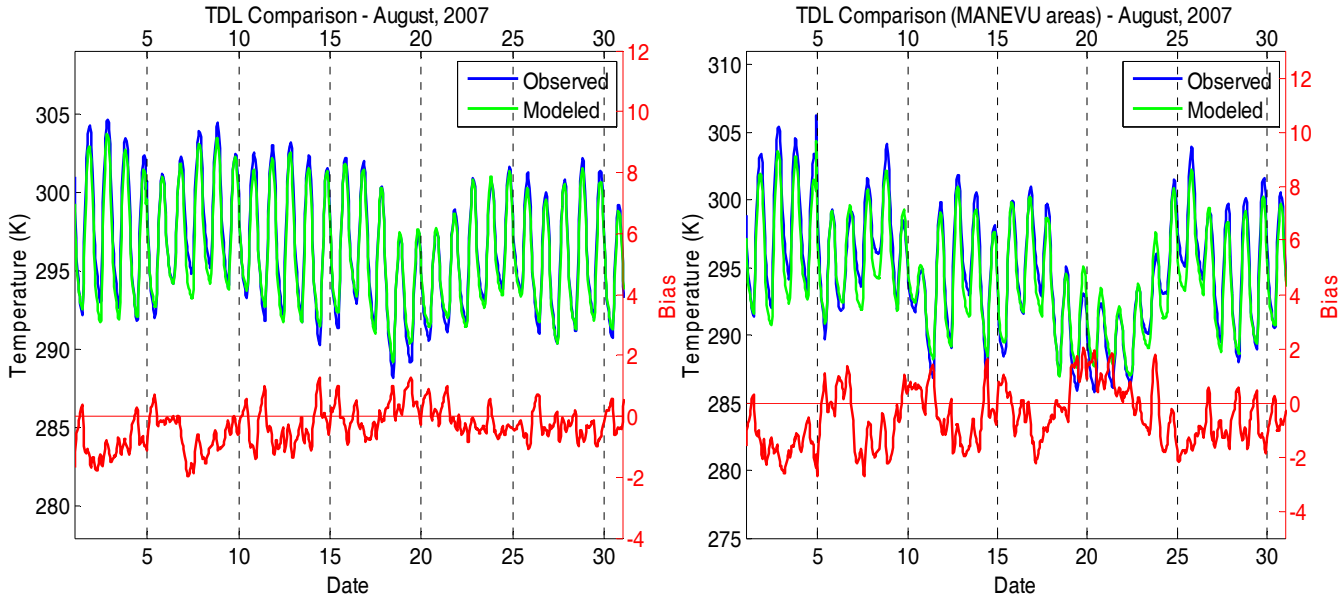
Temperature	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Sample_Size	130525	117480	131319	127015	131983	126779	131809	130928	127676	132503	127340	131827
Mean_Obs	272.73	267.94	275.76	280.42	288.67	293.00	294.67	294.79	291.53	287.60	277.86	272.59
Mean_Model	273.12	268.08	275.15	279.83	287.54	291.95	293.75	294.26	291.32	287.66	278.31	272.86
STD_Obs	8.16	6.12	8.26	6.89	6.71	5.54	4.99	5.48	6.03	6.40	5.50	5.55
STD_Model	7.06	5.42	7.16	6.02	6.06	5.16	4.71	4.85	4.89	5.25	4.74	4.93
Mean_Bias	0.39	0.14	-0.61	-0.59	-1.13	-1.05	-0.92	-0.53	-0.20	0.06	0.45	0.27
STD_bias	2.14	2.05	2.43	2.26	2.39	2.15	2.05	2.11	2.20	2.26	2.01	2.09
RMSE	2.18	2.05	2.50	2.33	2.64	2.40	2.24	2.18	2.21	2.26	2.06	2.11
Normalized_Mean_Bias (%)	0.14	0.05	-0.22	-0.21	-0.39	-0.36	-0.31	-0.18	-0.07	0.02	0.16	0.10
Mean_Fractional_Bias (%)	0.15	0.06	-0.21	-0.20	-0.39	-0.36	-0.31	-0.18	-0.06	0.03	0.17	0.10
Mean_Error	1.60	1.46	1.86	1.69	2.00	1.85	1.73	1.68	1.69	1.71	1.52	1.55
Normalized_Mean_Error (%)	0.59	0.54	0.67	0.60	0.69	0.63	0.59	0.57	0.58	0.59	0.55	0.57
Mean-Fractional_Error (%)	0.59	0.55	0.67	0.60	0.69	0.63	0.59	0.57	0.58	0.60	0.55	0.57
Correlation_Coefficient	0.97	0.94	0.96	0.95	0.93	0.92	0.91	0.92	0.94	0.94	0.93	0.93

Comparison of WRF and TDL daily Wind Speed and bias for August 2007 over 12 km entire domain and MANEVU Region

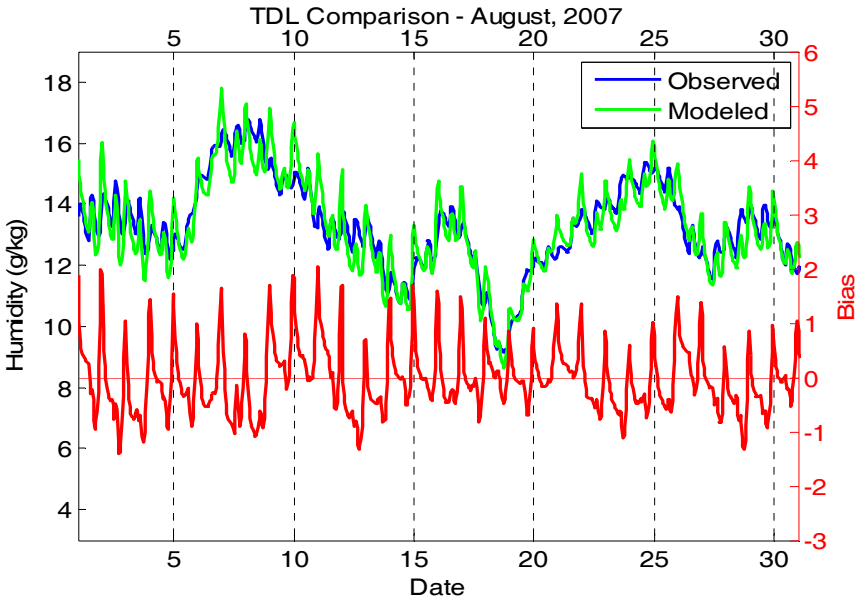


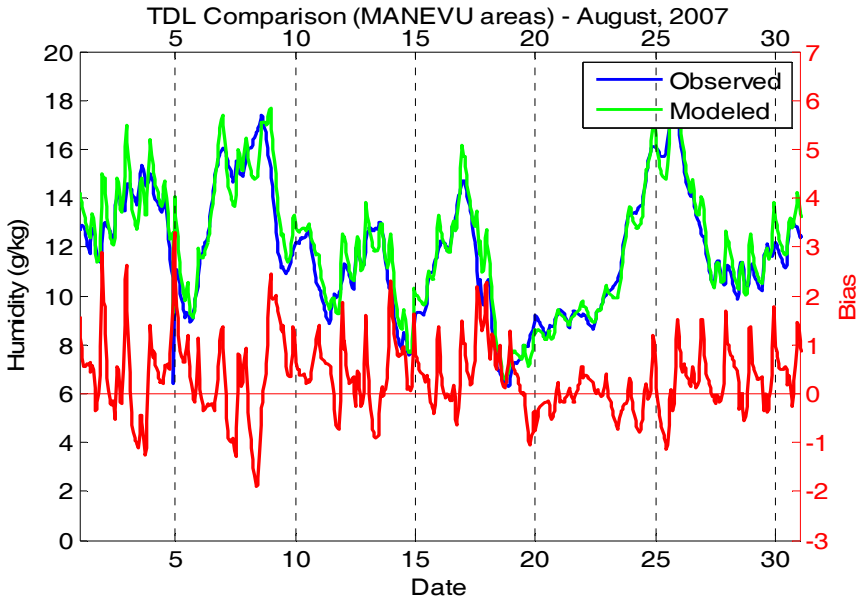


Comparison of WRF and TDL daily Temperature and bias for August 2007 over 12 km entire domain and MANEVU Region



Comparison of WRF and TDL daily humidity and bias for August 2007 over 12 km entire domain and MANEVU Region





- **WRF predicts the observed double peak**

- **However, it overpredicts the early morning peak and underpredicts the day time minimum**

CASTNet Data

- Wind Speed: WRF over predicted wind speed compared to measured by CASTNet
- Temperature: WRF predicted higher temperatures than those measured by CASTNet
- Note: Unlike NWS-TDL, CASTNet data were not used in the FDDA (four dimensional data assimilation) or nudging process
- Also, CASTNet measurements are at rural stations

Over the 12 km domain wind speed monthly statistics comparing WRF simulation against CASTNet data

Wind Speed	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Sample_Size	36234	31973	35355	32630	34636	33309	34065	33890	33507	35871	35561	37073
Mean_Obs	2.86	2.98	2.87	3.02	2.22	1.93	1.77	1.73	1.85	2.26	2.52	2.58
Mean_Model	3.71	3.87	3.59	3.67	2.54	2.20	2.06	1.89	2.11	2.74	3.18	3.20
STD_Obs	1.91	2.03	1.98	2.14	1.61	1.42	1.23	1.18	1.33	1.68	1.82	1.96
STD_Model	2.03	2.31	2.17	2.29	1.72	1.59	1.41	1.35	1.54	1.85	2.01	2.25
Mean_Bias	0.85	0.88	0.71	0.65	0.32	0.27	0.30	0.17	0.26	0.48	0.66	0.62
STD_bias	1.66	1.86	1.77	1.76	1.46	1.37	1.26	1.24	1.32	1.46	1.55	1.68
RMSE	1.86	2.06	1.90	1.87	1.50	1.40	1.30	1.25	1.34	1.54	1.68	1.79
Normalized_Mean_Bias (%)	29.67	29.69	24.78	21.39	14.40	14.00	16.84	9.65	14.17	21.35	26.29	24.03
Mean_Fractional_Bias (%)	25.67	21.68	18.72	15.33	4.53	1.01	2.99	-4.76	-0.50	10.18	18.51	14.37
Mean_Error	1.42	1.53	1.43	1.44	1.19	1.09	1.03	0.98	1.06	1.20	1.29	1.31
Normalized_Mean_Error (%)	49.60	51.31	49.87	47.82	53.47	56.67	58.26	56.90	57.15	53.09	51.35	50.64
Mean-Fractional_Error (%)	52.64	54.33	54.86	56.13	65.91	68.73	69.50	70.64	70.13	63.52	58.09	56.50
Correlation_Coefficient	0.65	0.64	0.64	0.69	0.61	0.59	0.55	0.53	0.59	0.66	0.68	0.69

Wind Profiler Data

- Five sites:

  Baltimore, MD (BLTMD),

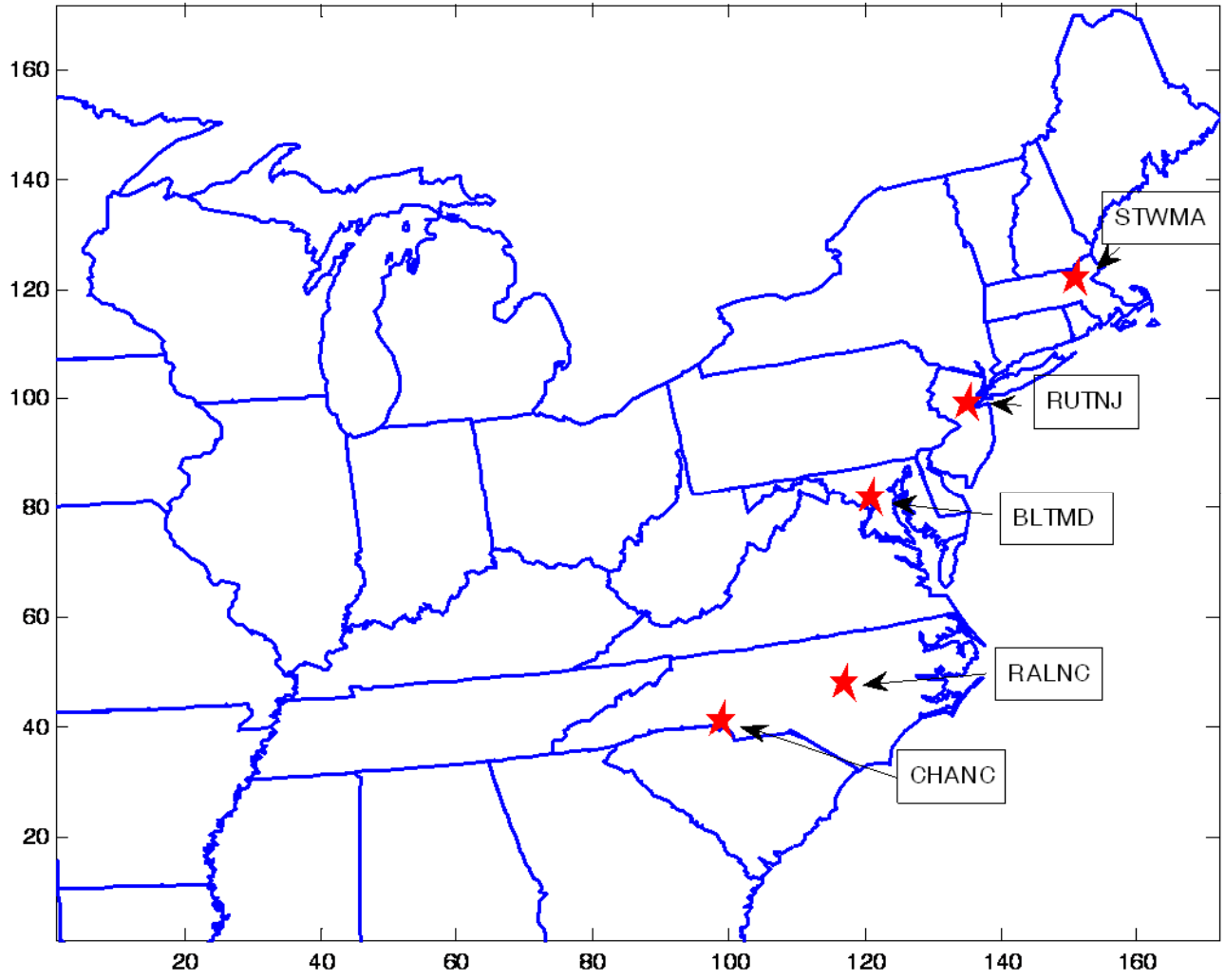
  Rutgers, NJ (RUTNJ),

  Stowe, MA (STWMA),

  Charlotte, NC (CHANC), and

  Raleigh, NC (RALNC)

- Qualitative comparison of the measured vertical profile of wind speed with WRF predictions


160
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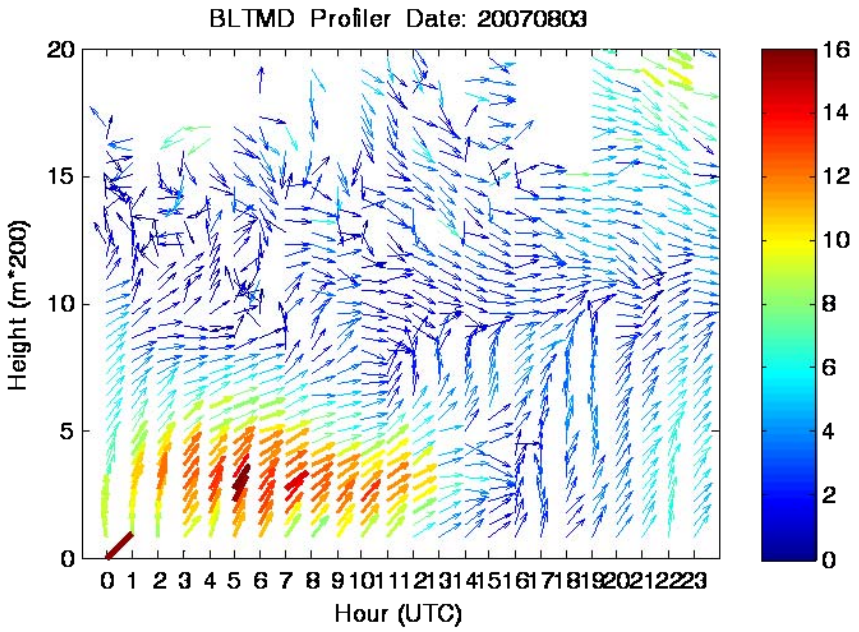
BLTMD
RALNC
CHANC


BLTMD Profiler Date: 20070803
Height (m*200)
Hour (UTC)
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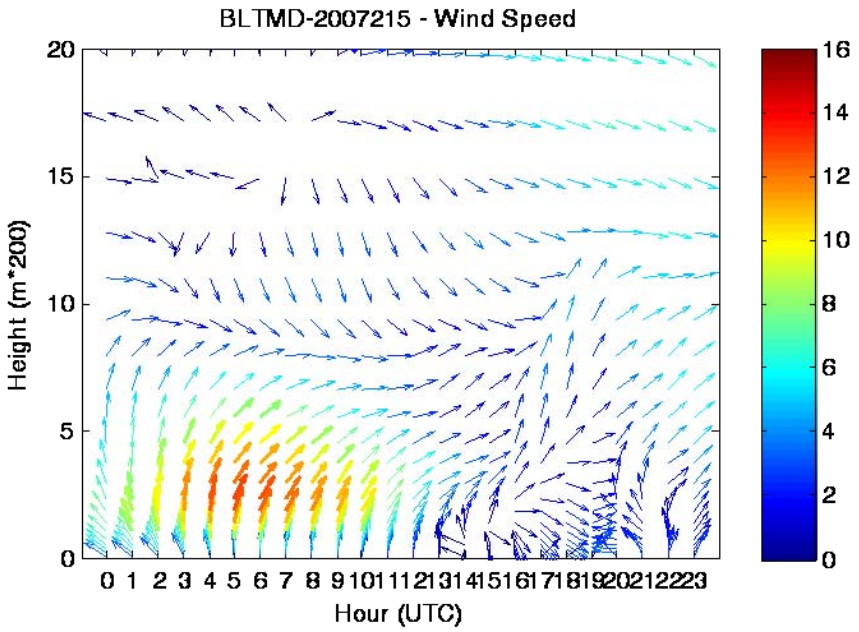
BLTMD-2007215 - Wind Speed
Height (m*200)
Hour (UTC)
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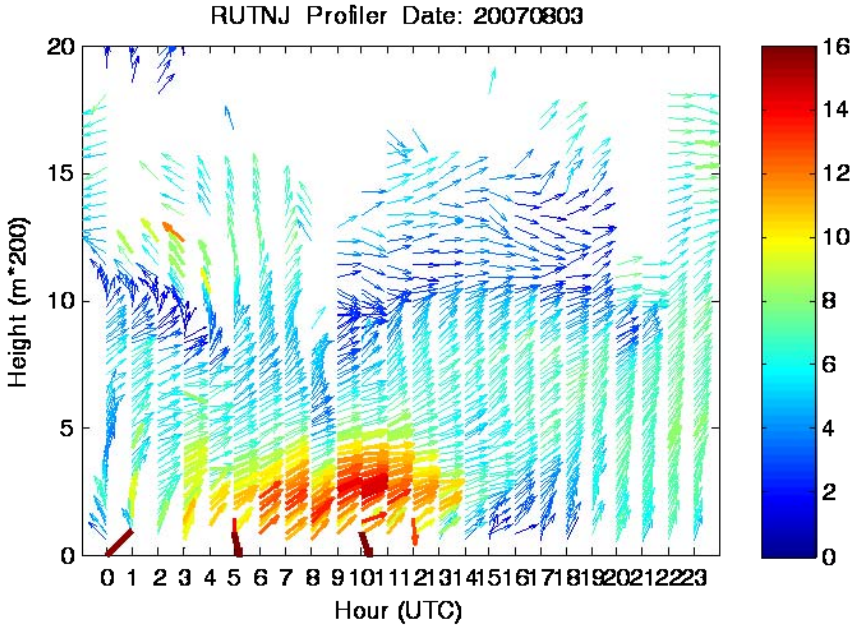
RUTNJ Profiler Date: 20070803
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Hour (UTC)
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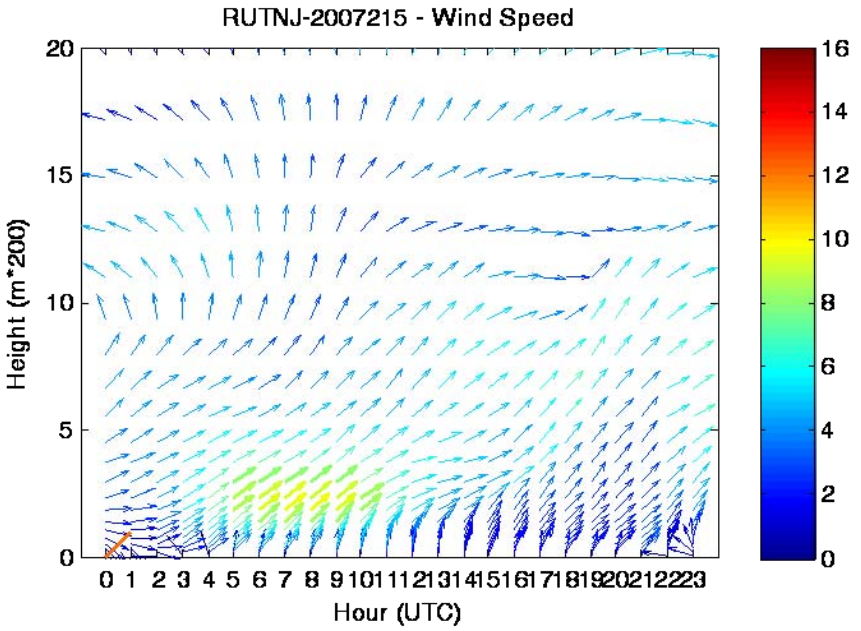
RUTNJ-2007215 - Wind Speed
Height (m*200)
Hour (UTC)
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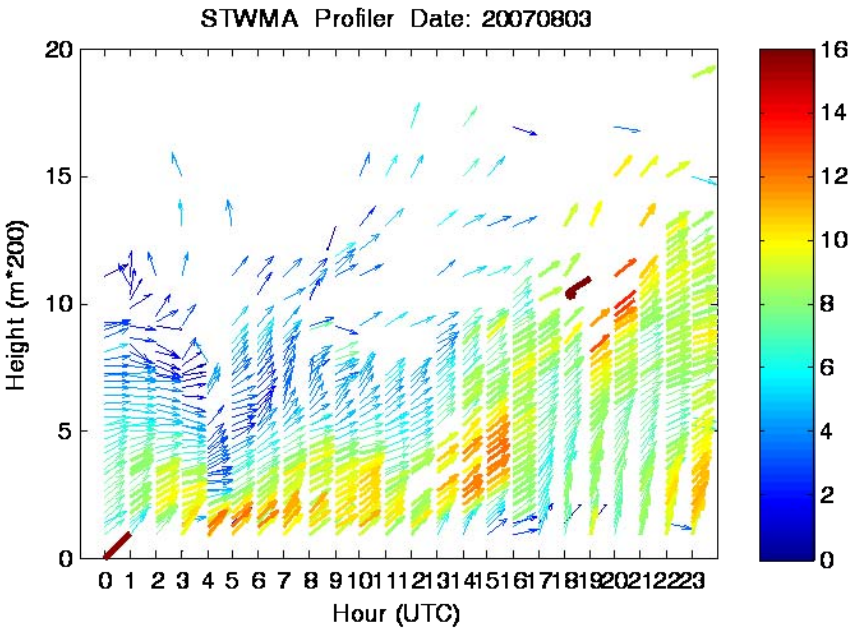
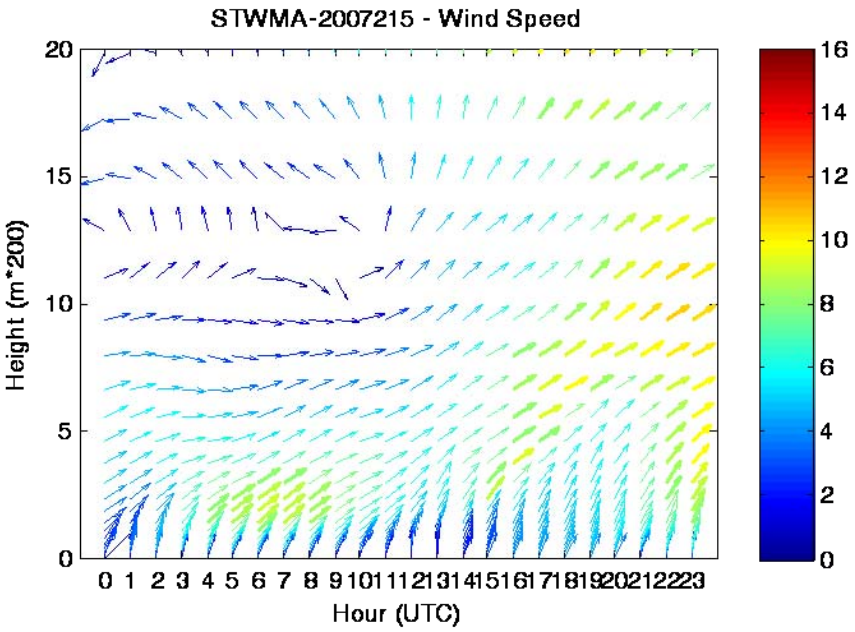
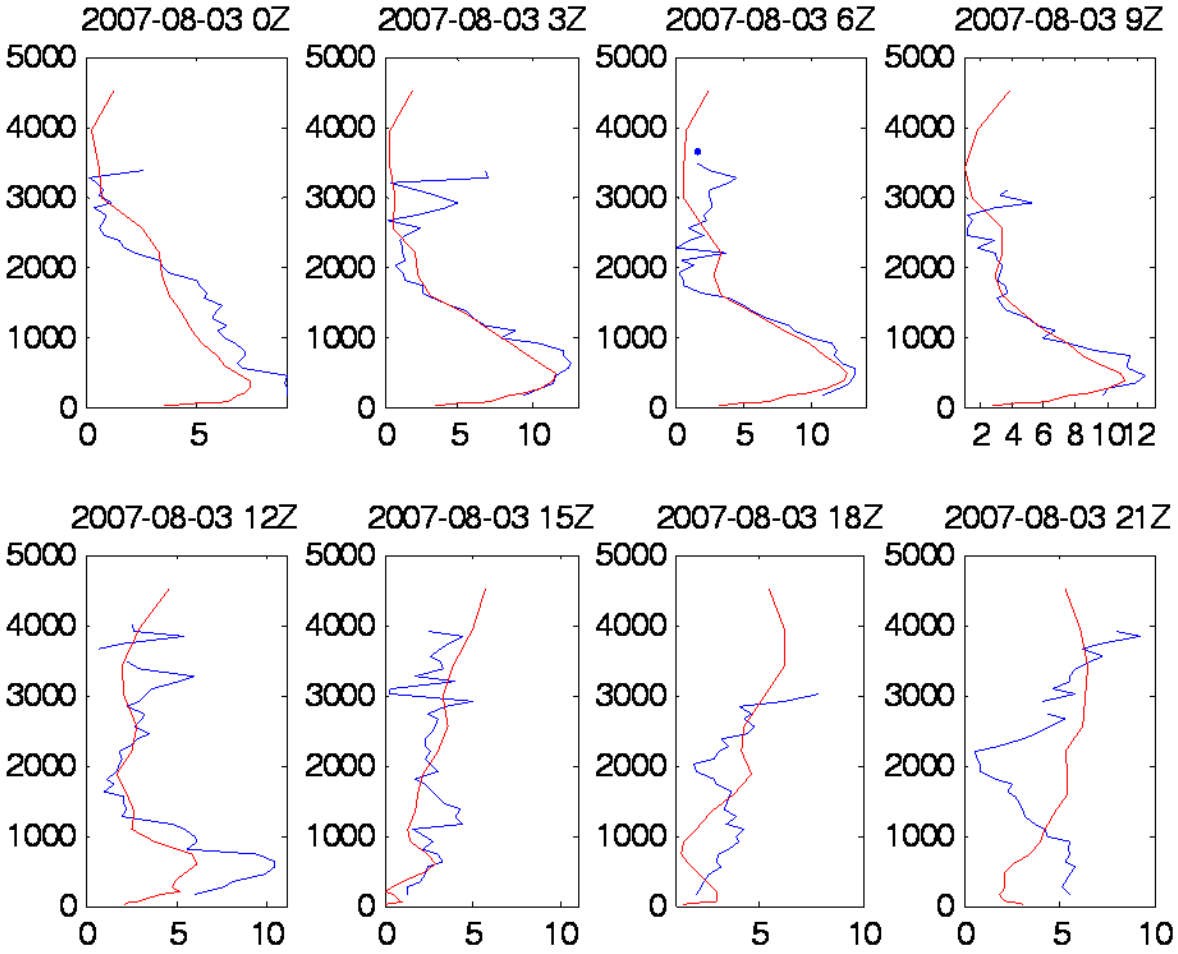
0 5 10 15 20
0 2 4 6 8 10 12 14 16


STWMA Profiler Date: 20070803
Height (m*200)
Hour (UTC)


STWMA-2007215 - Wind Speed
Height (m*200)
Hour (UTC)

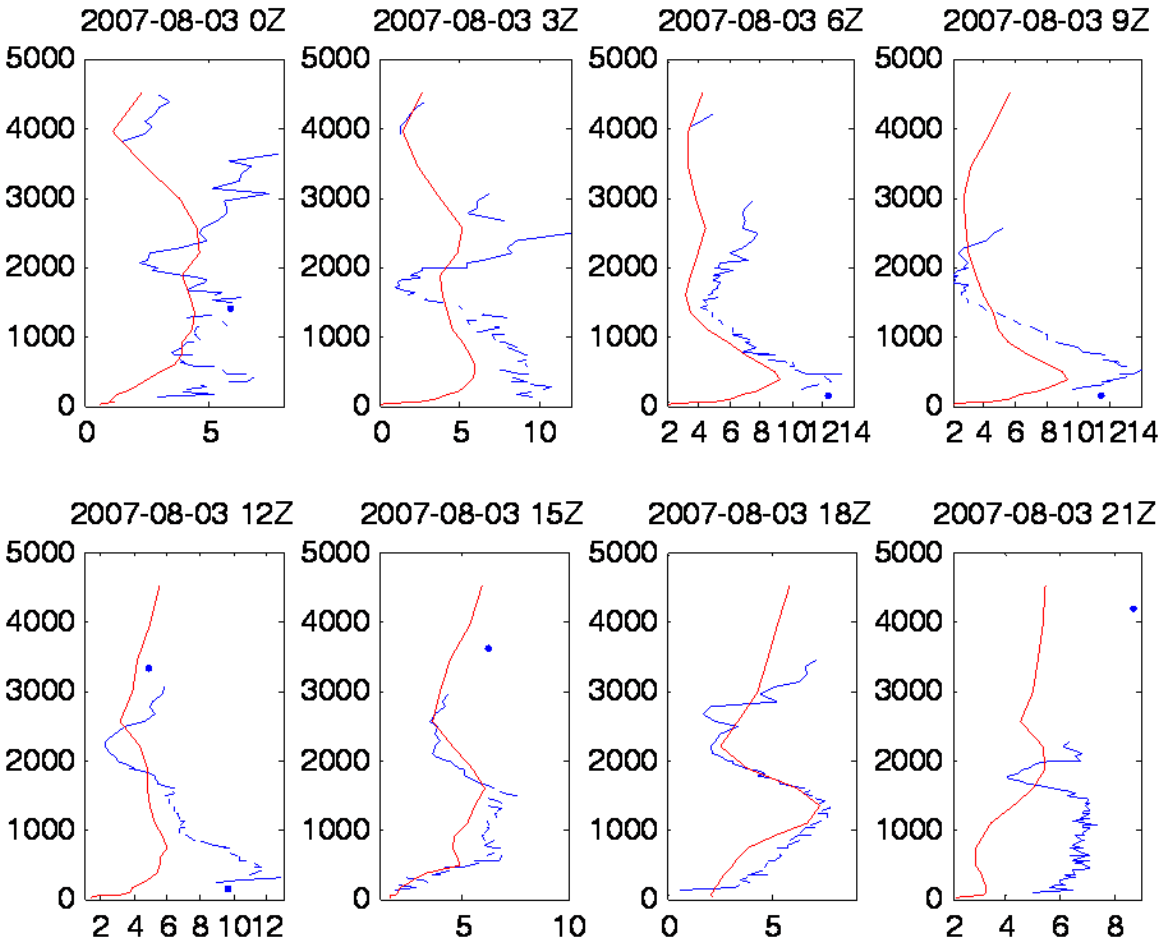
BLTMD

BLUE: Wind Profiler
RED: WRF



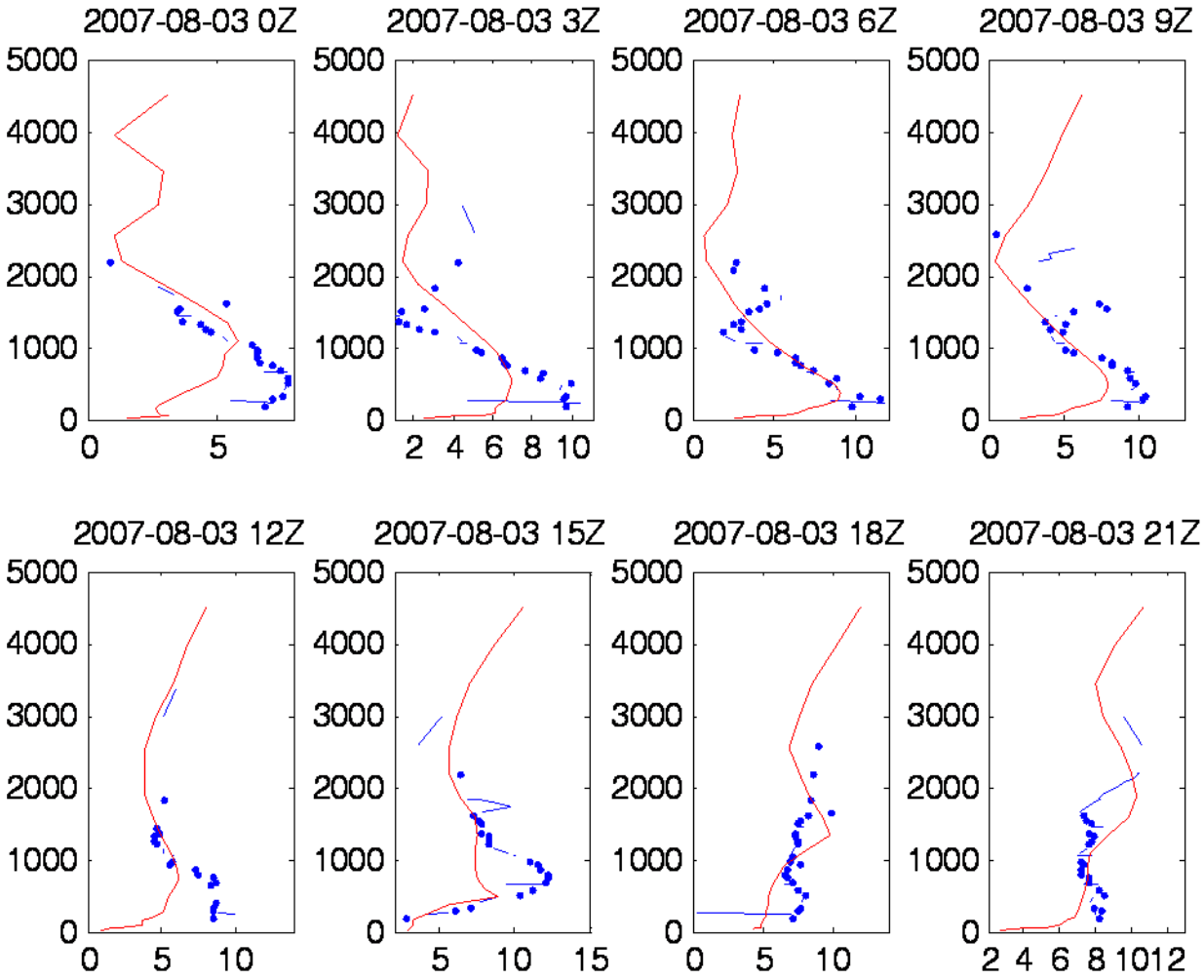
RUTNJ

BLUE: Wind Profiler
RED: WRF



STWMA

BLUE: Wind Profiler
RED: WRF



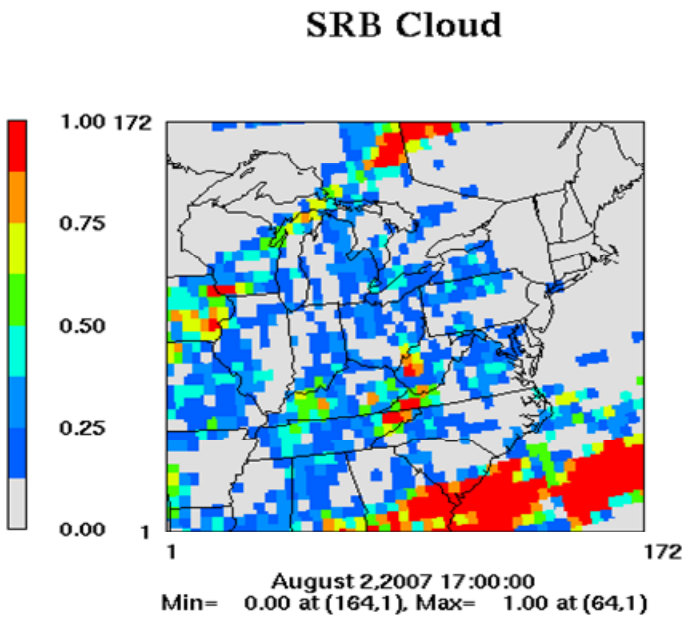
Comparison of Observed and WRF Cloud Fraction

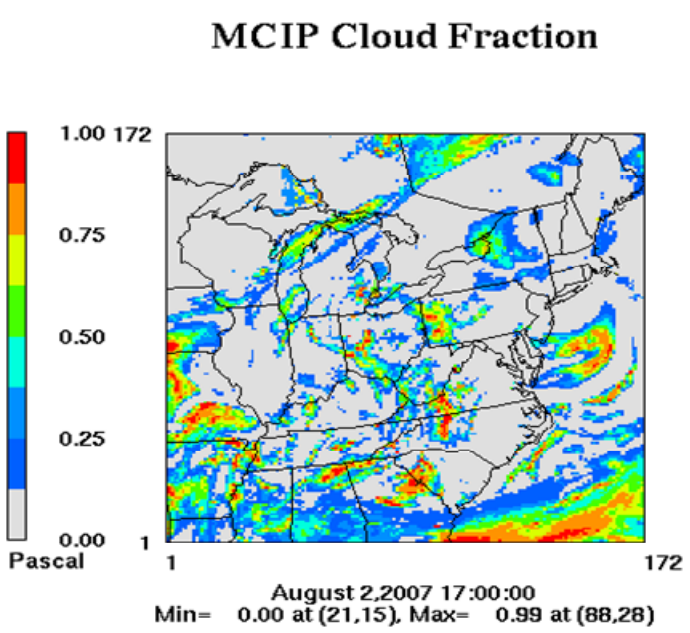
- Using GOES-12 satellite observations derived cloud fraction from UMD's Surface Radiation Budget (SRB)

- Cloud fraction estimates are made on an hourly basis at 0.5° resolution for an area bounded by 70-125 ° W longitude and 25 – 50 ° N latitude

- MCIP processed cloud fraction using WRF output

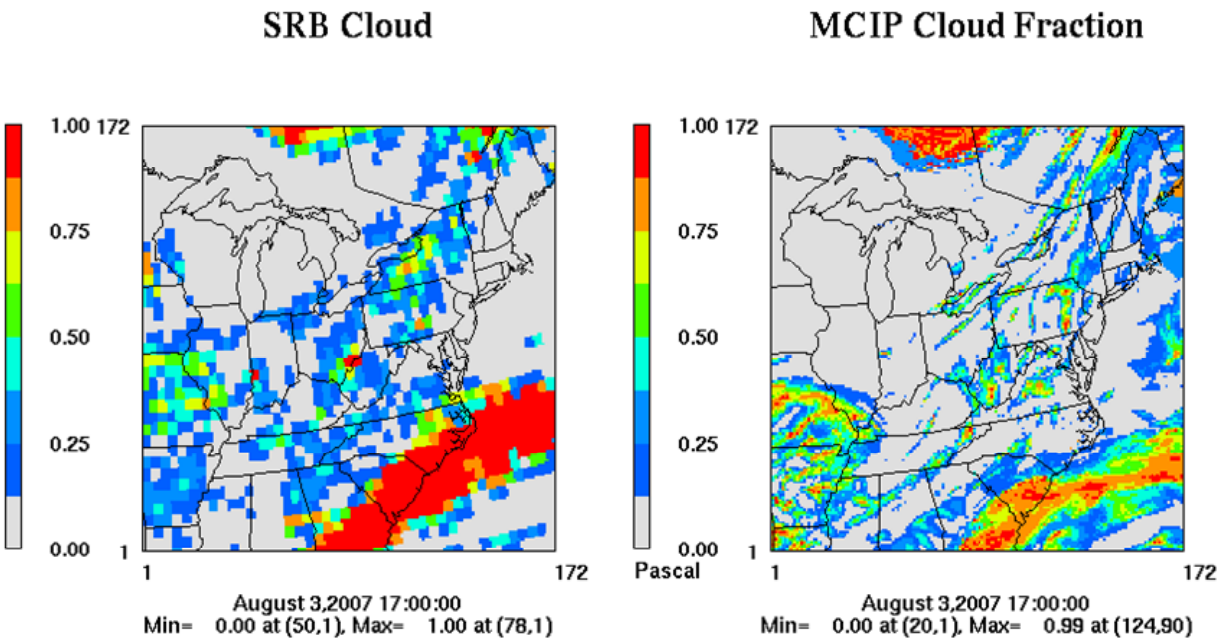
Comparison of Cloud fraction based on observed (SRB) and WRF predicted (MCIP) for August 2, 2007 at 1700





General agreement in pattern over the domain

Comparison of Cloud fraction based on observed (SRB) and WRF predicted (MCIP) for August 3, 2007 at 1700

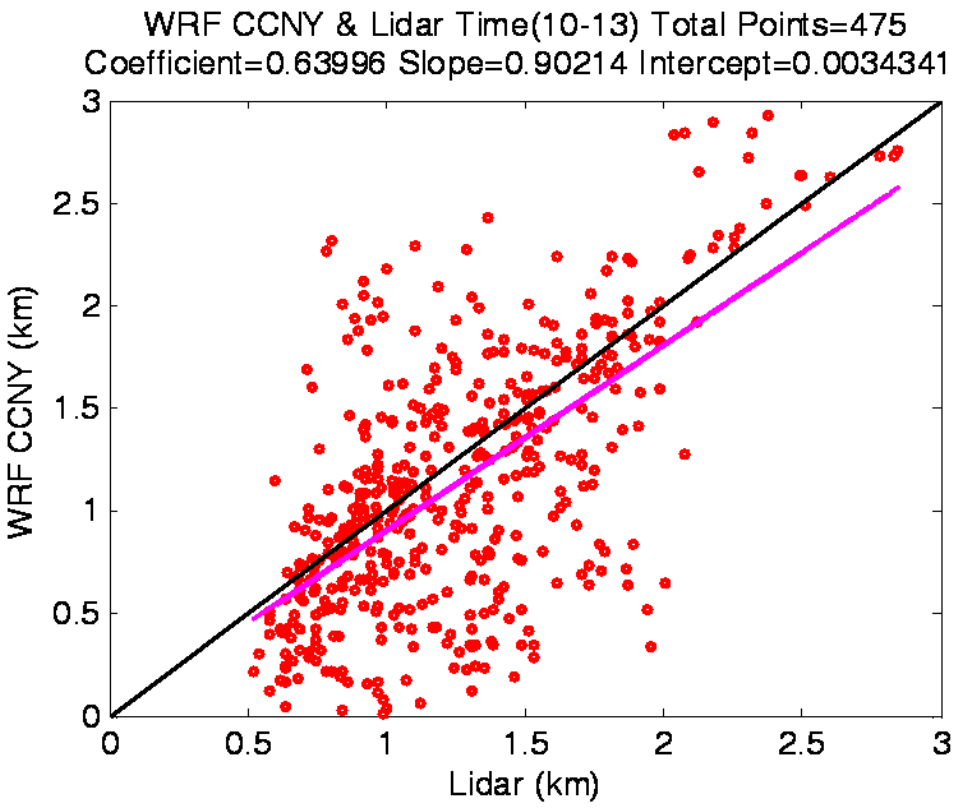


General agreement in pattern over the domain

Planetary Boundary Layer (PBL) Height Comparison

- Lidar-based observed PBL height at CCNY
- WRF-based PBL height at CCNY grid and maximum value of 9 by 9 grid surrounding CCNY grid
- The maximum of the 9 by 9 grid is found to be closer to Lidar-based observed PBL height

Comparison of PBL heights from Lidar and WRF at the CCNY grid during 2007

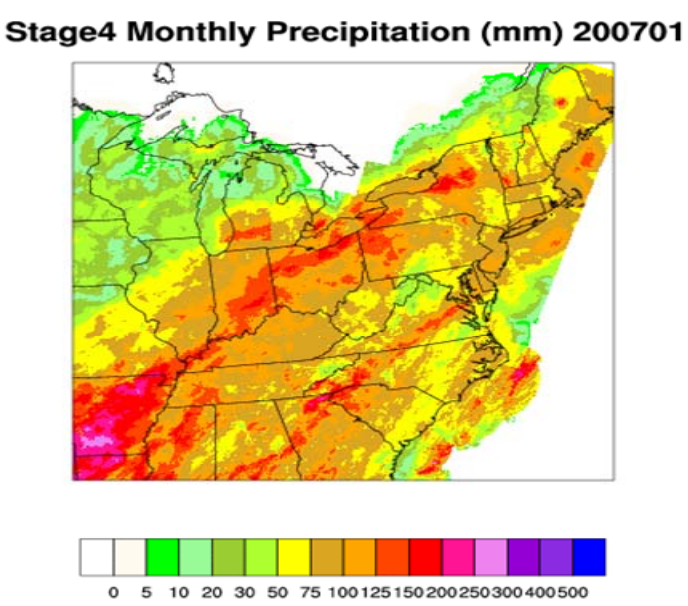


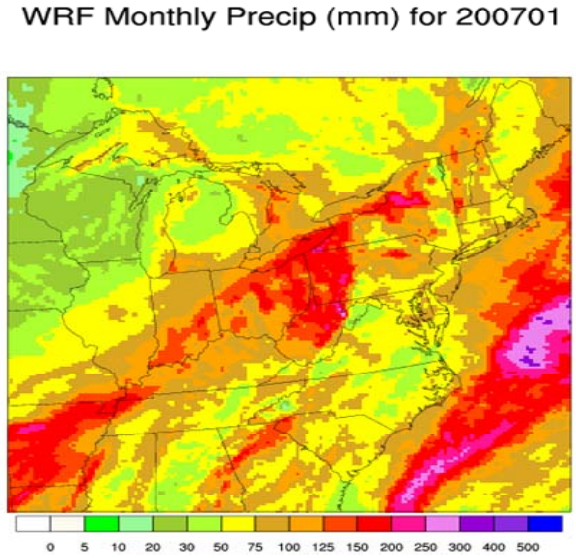
Data are from 1000 to 1300 hrs (EST) with 1-to-1 line and best fit

Precipitation

- Obtained NCEP gridded stage 4 precipitation data from measurements
- Compared against WRF estimate on a monthly accumulation basis
- Overall WRF performed fairly well over non-summer months, in terms of amount and pattern
- Over the months of April through September, WRF over-predicted precipitation amounts, except for August for which the model is found to under-predict the precipitation because of passage of Hurricane Dean in late August

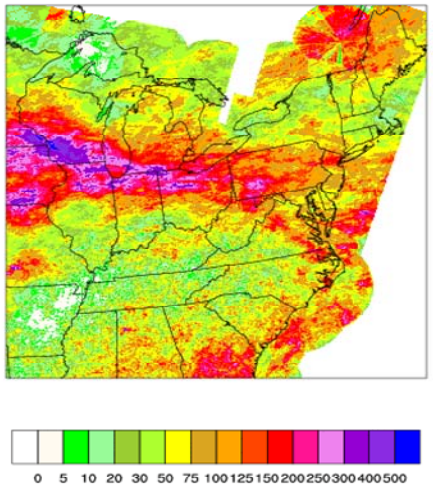
Comparison of precipitation based on measured (Stage -4) and predicted (WRF) for the month of January 2007



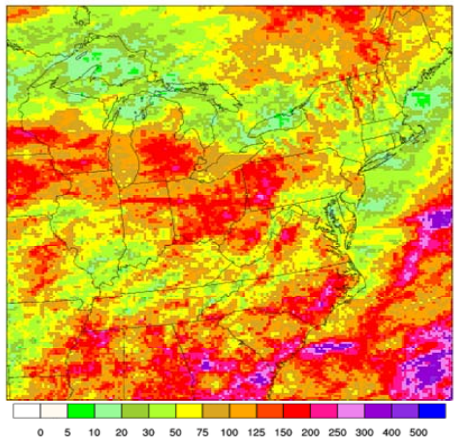


Comparison of precipitation based on measured (Stage -4) and predicted (WRF) for the month of August 2007

Stage4 Monthly Precipitation (mm) 200708



WRF Monthly Precip (mm) for 200708



Summary and Conclusions

- WRF simulations shows good comparison with NWS-TDL surface-based measurements
- Similarly good comparison was noted with CASTNet data
- WRF captured the cloud coverage pattern when compared with satellite-based data
- WRF simulated Low level jets (LLJ) and compares well with wind profiler data
- WRF based estimates of Planetary Boundary Layer (PBL) heights compared well with Lidar-based PBL heights at New York City location
- WRF simulated precipitation patterns are found to match well with measurements