



Statistical Analysis of Model Data for Operational Space Launch Weather Support at Kennedy Space Center and Cape Canaveral Air Force Station

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Outline



- Background/Objective
- Launch/Landing Weather Towers
- MesoNAM Grid
- Data and Methodology
- Data Formatting
- Results
- Graphical User Interface
- Summary and Conclusions





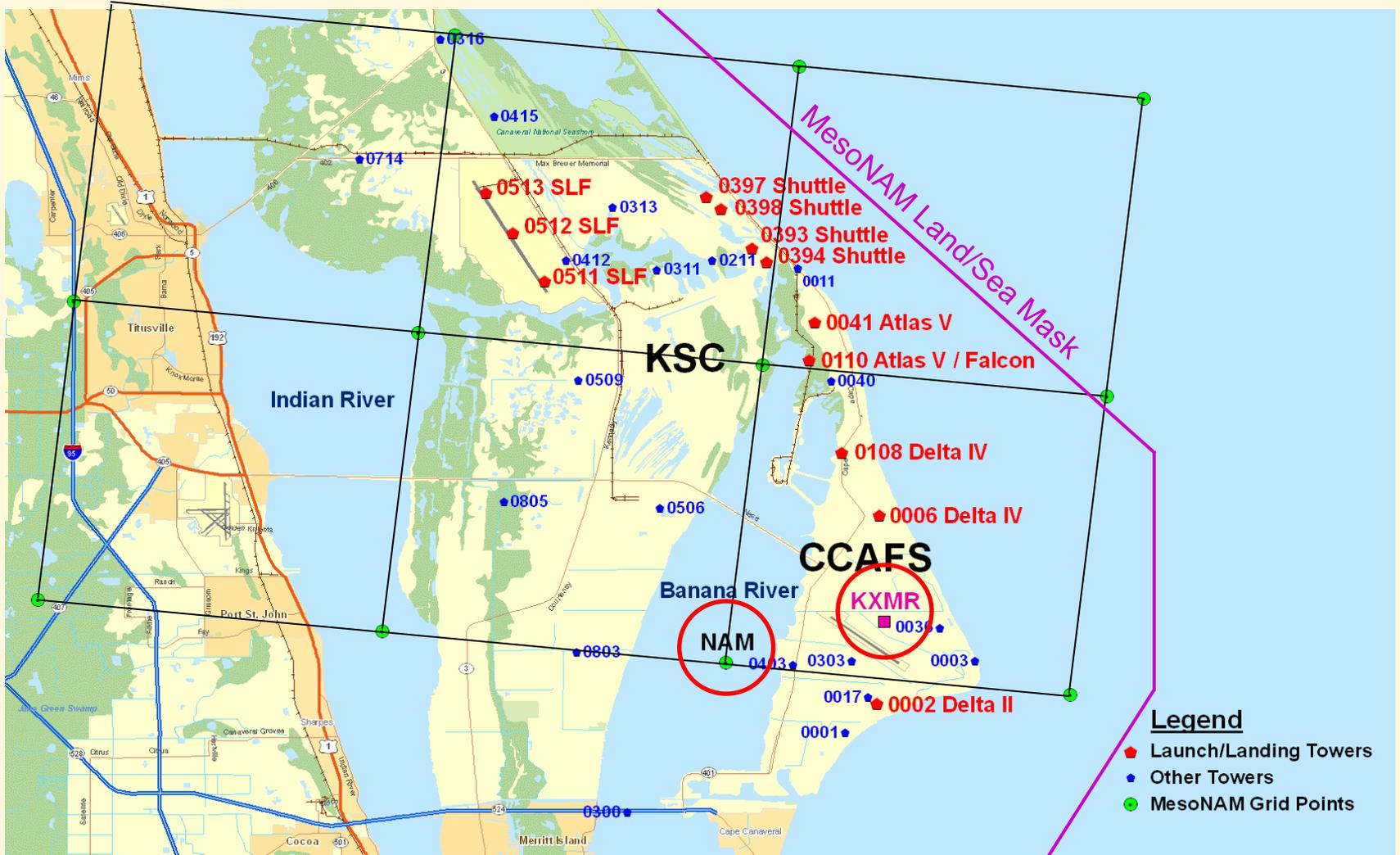
Background/Objective



- The 12-km NAM (MesoNAM) used
 - By 45 WS Launch Weather Officers
 - At KSC and CCAFS
 - To forecast T , T_d , and winds at launch and landing weather towers
- Model performance good anecdotally, but not measured objectively
- The 45 WS tasked the Applied Meteorology Unit (AMU) to conduct analysis of model versus tower observations
- Need to assess model performance at each tower and sensor height



MesoNAM Grid

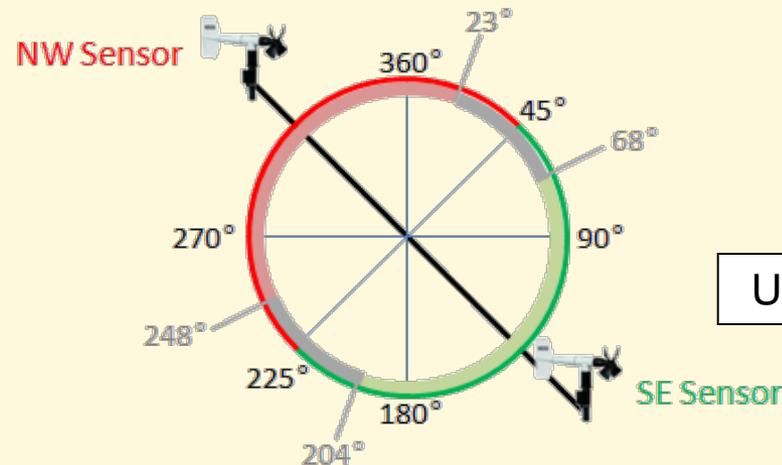




Launch/Landing Weather Towers



Tower Number	Supported Activity and Facility	Sensor Heights
002	Delta II (LC-17)	6 ft, 54 ft, 90 ft
006/108	Delta IV (LC-37)	54 ft
110	Atlas V (LC-41)/Falcon 9 (LC-40)	54 ft, 162 ft, 204 ft
041	Atlas V (LC-41)	230 ft
393/394	Shuttle (LC-39A)	60 ft
397/398	Shuttle (LC-39B)	60 ft
511/512/513	Shuttle Landing Facility	6 ft, 30 ft



Upwind sensor used



Data and Methodology

- Used MesoNAM textual forecasts from ACTA, Inc.
 - Hourly forecasts: 0 to 84 hours
 - Model initialization times: 00, 06, 12 and 18 UTC
- Verified operational MesoNAM
 - Sep 2006 → Jan 2010 (3+ years)
- Data sets stratified by
 - Month, Onshore/offshore flow, and Model initialization time
- Computed
 - Bias, Standard Deviation of bias, Root Mean Square Error, and Hypothesis Zero Test

Document - WordPad

File Edit View Insert Format Help

Station=747940

YYMMDD/HHMM	T2MS	TD2M	SKNT	DRCT	PMSL	PO1M	LCLD	MCLD	HCLD
090105/1200	17.6	14.6	0.6	180	1021.2	-9999.00	0	0	28
090105/1300	16.6	14.0	1.2	270	1019.6	0.00	0	0	0
090105/1400	19.6	14.6	1.6	330	1021.4	0.00	0	0	38
090105/1500	22.4	16.1	2.8	335	1021.7	0.00	0	0	0
090105/1600	23.5	16.3	2.1	338	1020.5	0.00	10	0	100
090105/1700	24.4	16.0	2.9	20	1021.0	0.00	10	0	0
090105/1800	24.9	15.9	3.6	49	1020.3	0.00	10	0	0
090105/1900	25.0	16.0	5.5	72	1019.0	0.00	10	0	0
090105/2000	24.6	16.7	6.8	72	1018.7	0.00	10	0	0
090105/2100	23.6	17.3	7.2	82	1018.4	0.00	0	0	0
090105/2200	22.3	17.4	7.0	82	1017.8	0.00	0	0	0
090105/2300	20.1	17.4	7.6	87	1017.8	0.00	0	0	0
090106/0000	19.2	17.3	8.4	103	1017.9	0.00	0	0	0
090106/0100	19.0	17.1	8.9	117	1017.8	0.00	0	0	0
090106/0200	19.0	17.0	9.4	130	1019.1	0.00	0	0	0
090106/0300	18.8	16.9	9.4	142	1018.4	0.00	0	0	0
090106/0400	18.7	17.0	9.8	156	1018.6	0.00	0	0	0
090106/0500	18.7	17.3	10.5	165	1018.6	0.00	0	0	0
090106/0600	18.8	17.8	11.8	166	1017.8	0.00	0	0	0
090106/0700	19.0	18.1	11.8	171	1017.5	0.00	0	0	0
090106/0800	19.0	18.1	11.3	180	1017.1	0.00	0	0	0
090106/0900	18.4	17.5	10.2	189	1016.6	0.00	0	0	0
090106/1000	17.8	16.9	9.9	192	1016.5	0.00	0	0	0
090106/1100	17.5	16.5	10.5	191	1016.3	0.00	0	0	0
090106/1200	17.3	16.3	10.5	191	1016.6	0.00	0	0	0
090106/1300	18.1	16.7	9.7	190	1017.2	0.00	0	0	0
090106/1400	21.0	17.5	9.6	189	1017.0	0.00	0	0	0
090106/1500	23.3	17.8	9.8	189	1017.4	0.00	0	0	0
090106/1600	24.9	17.6	10.5	183	1017.2	0.00	10	0	0
090106/1700	25.9	17.1	11.1	174	1016.1	0.00	10	0	0
090106/1800	26.7	16.9	11.5	164	1015.4	0.00	10	0	0
090106/1900	27.1	16.9	11.5	156	1014.3	0.00	10	0	0
090106/2000	27.1	17.4	12.1	147	1013.5	0.00	10	0	0
090106/2100	26.4	18.6	12.6	141	1013.0	0.00	10	0	0
090106/2200	25.0	19.9	13.9	141	1013.0	0.00	0	0	0
090106/2300	22.9	20.3	15.2	145	1013.3	0.00	10	0	0
090107/0000	22.5	20.1	16.4	149	1013.6	0.00	0	0	0

For Help, press F1



Data Formatting

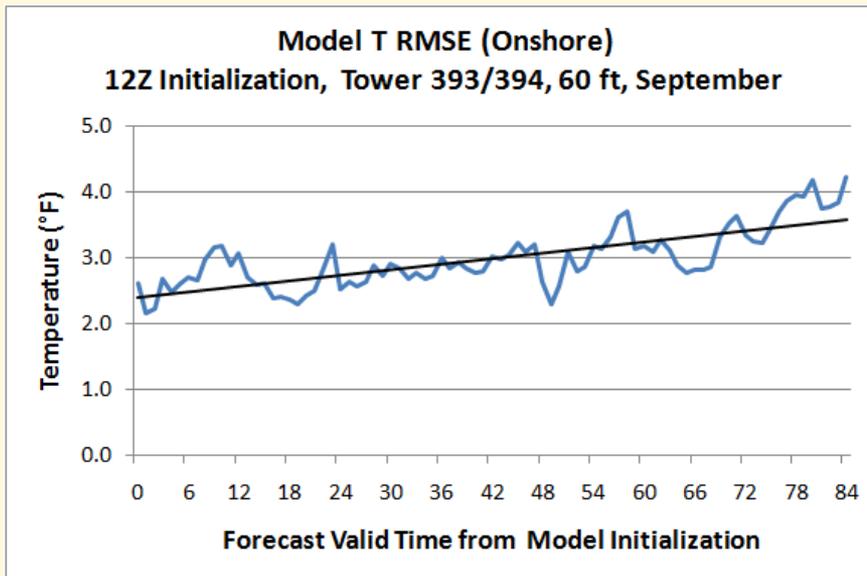
- MesoNAM files: space-delimited text files
 - Hourly forecasts
 - T and T_d in degrees °C
- Tower observations: tab-delimited text files
 - Five minute observations
 - T and T_d in degrees °F
- QC'd, Imported, Manipulated, Merged into Excel™
 - Result: 2,496 Workbooks
 - Four Worksheets per Workbook with 4,896 Charts

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Year	Month	Day	Hour	Mean Spd	Mean Dir	Mean T	Mean Td		YYMMDDHH	WRF Spd	WRF Dir	WRF T	WRF Td
2	2006	10	5	0	16.5	61	79.9	67.1		061005/0000	10.6	41	77.7	66.0
3	2006	10	5	1	15.6	64	79.8	67.0		061005/0100	15.9	51	78.4	64.0
4	2006	10	5	2	15.7	58	79.8	67.8		061005/0200	16.7	54	78.4	63.9
5	2006	10	5	3	16.2	51	79.8	68.6		061005/0300	18.6	53	78.4	65.5
6	2006	10	5	4	15.1	62	79.7	66.7		061005/0400	17.6	49	78.3	62.1
7	2006	10	5	5	12.8	67	79.5	66.1		061005/0500	16.1	44	77.0	63.3
8	2006	10	5	6	11.6	62	79.5	66.5		061005/0600	17.4	34	76.6	65.8
9	2006	10	5	7	11.7	54	79.6	66.9		061005/0700	18.2	42	76.8	67.1
10	2006	10	5	8	11.5	50	79.7	66.9		061005/0800	17.7	51	77.0	67.3
11	2006	10	5	9	12.9	50	79.4	67.5		061005/0900	16.6	53	77.0	69.4
12	2006	10	5	10	13.4	50	79.4	68.3		061005/1000	16.0	57	76.8	68.9
13	2006	10	5	11	15.0	43	79.5	70.0		061005/1100	14.9	48	76.5	67.5
14	2006	10	5	12	16.3	48	79.0	70.2		061005/1200	16.2	39	77.0	67.8
15	2006	10	5	13	17.2	48	79.3	69.4		061005/1300	15.1	37	79.3	67.6
16	2006	10	5	14	15.0	67	77.1	69.7		061005/1400	15.0	34	80.8	68.7
17	2006	10	5	15	14.4	53	78.6	70.9		061005/1500	15.8	34	81.7	71.3
18	2006	10	5	16	16.6	49	79.9	70.5		061005/1600	16.2	41	82.6	69.9
19	2006	10	5	17	16.6	49	80.3	69.8		061005/1700	15.9	50	82.6	71.3
20	2006	10	5	18	15.2	52	81.0	69.5		061005/1800	15.7	54	82.8	69.1
21	2006	10	5	19	13.6	59	81.3	69.1		061005/1900	15.2	54	82.6	70.0
22	2006	10	5	20	12.1	59	81.1	68.8		061005/2000	14.8	53	82.2	70.7
23	2006	10	5	21	11.1	51	80.9	68.7		061005/2100	14.6	55	81.1	71.1
24	2006	10	5	22	10.9	46	80.3	68.7		061005/2200	13.9	53	80.1	70.5
25	2006	10	5	23	10.4	46	79.9	69.1		061005/2300	12.8	62	79.0	70.9
26	2006	10	5	0	10.1	42	79.5	69.3		061006/0000	12.2	61	79.2	69.6
27	2006	10	5	1	10.1	37	79.5	68.6		061006/0100	11.2	56	78.8	66.2
28	2006	10	6	2	9.4	38	79.5	67.9		061006/0200	11.7	51	76.6	65.8
29	2006	10	6	3	9.8	45	79.4	67.4		061006/0300	11.7	51	75.9	65.7
30	2006	10	6	4	9.1	47	79.2	67.1		061006/0400	10	51	76.1	65.7
31	2006	10	6	5	7.6	45	78.9	67.0		061006/0500	9.9	54	76.8	65.8
32	2006	10	6	6	6.1	52	78.8	66.2		061006/0600	9.1	55	76.8	65.8
33	2006	10	6	7	6.2	44	78.7	66.2		061006/0700	8.4	56	76.6	66.0
34	2006	10	6	8	5.5	52	78.5	66.2		061006/0800	7.2	54	76.5	65.5
35	2006	10	6	9	5.4	42	78.3	66.1		061006/0900	6.5	41	74.5	65.7
36	2006	10	6	10	4.7	23	78.2	66.4		061006/1000	6.4	31	74.5	66.0
37	2006	10	6	11	3.1	357	77.0	67.0		061006/1100	6.3	22	75.4	66.2
38	2006	10	6	12	4.5	304	73.6	66.2		061006/1200	6.8	13	75.4	67.3
39	2006	10	6	13	3.8	292	74.3	66.7		061006/1300	8.0	13	78.1	65.9
40	2006	10	6	14	5.3	9	78.7	66.3		061006/1400	8.3	16	79.2	67.8
41	2006	10	6	15	6.5	23	79.7	65.3		061006/1500	8.0	23	80.4	68.5
42	2006	10	6	16	6.2	29	80.0	65.3		061006/1600	7.3	32	81.5	68.7
43	2006	10	6	17	5.9	32	80.3	65.2		061006/1700	6.9	43	82.0	68.7
44	2006	10	6	18	6.2	29	80.4	65.2		061006/1800	7.1	55	82.4	68.7
45	2006	10	6	19	6.3	23	80.5	65.7		061006/1900	7.9	62	82.2	68.5
46	2006	10	6	20	6.9	22	80.8	66.1		061006/2000	8.3	69	81.3	68.4
47	2006	10	6	21	7.7	38	80.5	66.8		061006/2100	8.2	78	80.2	68.2
48	2006	10	6	22	6.9	55	80.2	67.9		061006/2200	7.4	84	78.8	67.6
49	2006	10	6	23	5.6	61	79.6	68.6		061006/2300	6.6	97	75.4	68.0
50	2006	10	7	0	5.0	55	79.4	68.9		061007/0000	6.9	115	73.9	68.7
51	2006	10	7	1	5.8	53	79.5	68.8		061007/0100	7.2	128	73.2	69.3
52	2006	10	7	2	5.3	81	79.3	68.6		061007/0200	7.2	137	72.9	69.3
53	2006	10	7	3	3.8	129	78.7	68.3		061007/0300	7.6	151	72.7	69.3
54	2006	10	7	4	3.8	184	76.8	69.0		061007/0400	8.0	162	72.3	69.1
55	2006	10	7	5	3.5	197	75.7	69.7		061007/0500	7.5	168	71.8	68.9
56	2006	10	7	6	3.2	205	75.6	69.3		061007/0600	6.2	175	71.4	68.7
57	2006	10	7	7	4.8	237	74.4	69.8		061007/0700	3.8	195	70.9	68.7
58	2006	10	7	8	5.0	241	73.2	70.3		061007/0800	2.5	231	70.3	68.0

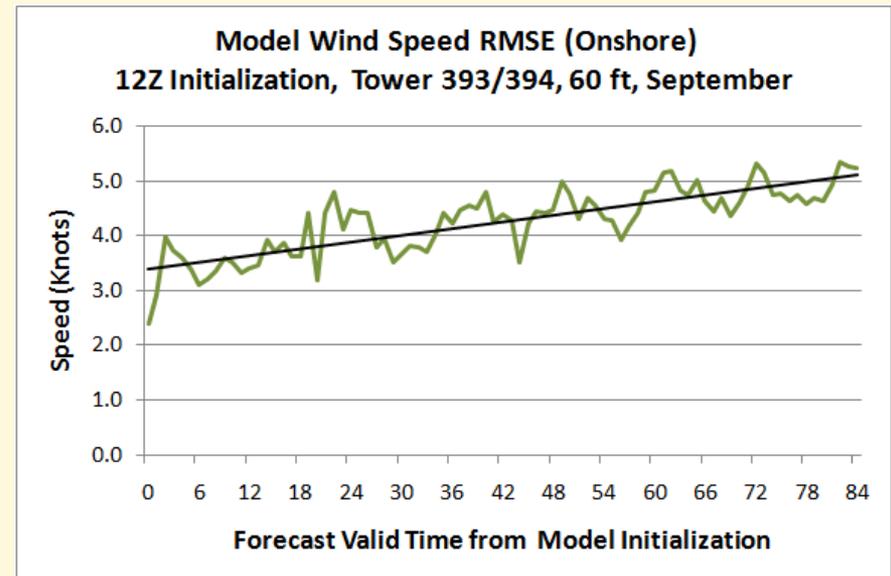


Model Error Trend

- LC 39A (Shuttle)
 - MesoNAM RMSE of temperature and wind speed
 - Model error increases during forecast period



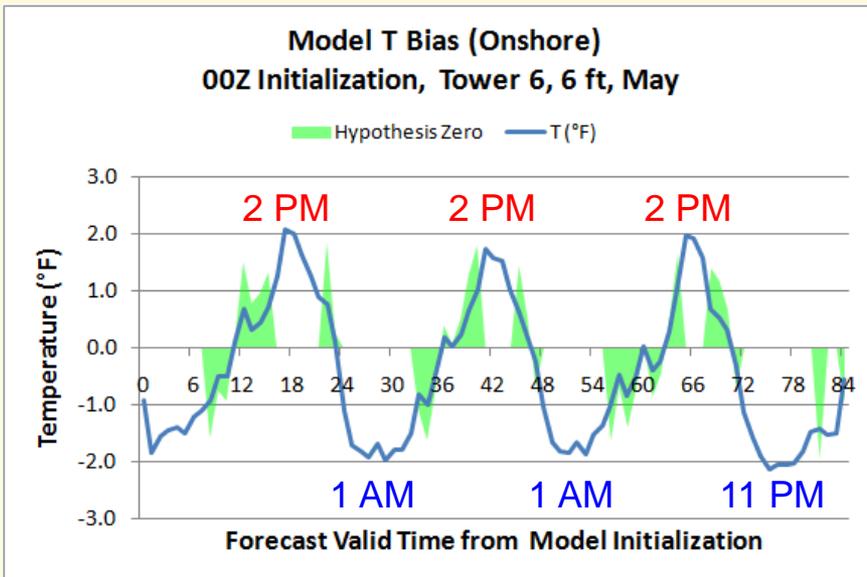
Temperature



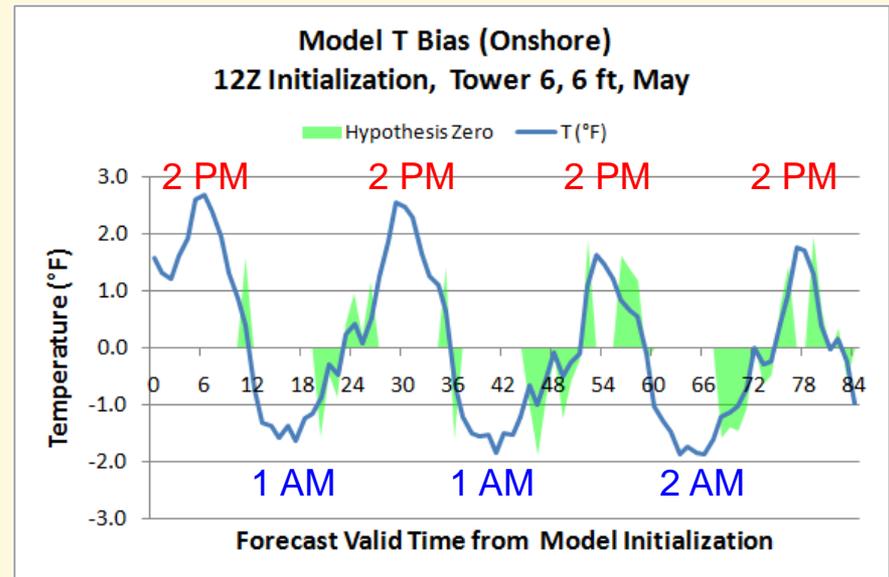
Wind Speed

Model Diurnal Bias

- Tower 006 (Delta IV)
 - MesoNAM temperature bias, 00Z and 12Z model initialization
 - Diurnal model bias
 - Warm bias local afternoon
 - Cool bias local night



00 UTC Initialization

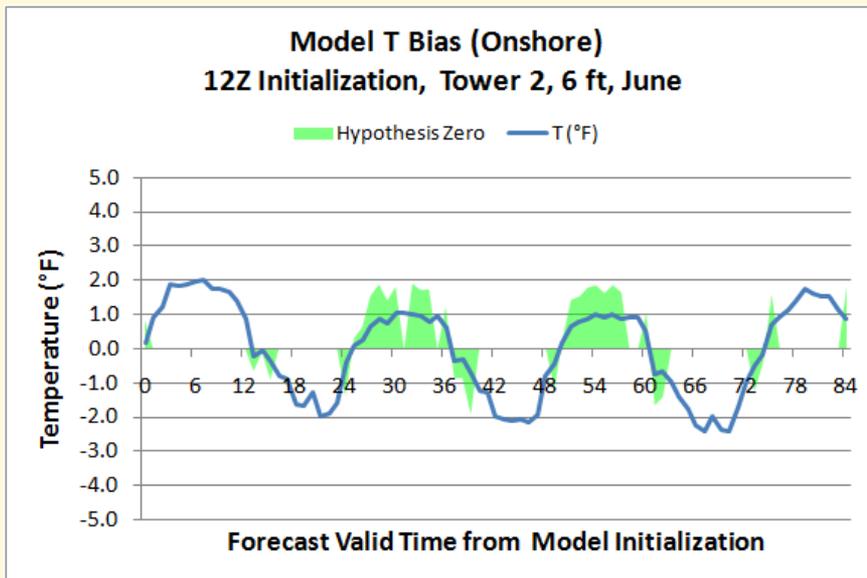


12 UTC Initialization

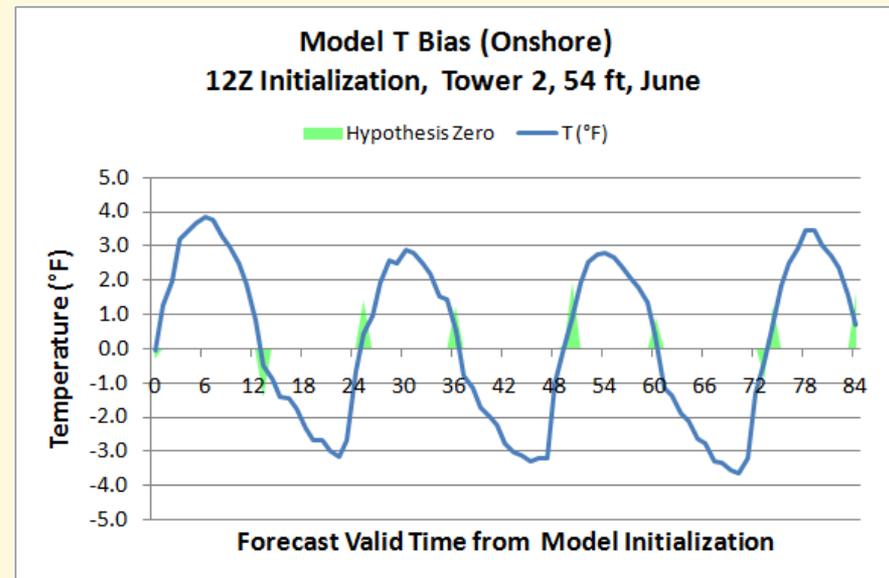


Model Forecast Level/Sensor Height

- Tower 002 (Delta II)
 - MesoNAM temperature bias, 6 ft and 54 ft sensor heights
 - Model temperature bias – model forecast at 2 m (~ 7 ft)
 - Bias smallest at 6 ft sensor height
 - Increases with height (54 ft sensor height and higher)



6 ft Sensor Height

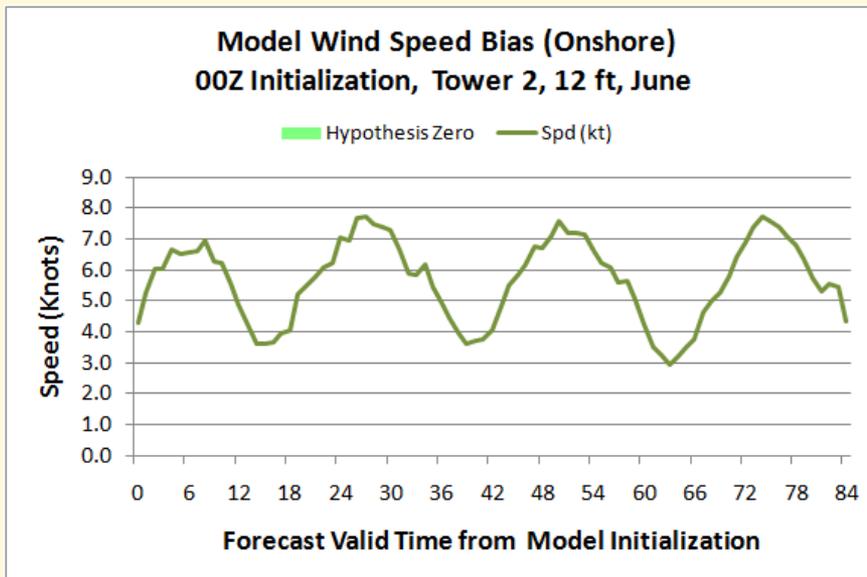


54 ft Sensor Height

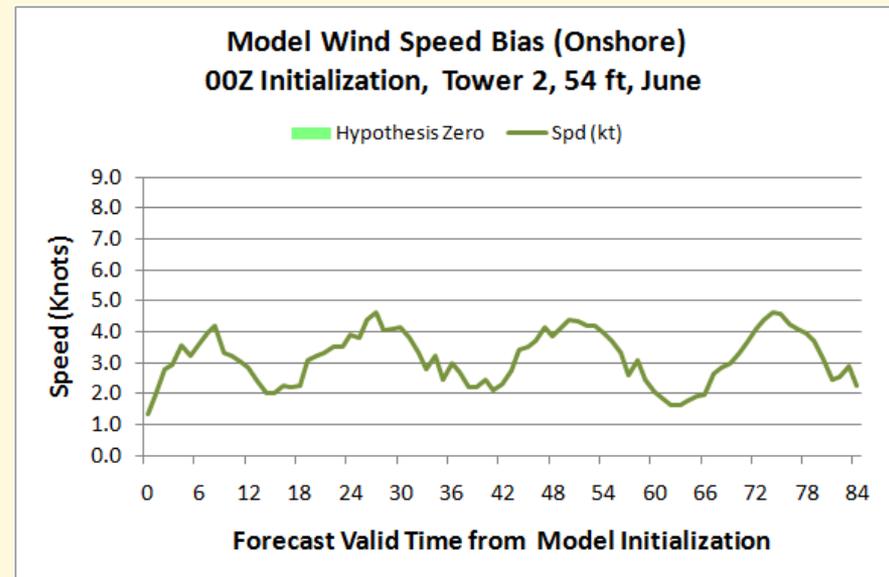


Model Forecast Level/Sensor Height

- Tower 002 (Delta II)
 - MesoNAM wind speed bias, 12 ft and 54 ft sensor heights
 - Model wind speed bias – model forecast at 10 m (~ 33 ft)
 - Bias largest at 12 ft sensor height
 - Decreases with height (54 ft sensor height and higher)



12 ft Sensor Height

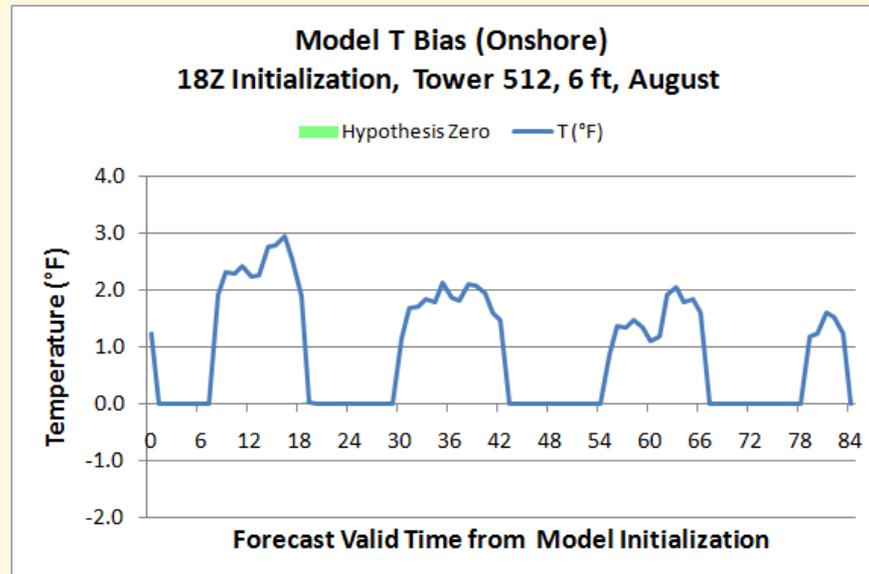


54 ft Sensor Height



Hypothesis Zero Test

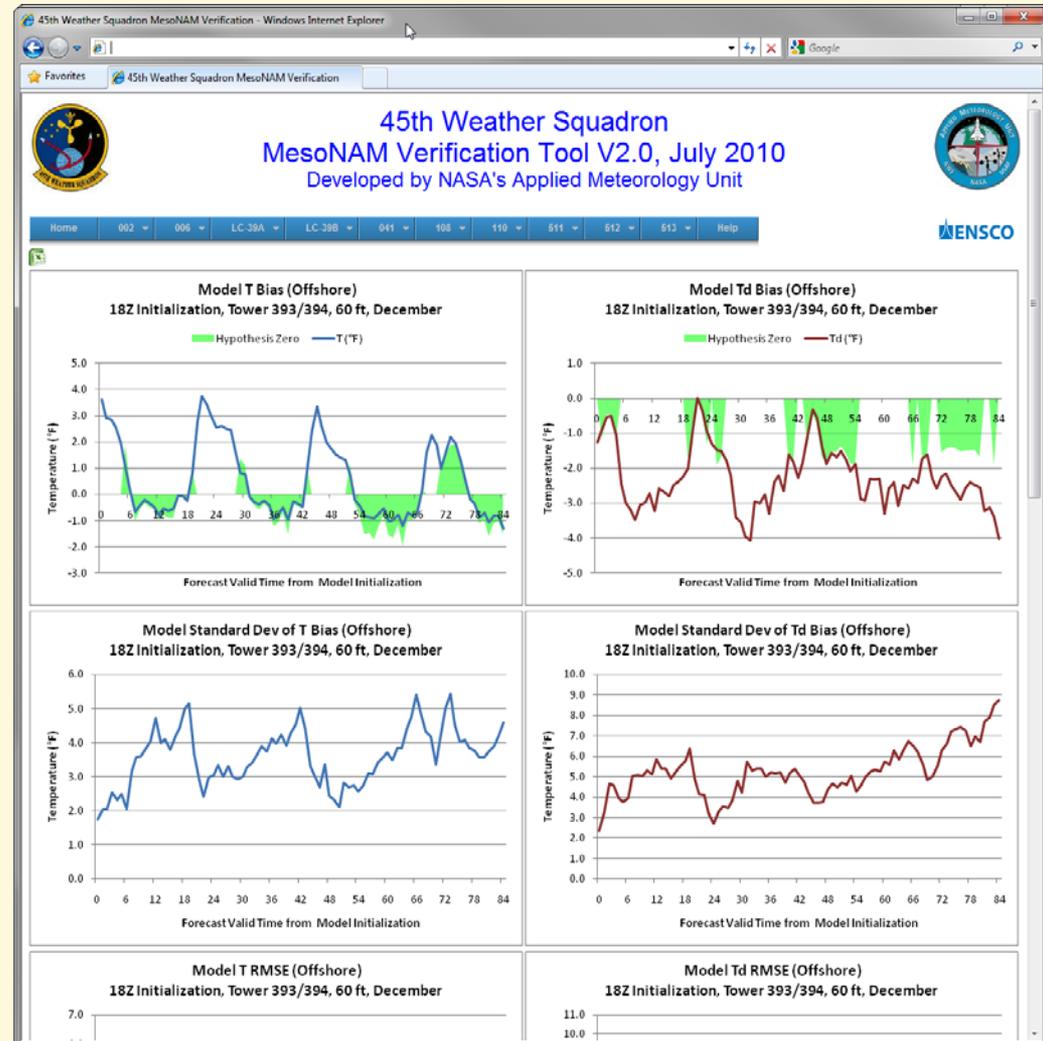
- Tower 512 (Shuttle Landing Facility)
 - Hypothesis testing uses statistics to determine the probability that a given hypothesis is true
 - Determine if the model bias of any of the parameters assessed throughout the model forecast period was statistically zero





Graphical User Interface

- Difficult and time consuming to search thousands of Excel files
- Develop GUI
 - JavaScript and HTML-based
 - Easy to navigate through all stratifications
 - Month, Fcst start time, Ht, On/Off shore flow
 - Browser and computer OS independent





Summary and Conclusions

- LWO's use MesoNAM for launch forecasts
- Model performance now evaluated objectively
- AMU conducted analysis of model versus observations
- Identifies model strengths and weaknesses
 - Model performance degrades during forecast period
 - Diurnal signals
 - Model bias vs. height varies with parameter
- Identifies when bias is not statistically different than zero
- GUI useful for navigation through data

