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Application of a Prognostic Model Validation System to Real-Time Dispersion Modeling

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7.3 APPLICATION OF A PROGNOSTIC MODEL VALIDATION SYSTEM TO REAL-TIME DISPERSION MODELING

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1. INTRODUCTION

The Atmospheric Release Advisory Capability (ARAC) at the Lawrence Livermore National Laboratory uses the U.S. Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) to supply high-resolution wind data for use in its real-time dispersion modeling system. ARAC has used COAMPS products to support several events and exercises, and COAMPS forecasts appear accurate, based on qualitative examination. Recently ARAC has developed a quantitative verification system which calculates COAMPS error and bias statistics, comparing COAMPS forecasts of various lengths with observational data. This paper shows how this system has been used to guide ARAC operators, who need an estimate of the likely behavior of COAMPS forecasts of various lengths in different regions, seasons, and weather patterns.

2. BACKGROUND

ARAC models the dispersion of hazardous materials in the atmosphere for emergency response applications. The ARAC system (Sullivan *et al.*, 1993) permits use of a variety of meteorological data sources as input to its dispersion models. Within the past year, several ARAC studies and responses (e.g. Nasstrom and Pace, 1998, Bowen *et al.*, 1998, and Pobanz *et al.*, 1999) have shown the benefit of using meteorological data generated by global or regional scale models.

COAMPS (Hodur, 1997) is a non-hydrostatic mesoscale prognostic model developed by the Naval Research Laboratory (NRL). NRL has provided the COAMPS model to LLNL for use at ARAC. COAMPS is operated for Navy operations by the Navy's Fleet Numerical Meteorological and Oceanographic Center (FNMOC).

The advantages for ARAC of using COAMPS include its high resolution in space and in time, and the model's accurate representation of a wide range of scales of atmospheric motion.

Boundary conditions for ARAC's COAMPS runs are drawn from forecasts of the Navy Operational Global Atmospheric Prediction System (NOGAPS), provided to ARAC by FNMOC, or from the Aviation Model operated by the National Centers for Environmental Prediction (NCEP).

ARAC generally runs COAMPS in a data-assimilation mode, with a 48 hour run starting every 12 hrs based on the previous run's 12 hr forecast. ARAC routinely operates COAMPS over two areas, the USWEST area over the western United States and eastern Pacific Ocean (Figure 1), and a similar USEAST area over the eastern United States and western Atlantic Ocean.

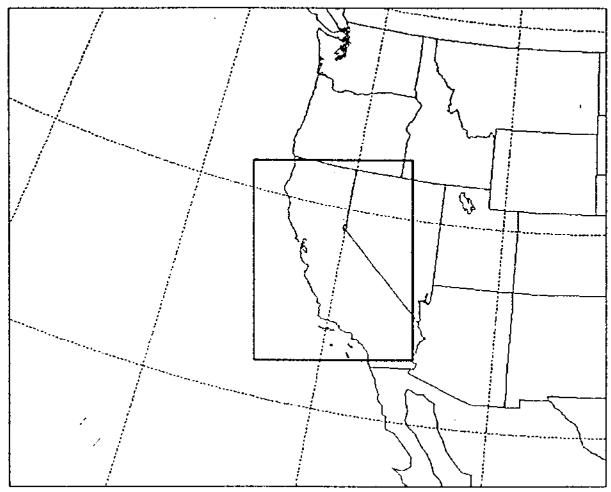

Figure 1. USWEST nests. The inner nest is the region over California, and the outer nest is the large region extending eastward from 140 degrees west to western Texas, and northward from Baja California to Canada.

COAMPS allows use of up to seven levels of nests, with each inner nest a factor of three higher resolution than the next outer nest. The USWEST and USEAST areas have two nests. For other windows, ARAC uses two, three or four nests.

The operational implementation of COAMPS at ARAC includes a very fast method for defining the grid location, allows hourly forecast products to be used soon after being generated rather than after the full model execution is completed, and allows use of up to 6 CPUs on ARAC's Dec ALPHA computers. A 48-hour forecast over the 2-nest USWEST area takes about 4 hours using 5 CPUs.

If an event occurs in an area where ARAC is running COAMPS, ARAC will use either COAMPS data alone, or COAMPS data together with observational data. If

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ARAC is not running COAMPS over the area of interest, ARAC generally starts a COAMPS run over the area, and uses observational data, NOGAPS data, or AVN data until the COAMPS data are available.

In addition to emergency response, ARAC often re-analyzes releases, sometimes long after the event (e.g. Pace (1999), Ellis *et al.*, 1998, and Pobanz *et. al.* (1999)). To support this, ARAC runs COAMPS based on NOGAPS and AVN data archived at LLNL.

3. MOTIVATION FOR VERIFICATION SYSTEM

The growing use of COAMPS by ARAC suggests a need for ARAC to understand COAMPS' error characteristics. ARAC routinely evaluates COAMPS forecasts anecdotally by comparing them with analyzed weather maps, and the forecasts usually appear to be excellent. However until recently ARAC had no way to evaluate quantitatively the accuracy of COAMPS. The system described here enables ARAC to make this evaluation.

The purposes of this system are to guide the ARAC operators using the data as to the likely accuracy of the forecasts, to reveal undesirable traits (if any) of the model or the operating system leading to improvements, and to allow quantitative evaluations of the impact of changes to COAMPS, new data sources, new operational configurations or procedures, etc.

4. APPROACH AND SYSTEM DESIGN

The current approach used in ARAC's COAMPS Verification System (CVS) is to evaluate the differences between rawinsonde observations of basic parameters (height, temperature, and winds), and COAMPS analyses and forecasts of the same parameters. The next step in the system development will be to compare COAMPS data with surface observations of the same basic parameters.

The CVS performs several procedures:

- Rawinsonde data are collected and stored
- COAMPS forecast profiles are saved
- Differences between the daily rawinsonde and COAMPS data are calculated
- The daily difference files are manipulated to generate average statistical values (root mean square error (rmse), bias, and geometric mean bias) for each variable (height, temperature, wind speed, wind direction, and the u and v wind components.)
- A plotting routine generates graphical displays

See Pace (1999) for a detailed description of these procedures.

The CVS was designed to reveal how COAMPS' error characteristics change with increasing forecast length, and how they vary in the vertical. Statistics for each rawinsonde location at each forecast length are shown separately, and are also combined to give an overall evaluation.

For example, the height rmse for a series of forecasts, all valid at a single time for a single location, is shown in Figure 2. Daily results can be combined to show the average behavior over any desired period; Figure 3 shows the bias of the v-wind component for March 1999 at a single location. An example of a combined profile, showing the wind speed rmse for all forecast lengths (0 - 72, at 12 hour increments) for all locations within the USWEST window for April 1999, is shown in Figure 4.

The CVS is adaptable to new configurations to evaluate COAMPS forecasts. For example, an intensive sampling period of the Atmospheric Radiation Measurement (ARM) project was conducted in March 1999. Rawinsonde soundings were taken at 5 locations in the ARM Oklahoma-Kansas region, at 3-hr intervals, from 1-22 March 1999. A COAMPS window (Figure 5) was set up over the region, and 72 hr, 2-nest forecasts were made through the intensive sampling period.

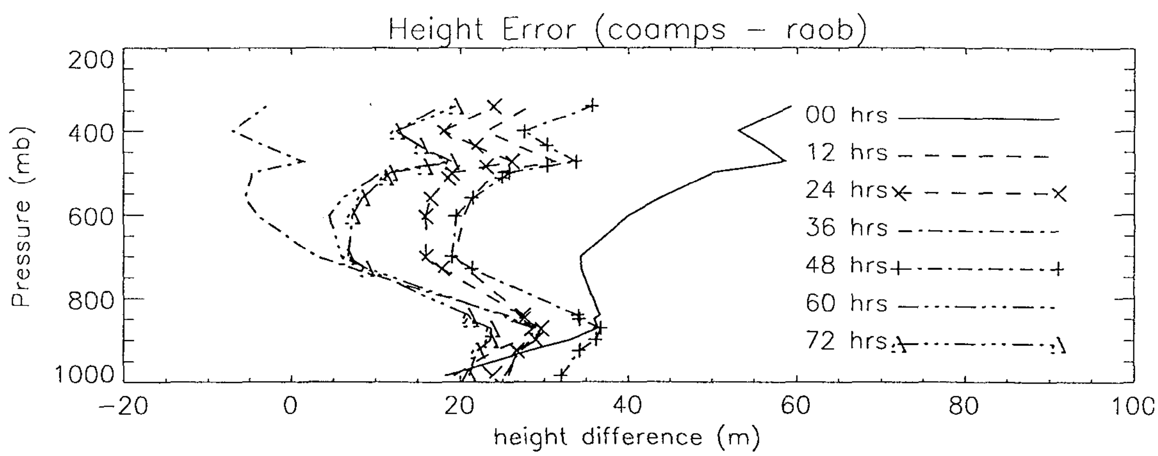

Figure 2. Height errors for COAMPS forecasts valid at 00 UTC on 30 March 1999 at Oakland CA, for forecasts of 00, 12, 24, 36, 48, 60, and 72 hrs.

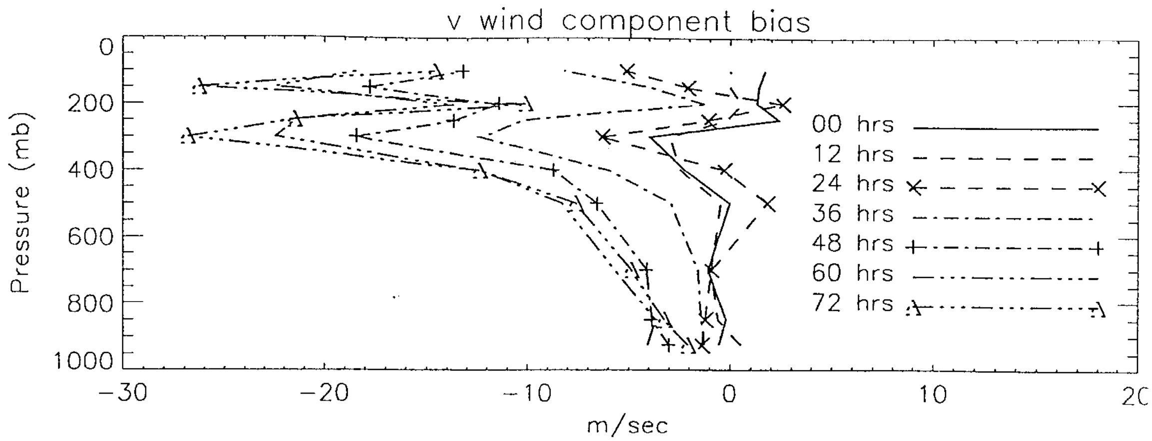

Figure 3. Average bias of the v-wind component for March 1999 at Oakland CA, for forecasts of 00, 12, 24, 36, 48, 60, and 72 hrs.

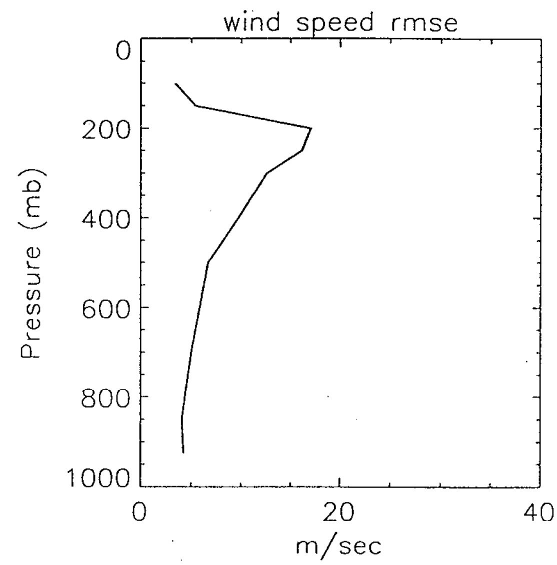

Figure 4. Wind speed rmse for all USWEST locations, for all forecast hours, for April 1999.

To match the increased rawinsonde frequency, the CVS was modified to generate statistical data at 3-hr intervals. This increased data frequency allowed closer examination of model behavior. Figure 6 shows how the temperature bias at low-levels increased almost monotonically from 0 to 72 hrs. This increase of temperature error has not been seen in other results, indicating the model's performance in the ARM region may have been affected by incorrect representation of local surface conditions. Developers can use results such as those in Figure 6 to identify areas where improvements are most needed.

5. OPERATIONAL USE OF CVS RESULTS

The CVS can provide valuable information to users of COAMPS by revealing systematic trends in its behavior. Previous CVS analyses have shown COAMPS forecasts are very accurate for the first 12-24 hours, and remain quite accurate from 24-36 hrs.

When ARAC responded to the release at the Tokaimura facility in September 1999, using the COAMPS window shown in Figure 7, these CVS results were used to select the COAMPS output files for use in ARAC's dispersion calculations. Figure 8 shows the intervals during which the hourly COAMPS forecast files were used. The release occurred at about 01Z on 30 Sept. ARAC set up its initial COAMPS run based at 12Z on 29 Sept, and the 13-18 hour forecasts from this run supplied data valid from 01-06Z on 30 Sept. The next run was based at 00Z on 30 Sept, and the 7-18 hour forecasts supplied data valid at 7-18Z. This pattern was followed with subsequent forecasts. Thus, the part of the forecasts with the highest degree of accuracy was used in ARAC's dispersion calculations.

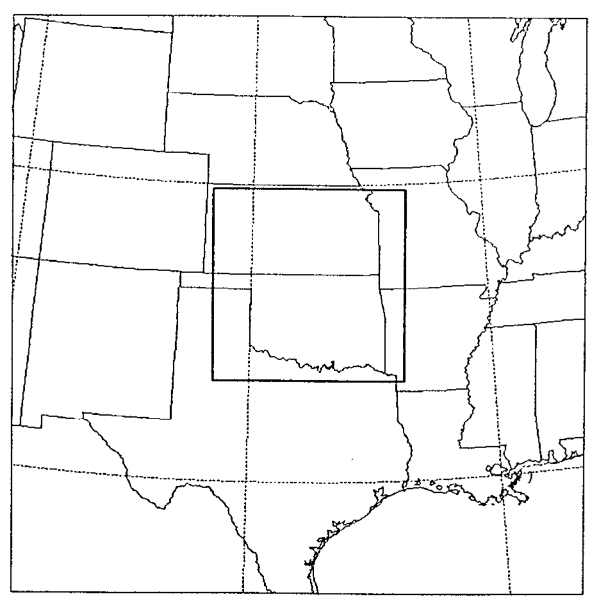

Figure 5. COAMPS nests used for ARM project.

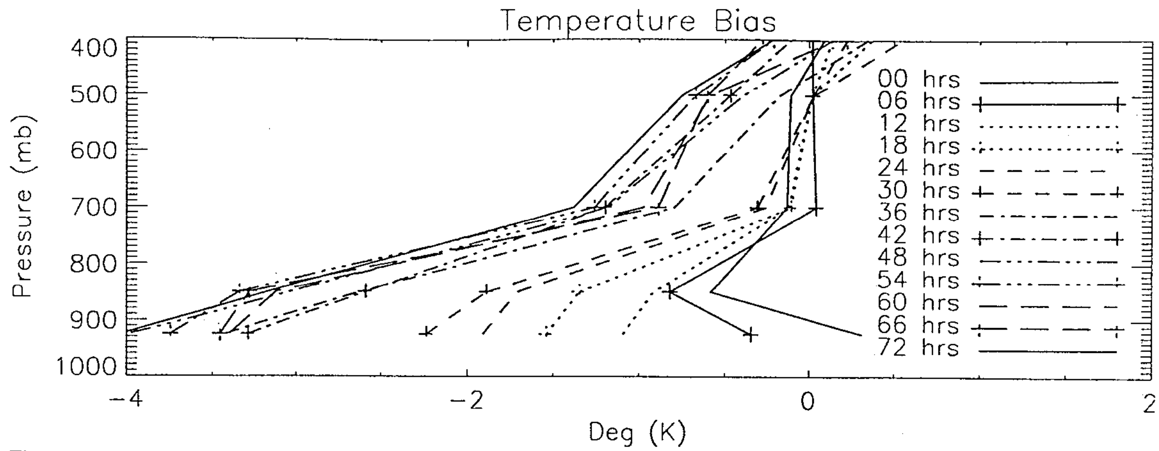

Figure 6. Average low-level temperature bias for 1-22 March 1999 for the five ARM sounding locations, for forecasts of 00, 06, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66 and 72 hrs.

6. TOKAIMURA RESULTS

The agreement between the observed wind patterns around the Tokaimura release location and the COAMPS predicted wind fields appeared to be excellent. Figure 9 shows observed winds reported at 01Z on 30 Sept over the eastern part of the main island of Japan, where the Tokaimura facility is located. Figure 10 shows the 13 hour COAMPS forecast valid at that time. The area shown in Figure 9 corresponds to the middle of Figure 10, about 1/3 down from the top of the figure.

Note the easterly on-shore flow along the coast in the northern part of Figure 9, with northerly winds at the cape farther south. Also note the convergence line west of the coast. Very similar features are seen in the streamlines in Figure 10. This agreement between COAMPS and observations was typical of the forecasts throughout the period of interest.

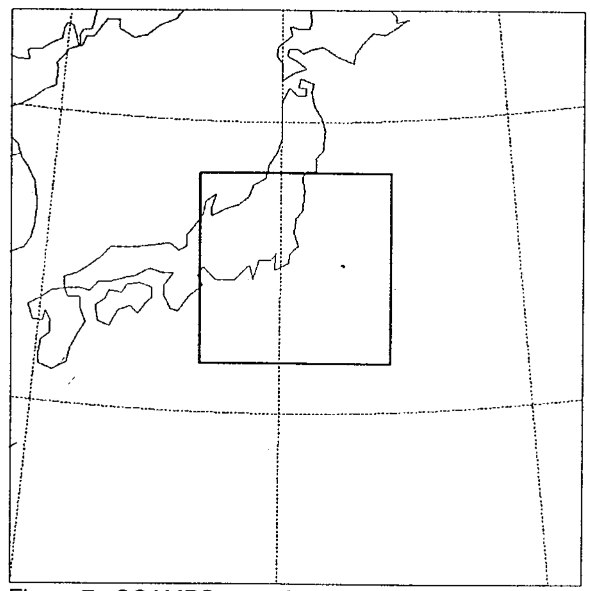

Figure 7. COAMPS nests for Tokaimura response.

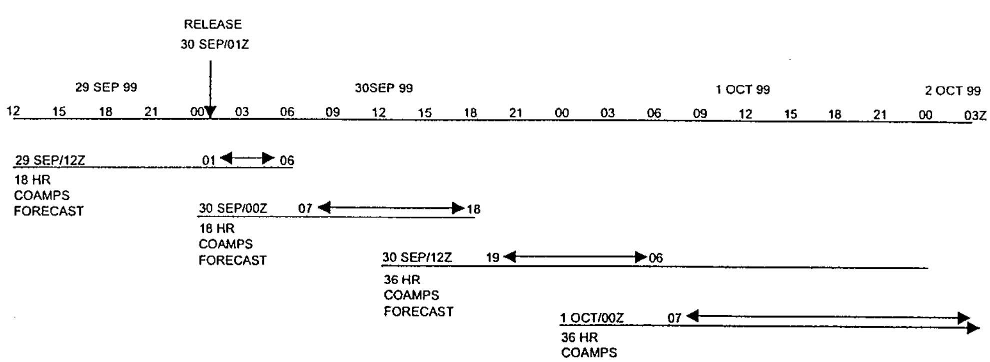

Figure 8. Timeline showing which COAMPS executions supplied forecast data for dispersion calculations.

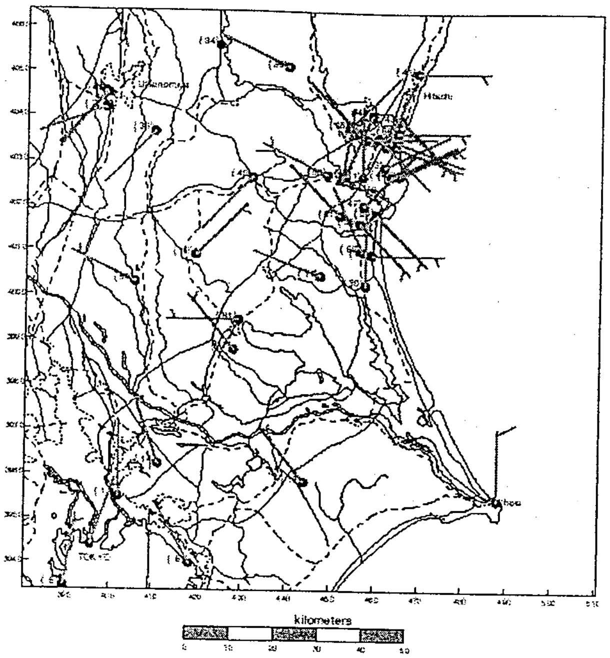

Figure 9. Observed near-surface winds at 01Z on 30 Sept over eastern Japan.

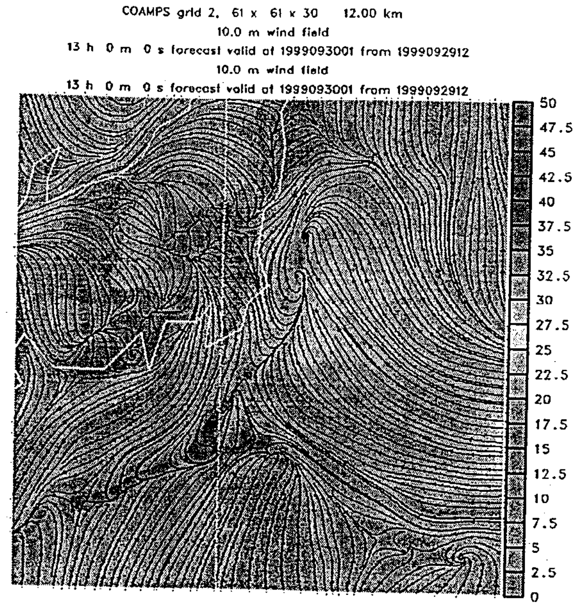

Figure 10. COAMPS 13-hour forecast valid at 01Z on 30 Sept, showing winds at 10 m AGL.

Error statistics for these forecasts were calculated to help users interpret the results of other evaluations. Hourly wind observations were obtained from 29 locations in the Tokaimura area. Error statistics (rmse and bias) were calculated at each of the 29 stations over 49 hours (hourly, from 02Z on 30 Sept to 02Z on 2 Oct), and for all 29 stations (Table 1). The same statistical parameters were also calculated for each of the 49 hours, and for the entire 49 hour period (Table 2).

The bias values were generally quite small: the overall direction and speed bias values were -4.52 degrees and 0.10 m/sec; 17 stations had direction bias values smaller than ±10 degrees; and 15 stations had speed biases smaller than ±1 m/sec. The hourly variation in direction bias shows larger errors from 02-04Z (1100-1300 local) on 30 Sept and after 23Z on 1 Oct than between these periods, suggesting a diurnal pattern. However, no corresponding increase in errors was seen after 00Z on 1 Oct, perhaps because of the higher wind speeds observed then.

The rmse values were larger than expected, based on the agreement between the maps. The speed rmse values are, on average, about 80% of the observed speeds. And, although 8 stations and 12 hours had direction rmse values of less than 50 degrees, the overall value was 66.30. These results provide guidance about the magnitude of forecast errors one might expect for good forecasts in fairly light wind conditions.

STATION ID	DIRECTION BIAS	DIRECTION RMSE	SPEED BIAS	SPEED RMSE
RJAA	-3.70	45.66	-1.07	1.46
RJAH	17.41	43.91	-0.11	1.79
RJAI	8.20	60.80	1.52	2.60
RJAK	-1.92	28.43	-1.49	1.93
RJSF	-25.72	49.89	-2.64	3.20
RJTC	8.48	64.49	-1.50	2.24
RJTF	-12.00	63.72	-1.89	2.30
RJTI	-37.56	75.31	-1.04	1.96
RJTJ	-0.20	56.87	-0.15	1.44
RJTK	1.79	43.96	0.68	2.26
RJTL	-9.39	50.71	-0.20	1.60
RJTR	-2.35	42.29	-1.10	1.65
RJTT	-22.99	51.19	-0.88	1.90
RJTU	38.44	91.46	-0.87	1.95
RJTY	5.08	52.90	-0.85	1.55
47570	-3.55	76.01	0.50	2.10
47595	2.38	85.23	-0.62	2.16
47597	-14.85	62.91	-1.07	2.92
47598	-19.95	64.04	2.16	2.66
47615	-2.17	89.25	-0.65	1.62
47624	3.27	87.99	0.24	1.72
47626	-8.77	82.52	-0.42	1.39
47629	18.63	49.95	0.46	1.46
47641	0.59	89.53	0.54	1.94
47648	0.52	36.47	2.55	3.14
47670	-32.05	56.25	1.43	2.21
47674	-21.68	70.52	3.52	4.22
47682	6.15	49.67	-0.46	1.68
47690	-11.17	95.59	1.27	2.07
TOTAL	-4.52	66.30	0.10	2.19

Table 1. COAMPS error statistics for near-surface wind direction and speed, at each station.

VALID TIME	DIR BIAS	DIR RMSE	SPEED BIAS	SPEED RMSE	AVG SPEED
30/02Z	-33.04	76.80	-1.24	1.67	2.34
30/03Z	-35.37	78.88	-1.89	2.64	2.80
30/04Z	-10.11	83.85	-1.89	2.49	2.71
30/05Z	7.27	71.29	-2.46	2.93	3.18
30/06Z	3.41	65.98	-2.46	3.07	3.37
30/07Z	-8.12	70.88	-2.31	2.82	3.37
30/08Z	24.37	80.01	-2.37	3.05	3.47
30/09Z	-10.11	75.72	-1.77	2.50	3.14
30/10Z	-23.83	77.33	-0.77	1.89	2.68
30/11Z	-14.85	76.75	-0.24	1.65	2.62
30/12Z	-22.21	77.76	0.03	1.98	2.55
30/13Z	-20.58	60.66	0.23	2.11	2.64
30/14Z	-6.39	58.61	0.91	2.01	2.31
30/15Z	-23.08	51.97	1.49	2.21	1.94
30/16Z	-17.19	53.01	1.62	2.48	2.00
30/17Z	-6.27	40.31	1.57	2.31	2.33
30/18Z	-30.49	52.66	1.93	2.71	2.13
30/19Z	0.31	48.30	1.80	2.72	2.27
30/20Z	7.13	43.08	1.60	2.48	2.35
30/21Z	0.72	55.81	1.12	2.17	2.63
30/22Z	-16.02	66.46	1.03	1.96	2.72
30/23Z	-13.03	73.68	-0.22	1.69	3.72
1/00Z	1.90	57.32	-0.37	1.99	4.00
1/01Z	5.57	43.23	-0.33	2.35	3.94
1/02Z	-3.25	54.80	-0.24	2.36	3.90
1/03Z	6.63	43.49	-0.36	2.32	3.98
1/04Z	15.25	42.07	-0.36	2.35	4.02
1/05Z	17.95	49.74	-0.68	2.17	4.21
1/06Z	9.68	65.19	-0.30	1.84	3.81
1/07Z	25.64	56.25	0.25	1.86	3.55
1/08Z	20.50	42.72	0.27	1.63	3.49
1/09Z	18.11	48.00	0.35	1.41	3.12
1/10Z	25.08	63.59	0.35	1.38	2.95
1/11Z	-8.61	58.72	0.31	1.69	2.81
1/12Z	-17.03	48.65	0.63	1.87	2.50
1/13Z	-11.66	51.72	0.91	1.78	2.45
1/14Z	6.71	52.94	1.25	2.28	2.31
1/15Z	-7.63	67.30	1.38	2.04	2.18
1/16Z	-1.49	65.05	1.51	2.09	2.14
1/17Z	10.02	49.49	1.66	1.97	2.11
1/18Z	-18.39	69.07	1.73	2.12	1.94
1/19Z	-25.31	68.76	1.70	2.02	1.92
1/20Z	-13.65	60.87	1.80	2.20	1.77
1/21Z	-9.25	59.68	1.67	1.91	1.81
1/22Z	20.62	48.86	1.88	2.19	1.35
1/23Z	22.10	83.26	1.55	1.84	1.42
2/00Z	-13.91	96.32	1.10	1.91	1.34
2/01Z	-58.36	124.31	-0.33	1.62	2.17
2/02Z	-38.07	118.78	-1.29	1.96	2.74
TOTAL	-4.52	66.30	0.10	2.19	2.80

Table 2. COAMPS error statistics at each forecast hour.

7. SUMMARY

ARAC's CVS provides a powerful, flexible tool for many applications. Its continued use will enable better use of COAMPS forecats in ARAC's operational system, and will enable model developers to target areas of needed improvement.

8. ACKNOWLEDGMENT

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