A METEOROLOGICAL REANALYSIS FOR 1991 PERSIAN GULF WAR

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1. INTRODUCTION

In support of the DoD's Gulf War Illness study, global and mesoscale meteorological re-analyses were conducted for a short duration (Westphal et al. 1999; Warner and Sheu, 2000). Now a two-month continuous meteorological reanalysis is performed to provide a quantitative atmospheric characterization of the Gulf region during the period between Jan 15 and March 15, 1991 to cover the entire Gulf War period. The archived operational products during the conflict are not adequate in spatial and temporal resolution to drive dispersion models for chemical contaminants and other environmental quality assessments. The reanalysis is conducted with Navy's operational global and mesoscale analysis and prediction systems: NOGAPS (Rosmond 1992, Hogan and Rosmond 1991; Hogan and Brody 1993) and COAMPS (Hodur 1997). The re-analyzed global and mesoscale fields can provide a synoptic and climatic description of the state of the atmosphere during the two month period in the early months of 1991. The purpose of this paper is to present the validation of the re-analysis. A brief review of pf the prediction systems, NOGAPS and COAMPS, will be given in the next section. The procedure of the re-analysis will be discussed in Section 3. In section 4, the validation of the reanalysis as compared to available rawinsonde observations will be shown.

2. THE PREDICTION SYSTEMS

The global prediction system NOGAPS includes a global spectral model and a data assimilation and quality control front-end. The hydrostatic dynamic model used in this analysis has 159 triangular harmonic truncation (T159) and 24 vertical layers (L24) in a σ-P vertical coordinate. Data quality control and the multivariate optimum interpolation analysis (MVOI) are the major components of the data assimilation system of NOGAPS. The quality control of the observations in the global database at FNMOC includes checking for gross errors and for internal consistency (Baker 1992). The complex quality control (CQC) of rawinsondes developed at NCEP is part of the QC suite (Baker 1994). In the data assimilation cycle of NOGAPS, the 6-h NOGAPS forecast provides the background fields (first guess). The MVOI technique utilizes observed data to compute increments to the background fields in such a way that the mean squared error of the analysis will be minimized statistically (Barker 1992; Goerss and Phoebus 1992).

The atmospheric component of COAMPS (Hodur 1997) with non-hydrostatic dynamics is used for the mesoscale analysis and prediction. A triply nested version of COAMPS with horizontal resolution of 45, 15, and 5 km is applied for the reanalysis. The domain of COAMPS covers the 1991 Gulf War Theater (Fig 1). The model has 30 σ-Z vertical levels with the highest vertical resolution in the planetary boundary layer, where the first few levels are at 10, 25, 55m, and etc. The COAMPS re-analysis uses the re-analyzed NOGAPS fields as lateral boundary conditions and initial conditions in a cold start. The COAMPS reanalysis also uses MVOI for data assimilation. Only observations in the COAMPS domain are used in the reanalysis.

There are a few improvements in this two-month analysis as compared to Westphal et al. (1999). Improvements are (1) more vertical layers (from 18 to 24) in NOGAPS, (2) more rawinsonde and surface data from NCDC which became available from various data archives, and 3) a global SST reanalysis. An additional improvement pertinent for the high resolution reanalysis is the utilization of a 1-km land-use data set. The global 1-km land-use data base gives albedo, soil temperature and ground wetness resulting in a better accuracy of those variables.

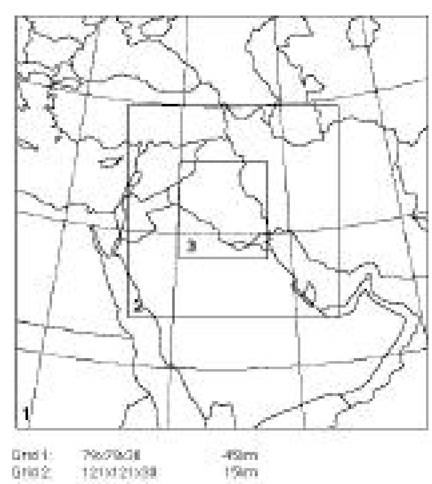

Figure 1. COAMPS triple-nested reanalysis domain with spatial resolution of 45, 15, and 5 km.

3. REANALYSIS PROCEDURE

The NOGAPS reanalysis starts from the archived operational global analyses at 00 UTC 31 Dec 1991. The re-analysis proceeds with a 6-hour data assimilation cycle, ending at the cycle of 18 UTC Mar 31 1991. NOGAPS reanalyzed fields are archived every 6 h.

The reanalysis of COAMPS starts at 00 UTC 13 January with the reanalyzed NOGAPS fields. A 12-h data assimilation cycle is used due to the lack of observation at 6 and 18 UTC within the COAMPS domain. In fact, over the entire two-months, there are no land-based observations available from Iraq. The COAMPS reanalysis stops at 00 UTC 16 March 1991. COAMPS reanalysis fields are archived hourly starting from 00UTC 15 January to 00 UTC 16 March 1991.

4. VERIFICATION OF CURRENT REANALYSIS

In order to establish the validity of the current reanalysis, a set of verification skill scores, which include bias (B), root mean square error (RMSE) and absolute error (AE) are calculated for the two-month analysis and that of Westphal et al. (1999). Only rawinsonde observations are used for comparison due to its better-known quality and errors.

For a given variable x, bias (B) is defined as

$$B(x) = \frac{1}{N} \sum_{n=1}^{N} (x_n^f - x_n^0) \qquad (1)$$

where N is the total number of observed values used in the calculation and the superscript *f* and *0* denote reanalyzed and observed values. While bias may cancel large errors of different signs, absolute error can reveal the true averaged error of a model. The absolute error (AE) is defined as

$$AE(x) = \frac{1}{N} \sum_{n=1}^{N} \left| x_n^f - x_n^0 \right| \qquad (2)$$

Another standard verification score to measure a model's performance is the root-mean square error, RMSE, which tends to give more weight to large errors and is defined as

$$RMSE(x) = \left[\frac{1}{N} \sum_{n=1}^{N} (x_n^f - x_n^0)^2 \right]^{1/2} \qquad (3)$$

All verification skill scores are calculated for the mandatory pressure levels from 1000 to 100 hPa.

Due to the lack of rawinsonde observations in the inner most domain of COAMPS (see Fig 13 of Westphal et al. 1999), the aforementioned skill scores are computed over nest 2 (with resolution of 15 km). Two sets of comparisons are presented here. The first set compares the current improved version of NOGAPS and COAMPS (as described in Section 2) with an older version used in Westphal et al. (1999). The skill scores over a short 36-h window from 00 UTC 8 Feb to 12 UTC 10 Feb are used, because of the unavailability of the reanalysis generated by the older version. Table 1 shows the comparison of the 12-h forecast verification scores. It is obvious that the reanalysis produced by the current vision of prediction systems reduces error measured by all three scores and for altitudes, especially for the 850-1000 h Pa level. We believe that it is mainly due to the adoption of the 1-km land use data resulting in better estimate of albedo, soil temperature and ground wetness. Another factor is the inclusion of previously unavailable rawinsonde data from NCDC. The wind direction error in the lower levels, however, is not reduced as much as other measures.

The second comparison is with other similar mesoscale models. Errors computed from analysis (0h) and forecast (12h) of the two-month reanalysis are also presented. Skill scores used for comparison are based on White et al. (1999). They compared the short-term forecast accuracy of six different models over the western United States for January, February and March 1996. These six models are the Medium Range Forecast (MRF), Nested Grid Model (NGM), the regional and mesoscale Eta models (ETA and MESO, respectively), the PSU/NCAR Mesoscale Model Version 5 (MM5), and the Utah Limited Area Model (ULAM). Comparing these model forecasts and the COAMPS reanalysis does not follow a set of stringent requirements used in a typical model intercomparison. Nevertheless, the comparison serves the purpose of ensuring the general behavior of COAMPS reanalysis, which is produced over a region almost completely devoid of *in situ* observations as opposite to the relatively data rich western U.S. As shown in Tables 2-5, COAMPS analysis and 12h forecast results are in general comparable and, in many cases, better than those in White et al. (1999). Errors in COAMPS humidity fields are large in comparison. An effort is undertaken to improve this aspect of the COAMPS model and analysis procedure.

5. CONCLUSIONS

The two-month reanalysis by the Navy global and mesoscale prediction systems NOGAPS and COAMPS is evaluated. It is encouraging that improvements made to both prediction systems lead to a reduction of error statistics. When compared with other mesoscale models with similar resolution covering complex terrains (in different geographic locations), the two-month reanalysis produced for the study of the Gulf War Illness shows similar if not smaller error statistics. It thus can be concluded that the combination of adequate global and nested mesoscale models, coupled with effective data assimilation, can be a powerful tool to characterize the atmospheric environment for many analysis and forensic applications.

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	RMSE		Bias		AE	
Wind speed (m/s)	**old**	**new**	**old**	**new**	**old**	**new**
1000 < Z < 850 mb	5.20	3.32	0.53	-1.15	4.28	2.44
850 < Z < 500 mb	7.98	3.16	2.67	-0.20	6.44	2.42
Wind direction (degree)						
1000 < Z < 850 mb	81.05	59.03	42.82	9.69	63.58	46.04
850 < Z < 500 mb	62.02	36.86	13.71	2.22	47.30	22.88
Temperature (^{0}C)						
1000 < Z < 850 mb	4.19	1.29	1.17	0.12	3.52	0.96
850 < Z < 500 mb	3.86	1.29	0.51	0.23	3.11	1.01
RH (%)						
1000 < Z < 850 mb	36.83	17.35	-5.03	1.42	28.13	14.13
850 < Z < 500 mb	34.30	21.29	3.27	4.23	25.11	16.16

Table 1 Verification scores of 12h forecast data calculated from the current and the previous reanalyses of COAMPS for Al Muthana case (00UTC 8 and 12UTC 10 February 1991).

	ETA	NGM	MRF	MESO	MM5	ULAM	COAMPS
			Geopotential Height (m)				
300 mb	-6.54	-8.80	-2.96	-5.94	-16.64	1.25	-0.83
500 mb	-3.9	-3.26	-4.05	-3.58	-10.83	-3.25	-0.51
700 mb	-1.17	-0.54	-2.15	-0.87	-5.95	-5.33	-0.41
			Temperature (^{0}C)				
300 mb	-0.67	-0.48	0.10	-0.57	-0.30	0.11	-0.12
500 mb	-0.60	-0.53	0.02	-0.47	-0.51	-0.20	-0.10
700 mb	-1.22	-0.62	0.12	1.55	-1.08	-0.74	-0.02
			Wind (m/s)				
300 mb	0.70	0.86	0.90	0.72	0.74	0.88	-0.25
500 mb	0.62	0.86	0.74	0.56	0.60	0.75	-0.13
700 mb	0.74	1.24	1.05	0.59	0.82	0.89	-0.11
			Relative Humidity (%)				
300 mb	-0.67	3.33	12.88	13.72	2.54	-2.65	3.23
500 mb	0.72	-0.37	-1.65	1.27	-1.55	0.69	0.08
700 mb	2.45	0.06	0.39	4.19	1.28	1.73	-3.42
Resolution	**48km**	**83km**	**~100km**	**29km**	**27km**	**30km**	**15km**

Table 2. Analysis Bias from COAMPS and six models used in White et al. (1999).

	ETA	NGM	MRF	MESO	MM5	ULAM	COAMPS
			Geopotential Height (m)				
300 mb	15.00	18.31	18.67	15.32	23.24	17.94	9.44
500 mb	9.07	11.09	12.56	9.45	17.31	14.84	7.57
700 mb	6.02	8.79	9.66	6.83	12.16	15.15	5.67
			Temperature (^{0}C)				
300 mb	1.27	1.40	1.16	1.37	1.16	1.31	0.98
500 mb	1.18	1.22	1.09	0.99	1.04	1.19	0.78
700 mb	1.64	1.34	1.28	2.08	1.57	1.39	0.90
			Wind (m/s)				
300 mb	3.80	4.75	5.90	3.63	4.04	4.46	3.06
500 mb	3.21	4.18	4.65	3.04	3.30	3.90	2.33

700 mb	2.70	3.90	4.02	2.32	2.89	3.07	2.19
			Relative Humidity (%)				
300 mb	16.16	18.51	19.72	21.21	12.04	14.02	12.40
500 mb	11.62	9.17	14.28	10.75	11.67	12.78	15.20
700 mb	9.16	8.41	14.07	9.70	10.20	10.53	18.46
Resolution	**48km**	**83km**	**~100km**	**29km**	**27km**	**30km**	**15km**

Table 3. Same as Table 2 except for analysis RMSE.

	ETA	NGM	MRF	MESO	MM5	ULAM	COAMPS
			Geopotential Height (m)				
300 mb	3.69	-5.30	-4.01	3.83	2.92	12.90	-6.54
500 mb	4.02	-5.50	-8.70	1.87	3.09	-0.35	-7.03
700 mb	6.16	-3.94	-6.71	3.53	6.55	-9.96	-5.76
			Temperature (^{0}C)				
300 mb	0.24	0.53	0.93	0.28	0.68	1.19	-0.28
500 mb	-0.30	-0.27	0.06	-0.14	-0.15	0.41	-0.23
700 mb	-0.70	-0.26	-0.05	-0.49	-0.55	0.85	0.05
			Wind (m/s)				
300 mb	1.32	1.95	2.20	1.28	1.72	1.95	-0.60
500 mb	1.06	1.09	1.21	1.09	1.70	1.54	-0.04
700 mb	1.49	1.43	1.34	1.22	1.55	2.03	0.02
			Relative Humidity (%)				
300 mb	-6.30	11.90	15.57	8.08	2.44	-2.05	18.32
500 mb	0.80	2.78	2.61	1.66	-0.72	-2.75	4.52
700 mb	1.98	0.40	1.31	1.10	-0.84	5.05	-3.21
Resolution	**48km**	**83km**	**~100km**	**29km**	**27km**	**30km**	**15km**

Table 4. Same Table 2 except for the 12h forecast bias.

	ETA	NGM	MRF	MESO	MM5	ULAM	COAMPS
			Geopotential Height (m)				
300 mb	21.78	24.79	22.96	19.73	23.55	26.65	19.75
500 mb	17.50	21.05	19.05	15.44	19.27	19.01	17.43
700 mb	15.21	17.92	14.81	13.91	16.44	19.35	14.90
			Temperature (^{0}C)				
300 mb	1.64	1.95	1.78	1.63	1.85	2.17	1.93
500 mb	1.49	1.70	1.52	1.41	1.57	1.69	1.47
700 mb	1.63	1.64	1.42	1.52	1.68	1.93	1.59
			Wind (m/s)				
300 mb	8.13	8.62	8.15	7.68	7.94	8.13	6.37
500 mb	6.05	6.48	6.14	6.12	6.61	6.69	4.76
700 mb	5.55	5.85	5.39	5.46	6.23	6.85	4.02
			Relative Humidity (%)				
300 mb	18.72	27.30	22.90	16.69	14.57	18.87	32.34
500 mb	19.56	24.51	19.11	19.41	21.06	22.27	26.21
700 mb	18.30	22.11	18.98	17.73	19.64	22.60	25.66
Resolution	**48km**	**83km**	**~100km**	**29km**	**27km**	**30km**	**15km**

Table 5. Same Table 2 except for the 12h forecast RMSE.