Numerical Experimental Analysis Data for the Year of 2002

Da-Lin Zhang and Shunli Zhang
Department of Atmospheric and Oceanic Science, University of Maryland
College Park, MD 20742
Tel. (301) 405-2018; Email: dalin@atmos.umd.edu

1. Introduction

A total of 128 numerical experiments, in 3-day segments, for the year of 2002 (i.e., from 0000 UTC 14 December 2001 to 0000 UTC 1 January 2003) have been conducted on our newly purchased Cluster using the nested-grid (36/12 km) Version 3.6 of the PSU/NCAR mesoscale model (i.e., MM5). The NCEP's Eta analysis with 40-km resolution was used to initialize the model integrations and specify the outmost lateral boundary conditions. To minimize the influence of model errors but retain as many mesoscale circulations as possible, the dynamical nudging or four-dimensional data assimilation (FDDA) technique was adopted to include observations of the surface winds and upper-level meteorological information. More attention was paid to the accuracy of surface winds due to their important roles in ozone transport. The model integrations were re-initialized every 3.5 days, allowing a 12-h period for the model spin-up (i.e., the first 12-h data could be truncated in the application of the datasets). Hourly model outputs were archived for the period of 12.5 months. This four-dimensional high resolution (in time and space) analysis dataset so assimilated was generated for air quality modeling and for regional haze studies. These integrations yielded a total of 830 Gbytes analysis data.

2. Model description

The Version 3.6 of MM5 with a Lambert conformal map projection, an MPP Version developed for clusters, was used for this project. The (x, y) dimensions of the coarse (36 km) and fine (12 km) mesh domains are 149 x 129 and 175 x 175, respectively. The vertical discretion uses terrain-following σ-coordinates, but the pressure at the σ-levels are determined from a reference state that is estimated using the hydrostatic equation from a given sea-level pressure and temperature with a standard lapse rate. There are 30 uneven σ levels, giving 29 layers, with higher resolution in the planetary boundary layer (PBL). The σ levels are placed at the following values:

1.000, 0.9974, 0.994, 0.989, 0.9820, 0.972, 0.959, 0.943, 0.923, 0.8990, 0.871, 0.839, 0.803, 0.763, 0.718, 0.668, 0.618, 0.568, 0.518, 0.468, 0.418, 0.368, 0.318, 0.268, 0.218, 0.168, 0.123, 0.080, 0.040, 0.00

The surface layer is defined at an altitude of about 10 m, the level at which surface winds are typically observed. The model top is set at 50 hPa with a radiative upper boundary condition. The time steps for the 36 km and 12 km resolution domains are 75 and 25 seconds, respectively.

Figs. 1 and 2 show the nested-grid (36/12 km) domain and the fine-mesh domain, respectively, that were used for this project.

<u>Domain 1</u> is centered at 40^0N latitude and 97^0W longitude with a grid size of 36 km, and it covers the U.S. continents, Mexico, Canada, the Gulf of Mexico, and part of the East Pacific and West Atlantic oceans.

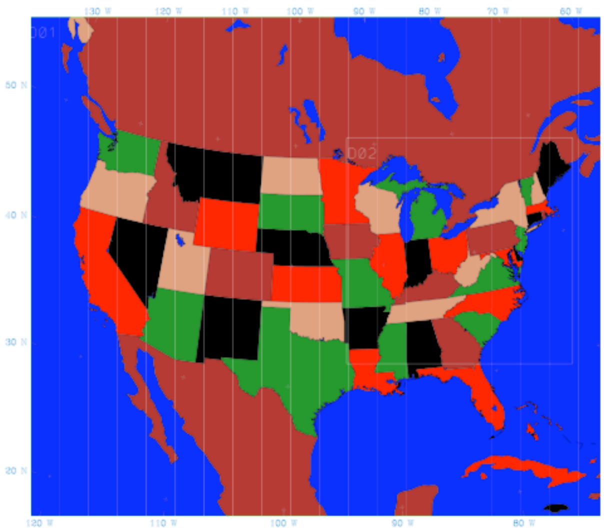

Fig. 1 The coarse-mesh (36 km) domain.

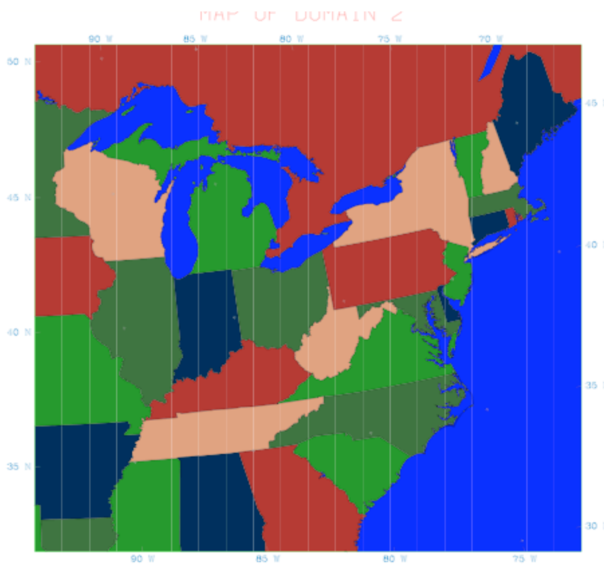

Fig. 2 The fine-mesh (12-km) domain.

Domain 2 uses a grid size of 12 km, and it covers the northeastern, central and southeastern US as well as Southeastern Canada.

The important model physics of the MM5 used for this project include:

(i) The latest version of the Kain-Fritsch (1993) convective scheme was used for both 36- and 12-km resolution domains;

(ii) An explicit moisture scheme (without the mixed phase) containing prognostic equations for cloud water (ice) and rainwater (snow) (Dudhia 1989; Zhang 1989);

(iii) A modified version of the Blackadar planetary boundary layer (PBL) scheme (Zhang and Anthes 1982; Zhang and Zheng 2004);

(iv) A simple radiative cooling scheme (Grell et al. 1997);

(v) A multi-layer soil model to predict land surface temperatures using the surface energy budget equation (Dudhia 1996).

Note that the Blackadar PBL scheme has been modified in order to reproduce the diurnal cycles of surface winds and temperatures, after performing a comparative study of the following five different PBL schemes: the Gayno-Seaman TKE scheme (Shafran et al. 2000), Burk-Thompson (1989), Blackadar (Zhang and Anthes 1982), MRF (Hong and Pan 1996), and Miller-Yamada-Jajić (Miller and Yamada 1974; Jajić 1990, 1994). These changes are given as follows (see Zhang and Zheng 2004 for more detail):

• K-coefficient is determined by the Richardson number according to Zhang and Anthes (1982), where the critical Richardson number is set to be 0.25. In addition, the mixing length is set to be the thickness of the model layer.

• Use of potential temperature rather than virtual potential temperature to calculate the bulk Richardson number Rb.

3. Nudging Processes

The MM5 provides options for nudging observations for each domain during the course of model integration (Stauffer and Seaman 1990; Stauffer et al. 1991). The Eta analyses of upper-air winds, temperature and water-vapor mixing ratio as well as their associated surface fields, were nudged every 6 hours, and the higher-resolution surface wind field was nudged every 3 hours. While only the surface winds were nudged, their influences could be extended into the PBL (see Stauffer et al. 1991).

Based on our previous experience with many numerical experiments, the following nudging coefficients have been used:

- Upper-air wind fields: 5.0E-4 for Domain 1, and 2.5E-4 for Domain 2;
- Upper-air temperature fields: 1.0E-5 for both Domains;
- Surface winds: 5.0E-4 for Domain 1, and 2.5E-4 for Domain 2; and
- Surface temperature and moisture: not nudged due to instability consideration.

4. Model initialization

The model is initialized with NCEP's Eta model analysis (ds609.2) as a first guess that is then enhanced by observations at upper levels and the surface.

(i) NCEP's ADP global upper-air observations (NCAR archive ds353.4) are used to further enhance the upper-level Eta analysis.

(ii) The following two sets of surface observations have been introduced into the model initial state to improve the Eta analysis of surface wind fields:

- The NCEP's ADP global surface wind observations (NCAR archive ds464.0): This dataset provides 6-hourly surface observations over land (i.e., at 0000, 0600, 1200, 1800 UTC) in one stream, and 3-hourly (i.e., at 0300, 0900, 1500, 2100 UTC) over both land and ocean surfaces in another stream.
- The TDL's U.S. and Canadian surface observations (NCAR archive ds472.0): This dataset provides hourly surface observations over the U.S. and Canadian regions.

The Eta model analysis has a domain covering the entire U.S. continents with a 40-km horizontal resolution. It includes the following types of observations:

- Rawinsonde mass and wind;
- Piball winds;
- Dropwindsondes;
- Wind profiles;
- Surface land temperature and moisture;
- Oceanic surface data (ship and buoys);
- Aircraft winds;
- Satellite cloud-drift winds;
- Oceanic TOVS thickness retrievals;
- GOES and SSM/I precipitable water retrievals.

The Cressman objective analysis option was used to enhance the Eta analysis. However, we analyzed the results and found that it still could not reproduce the right diurnal cycle of surface winds and temperatures. Thus, we repeated the Cressman procedures three more times to enhance the surface analyses. Results indicate that this procedure significantly improved the results.

Note that (i) because of the initial model spin-up, we recommend that the first 12-h model integration of each run be discarded; and (ii) because the synoptic-scale upper-air winds and temperatures were nudged, the flow fields above the PBL might contain less smaller-scale features (e.g., in low-level jets, mountain-forced perturbations and etc.).

5. Data Archive

As mentioned above, we have conducted a total of 128 experiments, in 3-day segments, from 0000 UTC 14 December 2001 to 0000 UTC 1 January 2003. The following table lists the experiments and their corresponding integration periods:

Exp. #	Period	Exp. #	Period
1	00/15/12-00/18/12*01	2	00/18/12-12/21/12*01
3	00/21/12-00/24/12*01	4	00/24/12-00/27/12*01
5	00/27/12-00/30/12*01	6	00/30/12-00/02/01*02
7	00/02/01-00/05/01*02	8	00/05/01-00/08/01*02
9	00/08/01-00/11/01*02	10	00/11/01-00/14/01*02
11	00/14/01-00/17/01*02	12	00/17/01-00/20/01*02
13	00/20/01-00/23/01*02	14	00/23/01-00/26/01*02
15	00/26/01-00/29/01*02	16	00/29/01-00/01/02*02
17	00/01/02-00/04/02*02	18	00/04/02-00/07/02*02
Exp. #	Period	Exp. #	Period
19	00/07/02-00/10/02*02	20	00/10/02-00/13/02*02
21	00/13/02-00/16/02*02	22	00/16/02-00/19/02*02
23	00/19/02-00/22/02*02	24	00/22/02-00/25/02*02
25	00/25/02-00/28/02*02	26	00/28/02-00/03/03*02
27	00/03/03-00/06/03*02	28	00/06/03-00/09/03*02
29	00/09/03-00/12/03*02	30	00/12/03-00/15/03*02
31	00/15/03-00/18/03*02	32	00/18/03-00/21/03*02
33	00/21/03-00/24/03*02	34	00/24/03-00/27/03*02
35	00/27/03-00/30/03*02	36	00/30/03-00/02/04*02
37	00/02/04-00/05/04*02	38	00/05/04-00/08/04*02
39	00/08/04-00/11/04*02	40	00/11/04-00/14/04*02
41	00/14/04-00/17/04*02	42	00/17/04-00/20/04*02
43	00/20/04-00/23/04*02	44	00/23/04-00/26/04*02
45	00/26/04-00/29/04*02	46	00/29/04-00/02/05*02
47	00/01/05-00/04/05*02	48	00/04/05-00/07/05*02
49	00/07/05-00/10/05*02	50	00/10/05-00/13/05*02
51	00/13/05-00/16/05*02	52	00/16/05-00/19/05*02
53	00/19/05-00/22/05*02	54	00/22/05-00/25/05*02
55	00/25/05-00/28/05*02	56	00/28/05-00/31/05*02
57	00/31/05-00/03/06*02	58	00/03/06-00/06/06*02
59	00/06/06-00/09/06*02	60	00/09/06-00/12/06*02
61	00/12/06-00/15/06*02	62	00/15/06-00/18/06*02
63	00/18/06-00/21/06*02	64	00/21/06-00/24/06*02
65	00/24/06-00/27/06*02	66	00/27/06-00/30/06*02

67	00/30/06-00/03/07*02	68	00/03/07-00/06/07*02
69	00/06/07-00/09/07*02	70	00/09/07-00/12/07*02
71	00/12/07-00/15/07*02	72	00/15/07-00/18/07*02
73	00/18/07-00/21/07*02	74	00/21/07-00/24/07*02
75	00/24/07-00/27/07*02	76	00/27/07-00/30/07*02
77	00/30/07-00/02/08*02	78	00/02/08-00/05/08*02
79	00/05/08-00/08/08*02	80	00/08/08-00/11/08*02
81	00/11/08-00/14/08*02	82	00/14/08-00/17/08*02
83	00/17/08-00/20/08*02	84	00/20/08-00/23/08*02
85	00/23/08-00/26/08*02	86	00/26/08-00/29/08*02
87	00/29/08-00/01/09*02	88	00/01/08-00/04/09*02
89	00/04/09-00/07/09*02	90	00/07/09-00/10/09*02
91	00/10/09-00/13/09*02	92	00/13/09-00/16/09*02
93	00/16/09-00/19/09*02	94	00/19/09-00/22/09*02
95	00/22/09-00/25/09*02	96	00/25/09-00/28/09*02
97	00/28/09-00/01/10*02	98	00/01/10-00/04/10*02
99	00/04/10-00/07/10*02	100	00/07/10-00/10/10*02
101	00/10/10-00/13/10*02	102	00/13/10-00/16/10*02
103	00/16/10-00/19/10*02	104	00/19/10-00/22/10*02

Exp. #	Period	Exp. #	Period
105	00/22/10-00/25/10*02	106	00/25/10-00/28/10*02
107	00/28/10-00/31/10*02	108	00/31/10-00/03/11*02
109	00/03/11-00/06/11*02	110	00/06/11-00/09/11*02
111	00/09/11-00/12/11*02	112	00/12/11-00/15/11*02
113	00/15/11-00/18/11*02	114	00/18/11-00/21/11*02
115	00/21/11-00/24/11*02	116	00/24/11-00/27/11*02
117	00/27/11-00/30/11*02	118	00/30/11-00/03/12*02
119	00/03/12-00/06/12*02	120	00/06/12-00/09/12*02
121	00/09/12-00/12/12*02	122	00/12/12-00/15/12*02
123	00/15/12-00/18/12*02	124	00/18/12-00/21/12*02
125	00/21/12-00/24/12*02	126	00/24/12-00/27/12*02
127	00/27/12-00/30/12*02	128	00/30/12-00/02/01*03

The datasets listed above include the MM5 outputs from Domain 1 (36 km) and Domain 2 (12 km), the analysis data used for FDDA, and initial and lateral boundary conditions. If necessary, any of the experiments listed above could be re-run. The MM5 outputs include the three-dimensional fields of temperature, horizontal winds, vertical motion, pressure perturbations, moisture, cloud water/rain water/ice water/snow water mixing ratio, and radiation tendency; and the two-dimensional fields of the map-scale factor, longitude and latitude, Coriolis parameter, land use category, terrain height, PBL depth, accumulated convective/non-convective precipitation, surface sensible/latent heat flux. A FORTRAN program to read the datasets has also been included.

6. Acknowledgments

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