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Evaluation of the Regional Atmospheric Modeling System (RAMS) with aircraft observations over East Asia during the spring of 2001

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1. INTRODUCTION

Three-dimensional photochemical modeling systems are the primary tools being applied by regulatory agencies for the development of emission strategies to improve air quality. Meteorological information is one of the most critical inputs to the photochemical models because meteorology encompasses many atmospheric processes that control and strongly influence the evolution of emissions, chemical species, aerosols and particulate matter, and is typically provided by prognostic regional/mesoscale models (Seaman, 2000; Chandrasekar et al., 2003). Due to the critical role played by the meteorological inputs in the photochemical modeling systems, there is a need to performance extensive evaluations of mesoscale meteorological models with observations in order to understand their limitations and strengths (Pielke and Uliasz, 1998).

The Regional Atmospheric Modeling System (RAMS) is a highly versatile numerical code developed by scientists at Colorado State University and the ASTER division of Mission Research Corporation for simulating and forecasting meteorological phenomena (Pielke et al., 1992; Walko and Tremback, 2001). Presently it is widely used to drive air quality models (e.g., Lyons et al., 1995; Sistla et al., 2001; Fast, 2002; Zhang et al., 2003, 2004) and has been evaluated using traditional statistical measures as well as qualitative assessments such as graphical comparisons of observed and simulated meteorological fields (Lyons et al., 1995; McQueen et al., 1997; Cox et al., 1998; Hogrefe et al., 2001; Oh and Ghim, 2001; Chandrasekar et al., 2003), but extensive evaluations are found nearly exclusively for applications to North American (e.g., Cox et al., 1998; Chandrasekar et al., 2003).

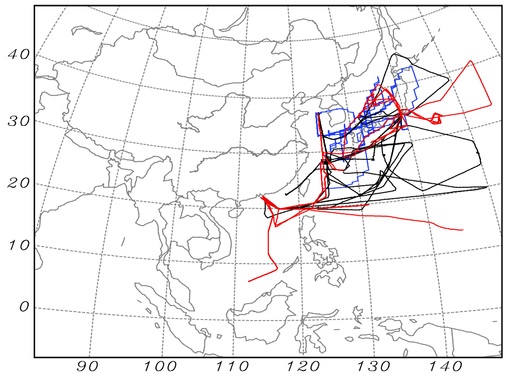

Fig. 1. Model domain for RAMS used in this study. Also shown are horizontal flight tracks of the aircrafts DC-8 (black lines), P-3B (red lines) and C-130 (blue lines) during the period.

In the spring of 2001 two large field campaigns, the transport and chemical evolution over the Pacific (TRACE-P; Jacob et al., 2003) and the Asian Pacific regional aerosol characterization experiment (ACE-Asia; Huebert et al., 2003), were consecutively conducted over the western Pacific and the islands of Japan. In the TRACE-P period from 4 March to 2 April 2001 two NASA aircrafts DC-8 and P-3B performed 11 (flight numbers DC-8 07~17) and 12 (flight numbers P-3B 08~19) observations, respectively, over the western Pacific with bases near Hong Kong, Okinawa and Tokyo, and each flight lasted more than 8 hours. During the ACE-Asia missions from 30 March to 3 May 2001, instrumented NCAR aircraft C-130 conducted 19 flights over the Yellow Sea, the Sea of Japan and south of Japan. Three aircrafts obtained an extensive suite of meteorological parameters, and this dataset provides a strong basis for extensive evaluations of mesoscale meteorological models. This study is to take advantage of the dataset to extensively examine

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regional-scale performances of RAMS when applied to Asia.

This paper is divided into four sections. We describe the RAMS application in Section 2. In Section 3 we first compare model results with observations from a mission-wide perspective, and then evaluate the model's ability to predict about absolute values of wind speed, wind direction, temperature and water vapor mixing ratio along flight tracks. Conclusion is presented in Section 4.

2. Model description

RAMS version 4.3 (RAMS 4.3) is evaluated in this study. Its code is based on an implementation of the full set of primitive equations, supplemented by optional parameterizations of several physical phenomena. In the study the Kuo-type approach (Molinari, 1985) was employed to represent the subgrid scale convective cumulus, and a scheme which employs prognostic turbulent kinetic energy approach (Mellor and Yamada, 1982) was chosen to parameterize the vertical diffusion. The radiation parameterization used the Chen and Cotton scheme (Chen and Cotton, 1983) and the bulk microphysics parameterization was activated. A soil-vegetation model was also activated. A general description of the model physics and application fields are given in Pielke et al. (1992).

During the simulations RAMS 4.3 was exercised in a four-dimensional data assimilation mode using analysis nudging with re-initialization every 4 days, leaving the first 24 hours as the initialization period. The three-dimensional meteorological fields for input were obtained from the European Center for Medium-Range Weather Forecasts (ECMWF) analyzed datasets, and were available every 6 hours with $1^o \times 1^o$ resolution. Observed monthly snow cover information and sea surface temperatures (SST) based on weekly mean values were used to set the boundary conditions for the RAMS calculation.

3. MODEL RESULTS AND DISCUSSION

Three-dimensional meteorological fields were simulated in the period from 22 February to 5 May 2001 by use of RAMS 4.3. To characterize the model's abilities and limitations, modeled meteorological parameters such as wind speed, wind direction, temperature and water vapor content are compared with observations obtained on board of three aircrafts DC-8, P-3B and C-130 during the TRACE-P and ACE-Asia field experiments. These aircrafts made totally 52 extensive observations over the western Pacific, the Yellow Sea and the Sea of Japan during the simulation period, and each flight lasted at least 8 hours. Their horizontal flight coverages are presented in Figure 1. The DC-8 flights had an altitude variation from 150 m to 12 km, the P-3B flight altitudes ranged from 150 m to 7 km, and the ceiling height of C-130 was ~ 8 km. For these comparisons the model was sampling along 11 DC-8, 12 P-3B and 19 C-130 flight paths at 5-min intervals and compared with the measured values in the merged data set. The merged data set consists of all measurements taken on the aircraft combined together in a single data set with common and uniform time intervals and consistent format. These data are available for download on the website http://www-gte.larc.nasa.gov and http://www.joss.ucar.edu/ace-asia. Model results are interpolated to the exact times and locations of the aircraft measurements.

Table 1 presents statistical summaries of the comparison of modeled and observed values of wind speed, wind direction, temperature and water vapor mixing ratio during the flights of DC-8 07~17, P-3B 08~19 and C-130 01~19 in the period from 4 March to 3 May 2001, respectively. In the table N is the number of paired samples, C_M and C_O are average values of modeled and observed meteorological parameters, R stands for the correlation coefficient, E_{MAGE} and E_{RMSE} stand for the mean absolute gross error and the root mean squared error, and B_{NMBF} and E_{NMEF} are the normalized mean bias factor and the normalized mean error factor.

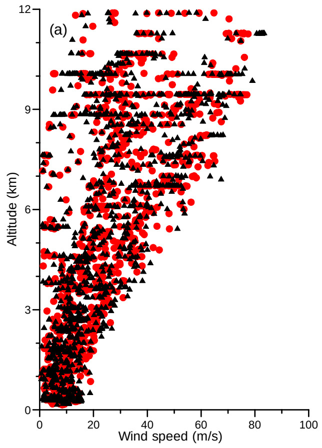
Table 1. Observed and modeled values of wind speed, wind direction, temperature and water vapor mixing ratio for the flights of DC-8 07~17

DC-8	WS[a]	WD[a]	TA[a]	QV[a]
N[b]	1189	1189	1198	1192
C_O[c]	24.2	248.2	260.5	2.64
C_M[c]	24.8	239.8	260.9	2.90
R[d]	0.96	0.76	0.99	0.98
E_{MAGE}[e]	3.47	18.2	1.71	0.55
E_{RMSE}[f]	4.92	30.4	2.22	0.86
B_{NMBF}[g]	0.03	-0.03	0.002	0.10
E_{NMEF}[h]	0.14	0.08	0.007	0.21

[a]WS, WD, TA and QV represent for wind speed (m/s), wind direction (deg), temperature (^{o}K) and water vapor mixing ratio (g/kg)
[b]N is the number of paired samples
[c]C_O and C_M are averaged values of observed and modeled meteorological parameters
[d]R stands for the correlation coefficient between observed and modeled meteorological parameters

[e]E_{MAGE} means the mean absolute gross error
[f]E_{RMSE} stands for the root mean squared error
[g]B_{NMBF} is the normalized mean bias factor
[h]E_{NMEF} represents the normalized mean error factor

Comparison of modeled and aircraft-based observed vertical distributions provides an assessment for the ability of the model to simulate the vertical structure of meteorological parameters. We plot the paired data points used in the previous statistics against height in Figures 2~4 to show their vertical variations. The figures show that observed maximum wind speeds increase with height and reached 70 m/s above 8 km (cf. Figure 2a), and in the layers above ~3 km prevailing wind directions are westerly, while temperatures and water vapor mixing ratios generally decrease with height. The figures also show that the observed meteorological parameters exhibit strong variations even at a fixed height. Comparing model results with the observations, we see that the model reproduced these major observed features quite well, and the simulated vertical distribution patterns are generally similar to their observed ones, even the model overestimated temperatures in the layers above 6 km and water vapor mixing ratios show a high model bias at low altitudes. Reasonable agreement of vertical distributions between observed and simulated meteorological parameters indicates that the model captured the tempo-spatial distributions reasonably well, as the aircraft observations covered a wide area over the western Pacific (cf. Figure 1) and lasted nearly two months.



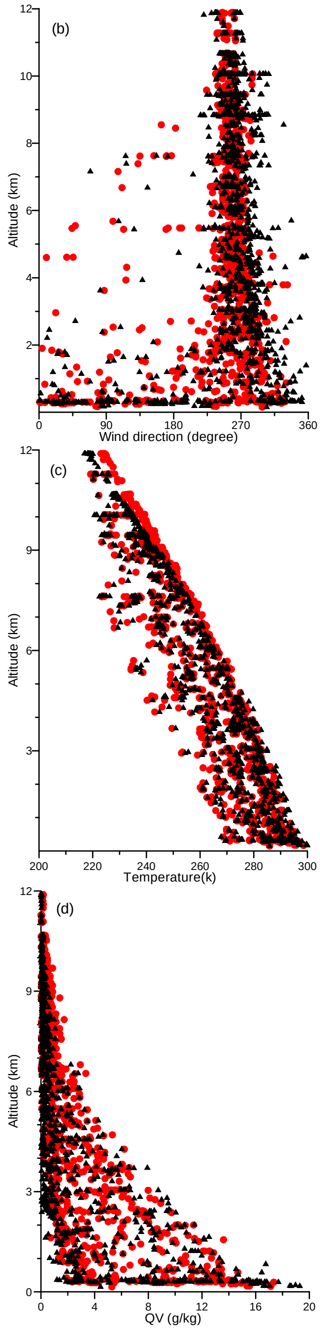


Fig. 2. Observed (triangles) and simulated (dots) vertical variations in (a) wind speed, (b) wind direction, (c) temperature, and (d) water vapor mixing ratio for the DC-8 flights 07~17 in the period from 4 March to 2 April 2001. Shown are values for each 5-min flight segments from the merged data set.

4. CONCLUSION

RAMS 4.3 was applied to East Asia to simulate three dimensional meteorological fields from 22 February to 5 May 2001, and modeled wind directions, wind speeds, temperatures and water vapor mixing ratios were compared with observations obtained on board of 3 aircrafts during the TRACE-P and ACE-Asia field campaigns to evaluate the model's performances. Comparison of the modeled and observed values on mission-wide perspective showed that 1) average values of the four simulated meteorological parameters are all in good agreement with their observations; 2) RAMS reproduces the mean observed wind speed to within about 0.7 m/s with rather mean absolute gross error and high correlation coefficients, and the percentages of simulated wind directions within the desired accuracy (Cox et al., 1998) are all over 67%; 3) modeled and simulated temperatures are high correlated, their correlation coefficients are all larger than 0.95, but model results have a positive bias of 0.6 ^{o}C for the flights of DC-8 and a negative bias of 0.5 and 0.6 ^{o}C for the flights of P-3B and C-130; 4) modeled water vapor mixing ratios have a good correlation with their observed ones, but RAMS generally overestimates them by 10%; 5) modeled vertical distribution patterns of the four parameters are quite similar to their observed ones, but the model tends to overestimate temperatures in the layers above 6 km.