# THREE-DIMENSIONAL MESOSCALE MODELING OF METEOROLOGICAL FIELDS OVER ZHUJIANG(PEARL) RIVER DELTA

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#### ABSTRACT

The CSU-RAMS-2A was used to simulate the meteorological fields over the Zhujiang River Delta in South China. Initialized from a horizontally homogeneous atmosphere, real topography and inhomogeneous surface boundary conditions, the model was run with thermal and terrain forcing. The modeling results of winter and summer cases are compared with those observed. The similarity of the predicted distributions of winds, temperatures and humidities to the observed patterns permits us to conclude that the mesoscale distribution of meteorological elements for the two study dates is the result of the thermal and dynamical forcing by the underlying surface and topography.

Key words: three-dimensional mesoscale modeling, initial characteristics, parameterization, Zhujiang River Delta

#### I. INTRODUCTION

The Zhujiang River Delta is an important economic developing area in South China. Because of its low latitude (the Coriolis effect is small), this Delta is strongly influenced by mesoscale meteorological systems. Almost every year, severe mesoscale systems cause considerable damage and loss of life. These systems include sqall-lines, tornadoes, hailstorms and thunderstorm gales. Generally speaking, severe mesoscale systems prevail from February to September in South China. The genesis and paths of mesoscale systems relate not only to the synoptic meteorological fields, but also to the topography and the sea-land distribution of South China. For instance, the mesoscale system over the Zhujiang River Delta often presents itself in this or that fixed area. River valley-mountainous areas or coastal areas are examples of the geographical environment in South China where well-defined mesoscale systems occur. Thus, the mesoscale topography and sea-land distribution are important factors for formation and development of mesoscale systems. Using routine synoptic charts or synoptic resolution mesh numerical forecasting models, people inevitably fail in the predictions of mesoscale systems. So, mesoscale modeling of the regional atmospheric circulations and meteorological fields over this area is needed to fundamentally understand the formation, development and movement of these systems. This paper presents a first attempt to document for this region the structure of atmospheric circulations which are forced by mesoscale variation in terrain.



Fig. 1. Topography of Zhujiang River Delta and vicinity (contour interval:250m).

### **II. GEOGRAPHY**

The Zhujiang River is the most important water system in South China and its tributaries are the West River, North River and East River. Facing the South China Sea in the southeast, the Delta of the Zhujiang River is situated in the south-central part of Guangdong Province. Hong Kong and Macau are placed at the eastern and western sides of the mouth of Zhujiang River, respectively. Guangzhou, the biggest city of South China, is at the head of the river. Other than some hills near or lower than 500 m, the Zhujiang River Delta is almost a plain. It is surrounded by mountainous terrain in the east, north and west. To the north of the Zhujiang River Delta there are the Nanling and Dayu mountains. The well-known border between central China's climate and southern China's climate occurs here. Generally speaking, the elevations of the Nanling and Dayu mountains are between 1000 and 1500 m, but some high peaks can be between 1500 and 2000 m. The contour map of the Zhujiang River Delta and its surrounding areas is shown as Fig. 1.

# **III. THE MODEL**

The CSU-RAMS-2A (version 2A of the Colorado State University Regional Atmospheric Modeling System) was used to simulate the meteorological fields over the Zhujiang River Delta. RAMS is the combination and development of the numerical atmospheric models designed independently under the direction of Roger A. Pielke (Pielke, 1974; Mahrer and Pielke, 1976; Mahrer and Pielke, 1977) and William R. Cotton (Tripoli and Cotton, 1982). It is a general and flexible modeling system rather than a single purpose model. It contains many options for various physical and numerical processes. The model used here has  $40 \times 40 \times 14$  grid points in the atmosphere and  $40 \times 40 \times 3$  grid points in the soil. The horizontal grid distance is 20 km and the vertical grid distance is 250 m in the atmosphere and is 0.1 m in the soil. The time step is 30

seconds. The model options are presented in Table 1 and the initial characteristics are shown in Table 2.

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Table 1. Model Options

Grid system:	three-dimensional simulation coordinate transform activated $\triangle Z = 250.00 \text{ m}$ $\triangle X = 20\ 000.00 \text{ m}$ $\triangle Y = 20\ 000.00 \text{ m}$ $\triangle t = 30.00 \text{ s}$
Initial field:	horizontally homogeneous initialization
Pressure calculation:	hydrostatic
Vertical velocity diagnosis:	anelastic
Top boundary conditions:	Klemp-Durran (1983) gravity wave radiation
Lateral boundary conditions:	Klemp-Wilhelmson(1978a; b) radiation type
Finite differencing:	second order horizontal, second order vertical advection
Cloud options:	water vapor as a passive tracer

Table	2.	Initial	Charac	teristics

Latitude of center:	22°56′N		
Longitude of center:	113°28′E		
Surface layer parameterization:			
Roughness	0.05 m		
Minimum friction velocity $(u^*)$ in surface layer parameterization	$0.01 \mathrm{m} \mathrm{s}^{-1}$		
Minimum velocity value to use in computing $u^*$	$0.10 \text{ m s}^{-1}$		
Radiation characteristics:			
Shortwave radiation type	Mahrer-Pielke (1977)		
Longwave radiation type	Mahrer–Pielke (1977)		
Frequency of radiation tendency update	1 min <sup>-1</sup>		
Soil characteristics:			
Soil model computational scheme	Tremback-Kessler (1985)		
Soil type	sandy clay loam [U.S. Dept. of Agriculture(1951)soil texture classes]		
Albedo	0.25		

For these options, the model can be briefly described as follows:

# 1. Coordinate System

In order to facilitate simulations over varying topography of Zhujiang River Delta and its surrounding areas, the terrain following coordinate system is employed.

The relationship of this coordinate system with the original cartesian system can be written as

$$x' = x, \tag{1}$$

$$y' = y, \tag{2}$$

and

$$z := \frac{z_H (z - z_G)}{(z_H - z_G)},$$
(3)

where  $x^*$ ,  $y^*$  and  $z^*$  are terrain following coordinates and x, y and z are Cartesian coordinates,  $z_G$  and  $z_H$  are the heights of surface and the model top, respectively. Thus,  $z_G$  is a function of horizontal coordinates:  $z_G = z_G(x, y)$ , while  $z_H$  is a constant here:  $z_H = 3250$  m.

# 2. Basic Equations

Since the model option is a hydrostatic one and no steep orography is there in Zhujiang River Delta and its surrounding areas, the basic equations can be written as

$$\frac{\partial u}{\partial t} + \theta \frac{\partial \pi}{\partial x} = -u \frac{\partial u}{\partial x} - v \frac{\partial u}{\partial y} - w \cdot \frac{\partial u}{\partial z} + g \frac{z - z_H}{z_H} \frac{\partial z_G}{\partial x} + fv - \hat{f} \frac{z_H - z_G}{z_G} w \cdot + \left(\frac{z_H}{z_H - z_G}\right)^2 \frac{\partial}{\partial z} \cdot K_{MV} \frac{\partial u}{\partial z} + \frac{\partial}{\partial x} K_{MH} \frac{\partial u}{\partial x} + \frac{\partial}{\partial y} K_{MH} \frac{\partial u}{\partial y} \equiv F_u,$$
(4)  
$$\frac{\partial v}{\partial x} + \theta \frac{\partial \pi}{\partial x} = -u \frac{\partial v}{\partial x} - v \frac{\partial v}{\partial y} - w \cdot \frac{\partial v}{\partial x} + g \frac{z - z_H}{z_G} \frac{\partial z_G}{\partial x} - fu$$

 $\frac{\partial v}{\partial t} + \theta \frac{\partial \pi}{\partial y} = -u \frac{\partial v}{\partial x} - v \frac{\partial v}{\partial y} - w \cdot \frac{\partial v}{\partial z} + g \frac{z - z_H}{z_H} \frac{\partial z_G}{\partial y} - fu$ 

$$+\left(\frac{z_{H}}{z_{H}-z_{G}}\right)^{2}\frac{\partial}{\partial z^{*}}K_{MV}\frac{\partial v}{\partial z^{*}}+\frac{\partial}{\partial x}K_{MH}\frac{\partial v}{\partial x}+\frac{\partial}{\partial y}K_{MH}\frac{\partial v}{\partial y}\equiv F_{v},$$
(5)

$$\frac{\Im \pi}{\Im z^*} = -\frac{g}{\theta} \frac{z_H - z_G}{z_H},\tag{6}$$

$$\frac{\partial \theta}{\partial t} + w \cdot \frac{\partial \theta}{\partial z} = -u \frac{\partial \theta}{\partial x} - v \frac{\partial \theta}{\partial y} + \left(\frac{z_H}{z_H - z_G}\right)^2 \frac{\partial}{\partial z} \cdot K_{HV} \frac{\partial \theta}{\partial z}$$

$$+\frac{\partial}{\partial x}K_{HH}\frac{\partial\theta}{\partial x} + \frac{\partial}{\partial y}K_{HH}\frac{\partial\theta}{\partial y} + S_{\theta} \equiv F_{\theta},$$
(7)

$$\frac{\partial q}{\partial t} + w \cdot \frac{\partial q}{\partial z} = -u \frac{\partial q}{\partial x} - v \frac{\partial q}{\partial y} + \left(\frac{z_H}{z_H - z_G}\right)^2 \frac{\partial}{\partial z} \cdot K_{HV} \frac{\partial q}{\partial z}$$

$$+ \frac{\partial}{\partial x} K_{HH} \frac{\partial q}{\partial x} + \frac{\partial}{\partial y} K_{HH} \frac{\partial q}{\partial y} + S_q \equiv F_q, \qquad (8)$$

$$\frac{\partial}{\partial z} \left( \rho \frac{z_H - z_G}{z_H} w^* \right) = -\frac{\partial}{\partial x} \left( \rho \frac{z_H - z_G}{z_H} u \right) - \frac{\partial}{\partial y} \left( \rho \frac{z_H - z_G}{z_H} v \right), \tag{9}$$

where  $S_{\theta}$  and  $S_{q}$  are the sources or sinks of heat and water vapour respectively.  $w^{*}$  refers as the component of velocity of air particle which moves between the  $z^{*}$  equiscalar surfaces  $(w^{*} = dz^{*} / dt)$ .  $\pi$  is the Exner function. Other symbols have their usual meanings.

### 3. Boundary Conditions

The top boundary condition used for this modeling is the Klemp and Durran (1983) gravity wave radiation condition. This boundary condition is derived to allow vertically propagating internal gravity waves to pass out of the model top for linear hydrostatic as well as Boussinesq waves. In this formulation, the pressure along the model top is determined from the Fourier transform of the vertical velocity at the model top. This boundary condition can easily be incorporated in the model and requires little additional computation (including the Fast Fourier Transform). Klemp and Durran (1983) have also shown reasonably good results for nonhydrostatic and nonlinear waves as well.

For lateral boundary conditions, a gravity wave radiation scheme suggested by Klemp and Wilhelmson (1978a; b) is used. These conditions are the advections of the normal velocity components out through the boundaries at a speed given by the sum of normal velocity component and an approximated intrinsic phase velocity  $(c^*)$  of the dominant gravity wave modes moving out though the boundary.  $c^*$  is selected as the Brunt-Vaisala frequency multiplied by the height of the model top (3250 m) and divided by 3.14159265.

At the bottom boundary, surface layer parameterization of Businger (1973) is employed to calculate the turbulent fluxes of momentum, heat and water vapour. The energy balance of ground surface includes longwave and shortwave radiative fluxes, latent and sensible heat fluxes and conduction from below the surface. To include the latter effect, a three level prognostic soil temperature model is provided (Tremback and Kessler, 1985).

### 4. Turbulence Parameterization

The turbulence parameterization is Smagorinsky-type, which calculates the exchange coefficients based on the deformation of stream field with Richardson number dependence. The vertical and horizontal momentum exchange coefficients are taken as

$$K_{MV} = \frac{0.25^2}{\sqrt{2}} l_V^2 \{ D + [Max(-N^2, 0)]^{1/2} \},$$
(10)

$$K_{MH} = \frac{0.25^2}{\sqrt{2}} l_H^2 D,$$
 (11)

where D is the deformation defined as

$$D^{2} = \sum_{j=1}^{3} \sum_{k=1}^{3} \left( \frac{\partial u_{j}}{\partial x_{k}} + \frac{\partial u_{k}}{\partial x_{j}} \right)^{2}, \qquad (12)$$

and N is the Brunt-Vaisala frequency defined as

$$N^{2} = \frac{g}{\theta} \frac{\partial \theta}{\partial z},$$
(13)

 $l_V$  and  $l_H$  are the vertical and horizontal scale lengths:

$$l_{\nu}^{2} = \left(\bigtriangleup z\right)^{2} \left(1 - \frac{K_{H\nu}}{K_{M\nu}} Ri\right)^{2}, \qquad (14)$$

$$l_{H}^{2} = (\triangle x)(\triangle y), \tag{15}$$

where  $K_{HV}$  is the vertical eddy exchange coefficient for heat and water vapour, and Ri is the local Richardson number given by

$$Ri = \frac{N^2}{D^2}.$$
 (16)

The relationship between heat (or water vapour) and momentum exchange coefficients is set as

$$\frac{K_{HV}}{K_{MV}} = \frac{K_{HH}}{K_{MH}} = 3.$$
 (17)

### 5. Radiation Parameterization

Shortwave and longwave radiation models described by Mahrer and Pielke (1977) are used. The shortwave radiation includes the effects of forward Rayleigh scattering, absorption by water vapour and terrain slope. The longwave one includes the emissivities of water vapour and carbon dioxide.

### 6. Numerical Integration Scheme

The model variables are defined on a spaced-staggered grid with variable spacing in both the horizontal and vertical directions. In this system, all scalar variables are placed at the midpoint of each grid volume. Velocity components are defined on the faces of the volume perpendicular to the component direction. Second-order space differencing is used to calculate all derivatives.

In order to allow a longer timestep, the forward-backward time-split scheme is utilized in RAMS. The object behind the time-split scheme is to compute the terms responsible for the propagation of the fast modes on a series of smaller timesteps that run simulaneously with the slower moving meteorological modes on a much longer timestep. The computational procedure is then as follows for forward-backward time differencing:

- (1) The right hand sides of (4), (5), (7) and (8) (i.e.  $F_{\mu}$ ,  $F_{\nu}$ ,  $F_{\theta}$  and  $F_{q}$ ) are computed.
- (2)  $\theta$  and q are stepped forward to  $t + \triangle t_i$ , where  $\triangle t_i$  is the long timestep:

$$\theta^{*r+\Delta r_i} = \theta' + F_{\theta} \triangle t_i,$$

$$q^{*\prime+\bigtriangleup t_{l}} = q' + F_{q} \bigtriangleup t_{l}.$$

(3)  $\theta$  is stepped forward to  $t + \triangle t_s$ , where  $\triangle t_s$  is the small timestep:

$$\theta^{t+\bigtriangleup t_s} = \theta^{*t+\bigtriangleup t_i} - \left[w^t \frac{\Im \theta^{t+\bigtriangleup t_i}}{\Im z}\right] \bigtriangleup t_s.$$

- (4) Pressure at  $t+\triangle t_s$  is computed with (6).
- (5) The horizontal velocities are stepped to  $t + \triangle t_s$ :

$$u^{t+\Delta t_{s}} = u^{t} - \left[\theta \frac{\partial \pi^{t+\Delta t_{s}}}{\partial x} - F_{u}\right] \Delta t_{s},$$
$$v^{t+\Delta t_{s}} = v^{t} - \left[\theta \frac{\partial \pi^{t+\Delta t_{s}}}{\partial y} - F_{v}\right] \Delta t_{s}.$$

(6) The vertical velocity at  $t + \triangle t_s$  is computed with (9).

(7) The small timestep is repeated *n* times until  $n \triangle t_s = \triangle t_l$ . For the options of this modeling, n=3.



Fig. 2. Initial fields for winter case: (a) u-components (in m / s); (b) v-components (in m / s);
(c) temperatures (in K); (d) mixing ratios (in 0.1g / kg).

## IV. MODELING RESULTS

# 1. Case 1: Winter

In this case, the modeling was homogeneously initialized from the sounding of Guangzhou (23°8'N, 113°19'E) for 12 Z (20 Local Standard Time, LST) on February 26, 1980 (see Figs.2a-2d) and run for 12 hours.

The winds near the surface predicted by the model are shown in Fig. 3a. The predicted winds over the South China Sea indicate a consistent direction from east to northeast. However, over the land surface, the directions of the winds are rather variable. There are several small eddies and convergence lines presented in Dayu, Jiulian and Dayao Mountains. It is very interesting to point out that these areas coincide with the normal travel paths of South China mesoscale systems (Chen and Yuan, 1985).

Figs. 3b and 3c are predicted temperatures and mixing ratios near the ground surface respectively. Both the temperatures and mixing ratios have a tendency to decrease from sea to land.

Unlike near the surface, the winds at the 1125 m level have a southwest direction, but the temperatures and the mixing ratios at this level still have the tendency to decrease from sea to land. The predicted winds at any level above 1500 m retain the southwestern direction



consistently. However, the temperatures over the South China Sea increase from west to east at levels above 1500 m and the mixing ratios there have the opposite tendency —— to decrease from west to east. Owing to saving the space of this paper, these figures are not shown here.

# 2. Case 2: Summer

In this case, the 12 h modeling was also homogeneously initialized from the sounding of Guangzhou, but for 00 Z (08 LST), June 18, 1986 (see Figs. 4a—4d).

Figs. 5a is the 12 h predicted streamlines near the surface layer. It is shown that the direction of streamlines is generally from south to north. Over the South China Sea, southeast winds predominate. There are not any eddies in the modeling domain, but a convergence line was simulated near the Dayao and Darong Mountains.

Figs. 5b and 5c are the predicted temperatures and mixing ratios near the surface. As constrasted to the winter case, the temperatures near the surface, predicted for summer case, increase from sea to land. But the predicted mixing ratios near the surface still decrease in the same direction even for the summer case.

Compared to those in the surface layer, the winds at the 1125 m level are more uniform from southwest to northeast, and the temperatures at this height retain the tendency to increase from sea to land. But the mixing ratios at the 1125 m level have a tendency opposed to that of the surface. The predicted winds above the 1500 m level are very similar to those at the 1125 m — uniformly from southwest to northeast, but the tendency of temperatures above 1500 m is



Fig. 4. As in Fig. 2, but for summer case.

increasing from west to east and that of mixing ratios is decreasing from west to east (figures not shown).

#### V. COMPARISON WITH OBSERVATION

#### 1. Case 1: Winter

Presented as Figs. 6a—6c, the contours and streamlines are depicted by the objective analysis program of RAMS from the observational data of 00 Z (08 LST), February 27, 1980.

Fig. 6a shows the winds near the surface. They are similar to those predicted (see Fig. 2a), especially over the South China Sea. But on account of the sparse nature of the observational network, the analysis program can not depict any eddy structure. Over the land area, prevailing north winds were observed near the surface. It is because of a synoptic process. The insertion of a cold surge on the early morning of February 27, 1980 caused this. Figs. 6b and 6c are observed temperatures and mixing ratios near the surface. Similar to those predicted (see Figs. 2b and 2c), the tendencies of the spatial distribution of these two meteorological elements to decrease from sea to land are very apparent. But owing to the cold surge, it is colder or drier than the predicted:

The streamlines near the 1000 m level are a little different to those predicted, and perhaps it is induced by the synoptic process too. The insertion of the cold air surge caused prevailing north winds at this level, and the mesoscale model could not predict such a large-scale synoptic

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10 m; (b) temperatures at 1.5 m (in K); (c) mixing ratios at 1.5 m (in g / kg).

process as cold surge. But the tendencies of spatial distribution of the observed temperatures and mixing ratios are still similar to those predicted at this level. Compared to those predicted, the horizontal distributions of observed winds, temperatures and mixing ratios are very similar to their predicted counterparts: the directions of winds are from southwest to northeast, the temperatures increase from west to east and the mixing ratios decrease from west to east. These figures are not shown here.

# 2. Case 2: Summer

Figs. 7a-7b are observed temperature and mixing ratios contours at the 1000 hPa



Fig. 7. Observations at 1000 hPa for summer case: (a) temperatures (in K) and (b) mixing ratios (in  $g \neq kg$ ).

isobaric surface, depicted by the objective analysis according to the sounding data of 12 Z (20 LST), June 18, 1986. Just as those predicted, the temperatures increase from sea to land and the mixing ratios decrease in the same direction. Unfortunately, we do not have enough data to objectively depict the streamlines near the ground surface for this sounding time.

The directions of streamlines above the 900 hPa isobaric surface, objectively depicted from the sounding winds, are almost uniformly southwest. The distribution of observed temperatures at the 850 hPa isobaric surface shows that some high temperature centers are along the coastline area as well as over the Leizhou Peninsula and Dongsha Islands. Also, there is a high humidity belt along the South China Sea coast at the 850 hPa isobaric surface. The observed temperatures above the 800 hPa level increase from west to east and the observed mixing ratios there decrease from west to east. All of these characteristics are very similar to their counterparts produced by the modeling. In order to save the space of this paper, these streamlines and contours, having been depicted objectively by the RAMS analysis facilities, are not shown here for 900 hPa isobaric surface and above.

#### VI. VERIFICATION

The verification analysis was performed by computing the root mean square error (*RMSE*), the standard deviation of observations ( $\sigma_{obs}$ ) and of predictions ( $\sigma_{mod}$ ), and the ratio *RMSE* /  $\sigma_{obs}$  as the functions of wind direction, wind speed, temperature and mixing ratio. Moreover, the vertical profiles of the wind direction, wind speed, temperature and mixing ratio at Guangzhou (23°8'N, 113°19'E), Hong Kong (22°19'N, 114°10'E) and Shantou (23°21'N, 116°40'E) are compared with those predicted.

 Table 3. Root Mean Square Errors between Observation and Prediction and Standard Deviations of Observation and Prediction (Winter Case)

	RMSE	$\sigma_{ m obs}$	$\sigma_{ m mod}$	$RMSE / \sigma_{obs}$ (%)
Wind direction (deg.)	66.37	121.24	95.51	54.74
Wind speed (m s <sup>-1</sup> )	5.51	6.83	5.25	80.67
Temperature (°C)	1.76	5.26	6.07	31.75
Mixing ratio (g kg <sup>-1</sup> )	1.66	3.87	2.91	42.89



Fig. 8. Vertical profiles of meteorological elements for winter case: (a) wind direction; (b) wind speed; (c) temperatures; (d) mixing ratio. (solid lines for observed, dashed for predicted).

Table 3 presents *RMSE*,  $\sigma_{obs}$ ,  $\sigma_{mod}$  and the ratio *RMSE* /  $\sigma_{obs}$  of wind directions, wind speeds, temperatures and mixing ratios for the winter case. As shown in this table, either the *RMSE* of wind directions or that of wind speeds is pretty large. The cause is that there was such a large scale synoptic process as the cold surge, which we can not predict it with mesoscale modeling, even though the topography and physical processes are very well parameterized.

Figs. 8a—8d are observed and predicted vertical profiles of wind direction, wind speed, temperature and mixing ratio at Guangzhou, Hong Kong and Shantou. The separation of vertical profiles of predicted wind from that of observed one for winter case is obviously reflected in Figs. 8a and 8b. *RMSE* of temperature and mixing ratio, as well as the vertical profiles of these two meteorological elements, shows that the modeling for temperature or humidity is better than that for wind.

	RMSE	$\sigma_{\rm obs}$	$\sigma_{mod}$	$RMSE / \sigma_{obs}(\%)$
Wind direction (deg.)	26.34	32.49	11.02	81.07
Wind speed (m $s^{-1}$ )	2.55	3.25	2.94	78.64
Temperature(°)	1.10	5.93	5.64	18.55
Mixing ratio (g kg <sup>-1</sup> )	1.13	3.90	3.66	28.97

 
 Table 4. Root Mean Square Errors between Observation and Prediction, and Standard Deviations of Observation and Prediction (Summer Case)

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Fig. 9. As in Fig. 8, but for summer case.

Table 4 is the same as Table 3 but for a summer case. As there was no strong synoptic process in this case, the RMSE of wind direction and wind speed is much smaller than that for winter case. The RMSE of temperature and mixing ratio for the summer case reflects that the modeling of these two meteorological elements is very realistic.

Figs. 9a and 9b, presenting the vertical profiles of wind direction and wind speed for summer case respectively, also show the same kind of situation as reflected by the RMSE of wind direction and wind speed in Table 4. The vertical profiles of predicted temperature and mixing ratio for the summer case are very similar to those of the observed too (see Figs. 9c and 9d).

# VII. DISCUSSION

Since both the winter and summer cases are homogeneously initialized, the modeling results are induced by the topographical forcing as well as the thermal and dynamical forcing of the underlying surface. The similarity of the predicted distributions of winds, temperatures or humidities to the observed patterns permits us to conclude that the mesoscale distribution of meteorological elements for the two study dates is the results of the thermal and dynamical forcing of the underlying surface and topography. RAMS is a very good modeling system which can describe topography and parameterize many physical processes in detail and reality. Moreover, the reasonable and economic gravity wave radiation schemes are used in RAMS for top and lateral boundary conditions. One interesting result is that using the same parameterization and over the same topography, but initialized from the different vertical construction of horizontally homogeneous wind, temperature and humidity, and during the different time of the year and the day (so the parameterizations of radiation are different), there are eddies presenting in the 12 h modeling result of the near surface layer of winter case, but none occurred in that of summer case.

As the routine observations are too scarce and the grid system of synoptic scale numerical weather forecasting is not dense enough, the routine forecasts fail to predict these mesoscale systems. But the experiments here suggest that even if we start the modeling with very uniform initial conditions (e. g., wind, temperature and humidity), which are horizontally equal in a 800 km  $\times$  800 km area, but use the real topography and horizontally inhomogeneous surface boundary conditions, the resultant meteorological fields are similar to those observed. This result is very significant if we are going to improve the numerical forecasting of mesoscale systems.

#### VIII. CONCLUSIONS

(1) With real topography and horizontally inhomogeneous surface boundary conditions, the modeling results are comparable with those observed, even if initialized from a horizontally homogeneous atmosphere.

(2) RAMS is a very good mesoscale numerical modeling system which can reflect the effects of topography and physical processes in detail and reality.

(3) It is possible to numerically predict surface forced mesoscale meteorological systems with routine synoptic observatory data, providing the topography and surface forcing are realistically represented with mesoscale resolution.

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