

Meteorological simulation of thermal environment in the Sichuan basin

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Abstract: A highly versatile numerical code – the Regional Atmospheric Modeling System (RAMS) was used into the heat island simulation of an inland mega-city – Chongqing and Sichuan Basin, China. The entire horizontal calculation domain 2000 km × 2000 km and the vertical calculation domain was from 50cm under ground to the altitude of 15 000 m. The USGS (U.S. Geological Survey) topography and land use data, the NCEP (National Centers for Environmental Prediction) meteorological data were used as the input data of this simulation. The simulation shows that the temperature of Chongqing's urban area was higher than that of suburb area corresponding to the topographical condition. It was confirmed that RAMS could be applied for the simulation of thermal environment. It was also demonstrated that the local climate in the smaller scale could be expressed by generating two-way interactive nesting grid.

Keywords: thermal environment; heat island, meteorological simulation; RAMS

1. Introduction

In the last 200 years, the industrial era, technological development, globalization and population growth have had urban areas grown so rapidly, and their populations increased so dramatically. Only from 1950 to 2000, the world's urban population increased from 30 % to 47 % (UN 2002) [1]. While, the most striking current changes are the levels of urbanization in less developed nations: rising from about 27 % in 1975 to 40 % in 2000 – an increase of more than 1,200 million people (United Nations Population Division 2001b) [1]. Furthermore, some prognostications indicate this trend will continue for the next 30 years, adding 2000 million people to the urban population of the presently less-developed nations. The accumulation of people, their consumption patterns and their urban activities have a large impact on the environment, such as water, air pollution; flooding and soil erosion; scarcity of natural resources; waste discharge; destruction of sensitive ecosystems and climate change, etc. Thermal environment is one of the existing environmental problems in many cities and one poses a threat to the long-term sustainable development of localities.

The urban thermal environment is also described as heat island, which is a phenomenon that the temperature of urban areas is higher than that of their surroundings. Urban heat island has been reported in dense and highly urbanized cities around the world, and can be quite troublesome in the warm, sunny

summer days. Especially in the developing countries, because most big cities locate in the tropical or subtropical regions, there is a great chance that the urban heat island could become a serious problem in the near future.

1.1 Heat island's mechanism

Urban heat island is attributable to the increase of anthropogenic heat discharge, changes in the thermal characteristics of surface and the decrease in evapotranspiration. Industries and most urban activities are accompanied with energy consumption and the most of these energy consumption finally discharge heat into urban environment directly. A closer look at Tokyo reveals that the anthropogenic heat of the center is beyond 400 W/m² in winter, which can almost match the total income solar energy (Ichinose et al 1999) [2].

Reflectivity of a surface is known as its albedo. Urban surfaces, such as rooftops, asphalt, and concrete, have relatively low albedo in comparison with natural surfaces. So, they can absorb higher levels of solar radiation throughout the daytime and reach a quite high temperature. After sunset, those surfaces re-radiate this stored heat into atmosphere, which leads urban areas to keep a relative high temperature at night.

Loss of natural land covers, such as grasses and trees, inhibits the evapotranspiration process in which plants use heat from the air to evaporate water from their leaves. This process enables vegetation to act as heat

sink. Natural land covers also help the soil retain water; when water retention is reduced, evaporation from the soil decreases. Studies have shown that in the last 100 years, the temperature in Tokyo has gone up by 2.0 degrees C on average and its relative humidity has fallen by 15 % [3].

1.2 Heat island's defect

Heat island not only increases the risk of heat-related illness, but also increases air pollution levels, energy consumption for cooling in summer, and has a close relation to the other environmental problems such as urban concentrated downpour, etc.

According to the research in Tokyo (Tokyo Environmental Office, 2002) [3], the mid-summer days (a day in which the maximum temperature reaches 30 degree C or more) increased about 10 days in the past 20 years, and the number of people have been taken to hospital for heat stroke and related symptoms increased about 3 times (Fig.1).

Heat stroke: a general term used to refer to symptoms including heat cramps, heat syncope (loss of consciousness), sunstroke, and heat exhaustion. It generally occurs under high-temperature conditions, when the person is outside or in a gymnasium on a very hot day. It is a progressive condition that can range from loss of coordination resulting from a biological reaction to the body's attempt to maintain body temperature to a total shutdown of the body's internal organs.

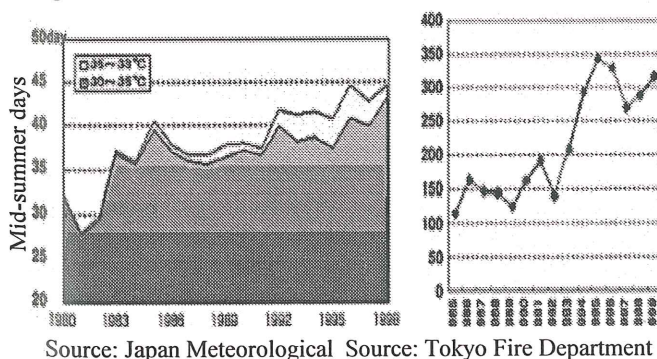


Fig1. Movement of mid-summer days and the number of heat strokes

Because temperature becomes higher in the city part, an ascending current arises from the suburbs to the center of city, and high up in the sky, an adverse circulation style occurs. This gathers pollutants and aerosols from the air in the city and creates a dust dome over the city.

In recent years, some reports also demonstrate the strong relationship between heat island and urban concentrated downpour and the other environment issues (Ministry of the Environment Government of Japan) [3]

1.3 Heat island's simulation

In order to clarify a city's thermal environmental status, or to predict its changes in the future, simulation is the best way.

The term "meso-scale" refers to structures and phenomena, which usually ranges from 1 km to 1000 km in the meteorology. Simulating city climate with a meso-scale extent can analyze the whole city synthetically, and can give advices when forming the whole city plan, so three-dimension meso-scale meteorological model plays a very important role. But, the most models have been used in the simulation of heat island are based on hydrostatic, and cause various problems such as limits of mesh cell size, calculation of boundary layer eddies, sub-microscale turbulent flow, etc.

2. Object

In this research, a relative high versatile numerical code - RAMS (the Regional Atmospheric Modeling System), which is constructed around the full set of nonhydrostatic, was applied into the simulation of heat island. Using RAMS's nesting function, it becomes possible to do the synthetical analysis of the whole city and the finer evaluation of a specified area at the same time. The target area of this research is Chongqing city and Sichuan Basin. This area owns a complex topography that is usually considered difficult to evaluate using the hydrostatic models, and its very hot summer has been troubling the people living there from long time before. Also, this area is the most important development area of China government, the population and urbanization explosion will occur, so clarifying this area's thermal environment situation and searching the counter measure before aggravating is meaning full.

3. Methodology

RAMS is usually used as a limited area meteorological model, and many of its parameterizations have been designed for mesoscale or high resolution cloud grids. RAMS's atmospheric model is constructed around the full set of nonhydrostatic,

compressible equations that atmospheric dynamics and thermodynamics, plus conservation equations for scalar quantities such as water vapor and liquid and ice hydrometeor mixing ratios.

3.1 Domain

Because Chongqing has a large area, and the topography is complex, a wide range of meteorological phenomenon should be taken into consideration in its simulation. The total domain area (grid1, coarse-grid) was set as 2000 km×2000 km, with a center point at (E104°, N31°), and was divided into 100×100 meshes. On grid1, another smaller grid (grid2, fine-grid) having a area of 500 km × 500 km and 100×100 meshes was nested in order to resolve Chongqing city finer. Its center point is at (E106.5°, N29.5°) where the central part of city lies. That can be seen in Fig.2. In RAMS, the simulation in the grid1 area was done at first for predicting variables on the coarse-grid. These predicted variables were then used for the interpolation of variables at the boundary points of grid2. Simulation in the grid2 area was then carried forward on the interior of fine grid mesh. Finally, the grid1 values in the grid2 domain were replaced by local averages from the fine grid variables.

The vertical domain was from 50 cm under ground to about 15 000m on the ground. About the under ground part, both grid1 and grid2 were divided into 11 layers as the same way. The thickness of the underground layers was, starting from the top, 1cm, 2cm, 3cm, 3cm, 3cm, 4cm, 4cm, 5cm, 5cm, 10cm, and 10cm.

About the above ground part, the height was based on a terrain-following height coordinate system, Z^* :

$$Z^* = H \frac{Z - Z_{\text{terr}}}{H - Z_{\text{terr}}} \quad (1)$$

where Z is the height above ground of the model surface; Z_{terr} is the topographical height at that grid point; and H is the height of the model top.

This formula ensures that the model top is a geopotential surface and the other levels are a given fraction of the distance between the surface and the top geopotential. The structure was shown in Fig3. The number of layers of grid1 was 19, while it was 25 in the case of grid2. The bottom layer's height of grid1 was 100m, and from the second layer, its thickness would be 1.15 times of its lower one. If its thickness became more than 1,200m, it would be set as 1,200m

constantly. In the case of grid2, the upper part was as same as that of grid1, while about the lowest 4 layers, they were divided further into 3, 3, 2, 2 respectively.

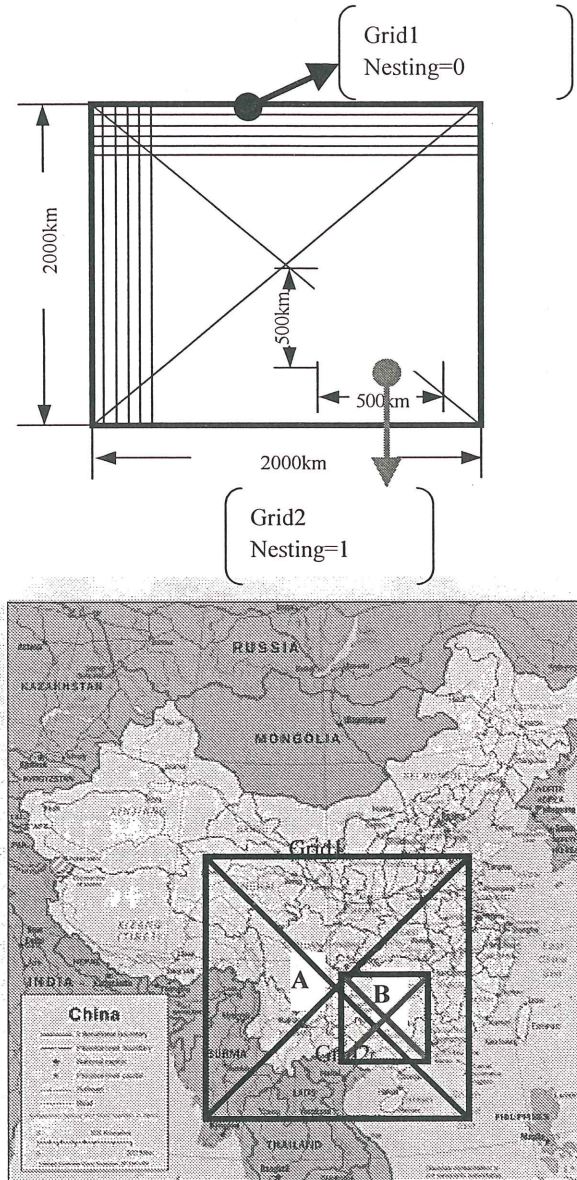


Fig2. horizontal domain area and meshes

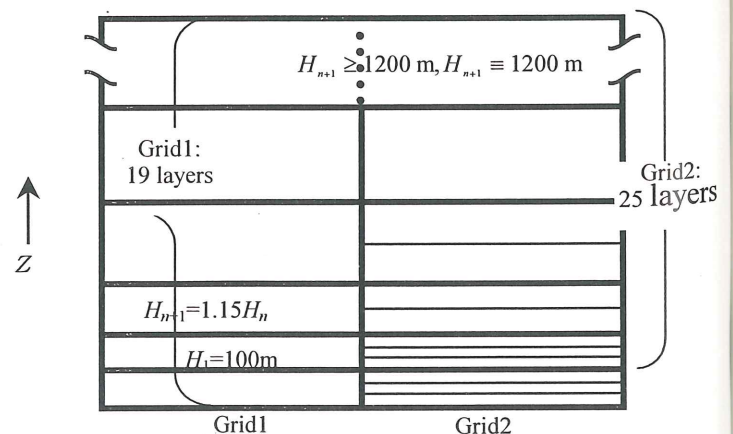


Fig3. vertical layers – above ground part

3.2 Input data and surface parameter setting

The following data sets were used as the input data of simulation

Table1. Input data

Name of data set	Description
Digital Elevation Model 30 s	Contains the global USGS (U.S. Geological Survey) topography dataset at 30s, or about 1km resolution.
Landuse	Contains the USGS global land use data at 30s, or about 1km resolution. The dataset is based on 1-km Advanced Very High Resolution Radiometer (AVHRR) data spanning April 1992 through March 1993
Sea Surface Temperature	Contains the USGS global monthly climatological sea surface temperature data at 1 degree resolution (about 100km).
Meteorological data*	NCEP (National Centers for Environmental Prediction) Global Tropospheric Analyses on 145x37 2.5 degree grids.

*Pressure-Level Data - the geopotential height, temperature, u-wind component, v-wind component. And relative humidity, at 1000mb, 925mb, 850mb, 700mb, 500mb, 400mb, 300mb, and 100mb respectively were used.

The main surface parameters were set as shown in table2.

Table2. Main surface parameters [5]

Land Cover Type	Albedo	Emissivity	Roughness /m
Lakes, rivers, streams	0.14	0.99	0.00
Snow, ice	0.40	0.82	0.01
Evergreen broadleaf tree	0.15	0.95	2.00
Evergreen needleleaf tree	0.10	0.97	1.00
Deciduous broadleaf tree	0.10	0.95	0.80
Deciduous needleleaf tree	0.2	0.95	1.00
Short grass	0.26	0.96	0.02
Tall grass	0.16	0.96	0.10
Mixed woodland	0.15	0.96	0.80
Crop/mixed farming	0.20	0.95	0.06
Irrigated crop	0.18	0.95	0.06
Bare ground	0.16	0.86	0.05
Cropland	0.10	0.95	0.11
Urban and built up	0.15	0.90	0.80

4. Results and discussion

The simulation was performed for 24 hours, from 0

UTC (Chongqing local time, AM7:00) to 0 UTC. Fig.4 and Fig.5 show two examples of the results.

In Fig4, left is the temperature distribution of grid1 at 9 UTC (Chongqing local time: PM4:00), right is that of grid2 at the same time. At this time, the temperature of Chongqing and Sichuan Basin is higher than its surrounding at a maximum of 7degrees C, which is also higher than the temperature of Hunan, Hubei Province about (4 to 5) °C.

In Fig5, left is the temperature distribution of grid1 at 21 UTC (Chongqing local time: AM4:00), right is that of grid2 at the same time. The temperature of Chongqing and Sichuan Basin was still higher than 25 degrees C, which means a tropical night (a day in which the minimum temperature is higher than 25 degree C) in the meteorology.

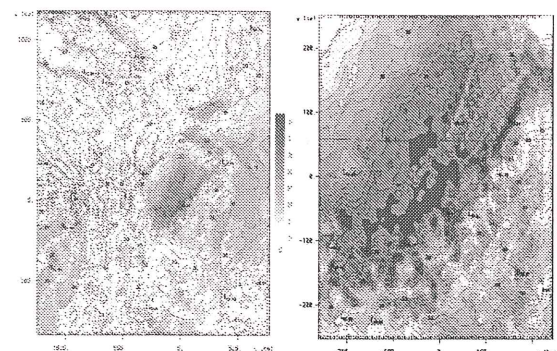


Fig.4 Temperature distribution at 9 UTC, July 26, 2001

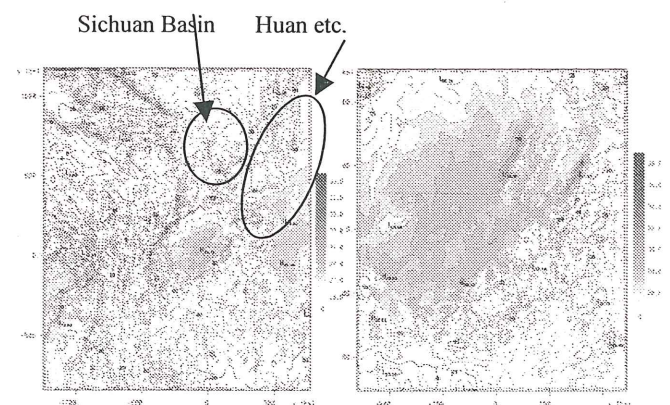


Fig.5 Temperature distribution 21 UTC, July 26, 2001

This simulation used the meteorological data of a warm sunny day (July 30, 2001). During this simulation, the temperature of Chongqing and Sichuan Basin keeps at a relative high level comparing with the other regions in the whole time, and the maximum temperature at 26m above ground reached 39.89 degrees C. Even in the night the difference kept at more than 3 °C.

While in the case of another cloudy day's simulation

(July 30, 1996, Fig.6), the temperature difference was not so conspicuous. Though the temperature of Chongqing and Sichuan Basin was still higher than out basin about 1 to 3 degrees C, it was almost at the same level of the other regions at the elevation (Hunan, Hubei Provinces etc.).

The temperature difference between inside and outside of basin was quite great, especially in the warm sunny days. Even the orthometric height of Chongqing and Sichuan Basin is higher than that of Hunan, Hubei, Henan, and Anhui province etc., the peak temperature of Chongqing and Sichuan Basin was much higher than theirs in the warm sunny days. The temperature of Chongqing and Sichuan Basin at night was not so high in the night comparing with Hubei, Henan, and Anhui provinces etc., they became almost the same in the mid-night. While after sun rising, Chongqing and Sichuan Basin's temperature rises more quickly.

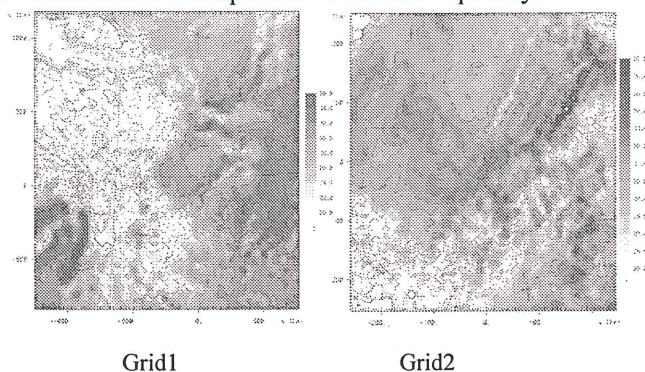


Fig6. Temperature distribution at 9 UTC, July 30, 1996

5. Conclusion

This research applied RAMS into the simulation of thermal environment. Using RAMS's nesting function, a specified area - Chongqing city and Sichuan Basin, was resolved finely in one simulation.

The result of this research clarified the relationship between the natural geography and the temperature distribution of Chongqing and Sichuan Basin. The temperature of Chongqing and Sichuan Basin was not so high in the night comparing with the other provinces with the same orthometric height, while after sun rising, Chongqing and Sichuan Basin's temperature rises more quickly. In a warm sunny summer day, the temperature of Chongqing and Sichuan Basin can be 4 °C to 5 °C higher than Hubei, Henan, and Anhui provinces etc. at the maximum.

References

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