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Experiments on fog prediction based on multi-models

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1. Abstract

A 1-D fog model (PAFOG) is coupled to MM5. MM5 provided the initial and boundary conditions (IC/BC) and some other necessary input parameters for PAFOG. Thus, we can run PAFOG for any interested area. Then, nine fog events observed in Nanjing during the winters of 2006 and 2007 are simulated by the two models. General performances of the two models for the nine fog cases are presented. The results of MM5 and PAFOG for two cases are verified against the field observations in detail. PAFOG outperformed MM5 in simulating radiation fog; however, MM5 performed better than PAFOG in simulating advection fog. The coupling method still needs improvements. The impacts of advection on fog should also be included in the 1-D model.

2. Introduction

The low visibility on fog days usually endangers all kinds of transportation and causes huge economic losses. Therefore, it brought more and more attentions of meteorologists in the world.

Although the numerical weather prediction (NWP) has been improved evidently with the development of computer technology, fog is still not a direct model product by any current NWP models (Zhou and Du 2010). Gultepe et al (2007) summarized the achievements on fog researches during the past several decades and pointed out that the future direction to study and forecast fog would be utilizing both 3D regional model and 1-D fog model.

Since neither 3D NWP nor 1D fog model is perfect for fog prediction currently, the objectives of this paper are: 1) to carry out experiments on fog prediction based on multi-models, a meso-scale model and a 1-D fog model; 2) To investigate whether the model profiles can be used to run the 1D fog model.

3. Study region and observational data

The region of interest covers provinces in eastern China, including Anhui, Jiangsu, Shandong, Henan, Hubei, Jiangxi, Zhejiang and Shanghai (See Fig 1 in Shi et al, 2009). Among those provinces, Anhui, Jiangsu and Zhejiang have higher fog occurrence frequencies, exceeding 20 day/year in most areas and even over 60 day/year for some areas (Liu et al, 2006). Usually, October to April are months with highest fog occurrence frequencies, especially in December and January (Zhou et al, 2007). By statistics on routine data of Anhui province during the past half century, Shi et al (2008) found that the maximum fog occurring time is 05 to 08 LST in the morning.

Around 800 routine meteorological stations, including 3-h ground level observations, in CMA (Chinese meteorology Agency) network were selected in this study. At the same time, profiles of temperature, humidity, wind and pressure from a sounding station in Nanjing (118.8°E, 32.0°N) were also used. In addition, field observations of fog were conducted by the Nanjing University of Information Science and Technology (NUIST) on NUIST campus (118.72°E,32.21°N) in northern suburb of Nanjing during the winters of 2006-2008 (Pu et al, 2008). Abundant data have been accumulated, based on which a series of scientific papers were published (Yang et al 2009).

Based on the routine visibility data, we analyzed the visibility distributions at 08 LST on fog days (Yang et al 2009). It was found that the fogs observed in Nanjing are not isolated. Almost all fog cases are parts of regional fog events. The regional characteristics of these fogs have been studied and identified (Zhou et al 2007).

4. Models and coupling method

Two models, MM5 and a one-dimensional fog model (PAFOG) are used in this study.

4.1 MM5 and configurations

MM5 and its configurations are mainly the same as those used in Shi et al (2009), except that different first-guess fields and boundary conditions are used here. In this paper, first-guess fields and boundary conditions for the coarse domain for every 6 hours were obtained from NCEP FNL (1°×1°). The simulations began at 08LST before the fog event day to 20 LST of the fog day, 36 h in total.

4.2 PAFOG

The 1-D model PAFOG (Bott et al,) was derived from the detailed spectral microphysical model MIFOG (Bott and Trautmann, 1990). The PAFOG was once used by Muller et al (2007) to set up an ensemble fog forecast system. The grid of our PAFOG model domain is divided into two subregions like Bott and Trautmann (2002). The simulations started at 20LST before the fog event day to 20 LST of the fog day, 24 h in total.

4.3 Coupling method between MM5 and PAFOG

To run PAFOG, we need to provide the initial temperature, humid, pressure in the PBL, geostrophic wind and soil data, etc. In this paper, we use MM5 output to provide the necessary input data for PAFOG, including the initial and boundary conditions (IC/BC), the high, medium and low cloud covers, and so on, so that, PAFOG can be run for any area of interest.

5. General descriptions of model performances on fog events in Nanjing

During the winters of 2006 and 2007, nine fog events were captured on the NUIST campus by the NUIST fog research group (Yang et al, 2009). Utilizing MM5, PAFOG and the above coupling method, simulations were conducted for the nine fog events in this study.

Table 1 compares simulated fog duration with measurements on NUIST campus. As for NUIST, if we use the LWC-only criterion, LWC>0.01g/kg, to decide fog production, MM5 reproduced 7 out of 9 Nanjing fog events successfully, although the simulated fog dissipated earlier than the observed fog. However, if we looked at the MM5 output for the two failed cases carefully, we found that MM5 produced relative humidity (RH) reached 100% at the lowest model layer (See Fig.1, 3, 4). If we use RH>98% as another criterion for fog production like Yang et al(2010), MM5 succeeded in reproducing all fog cases in Nanjing.

As for the situations in the model domain, the distributions of LWC and RH at 08LST are compared to the corresponding observed visibility distributions (See Fig.1 and 3). If the LWC-only criterion is used, the MM5 simulated fog regions are generally smaller than the observed fog area. MM5 performs well for those advection-radiation fog cases, e.g. fog events during December 25-27, 2006 and December 20-21, 2007. Although there are still false alarm and missing forecast in those cases, MM5 basically reproduced the major part of the fogs. For those fog cases mainly resulted by radiation cooling, the simulated fog regions are generally smaller than the observations, and the simulated fog area do not match the observations well in some cases. However, if we also use the criterion of RH (>98%), then the simulated fog regions cover the observed ones for all cases, even larger. It is easy to deduct that if we use some restrictive conditions, e.g., wind speed, cloud bottom like Zhou et al (2010), the false alarm area will be reduced.

Due to the availability of field observations, PAFOG was only used for NUIST by now. The results of PAFOG were evaluated using the measurements from the field observations, including LWC, visibility, etc. Generally, PAFOG captured almost all fog events, even for the advection-radiation fog on December 25, 2006. For the two cases on December 25-27, 2006 and December 14, 2007, for which we have the field measurements at hand, the simulated fog depths are shallower than the measurements.

In conclusion, MM5 performs better for the advection-radiation fog than for radiation fog; while PAFOG performs better for radiation fog.

6. Evaluations of model performances for two typical fog events

Considering the availability of data, the simulations of two fog cases were compared with the field observations in detail. The two fog cases are the advection-radiation fog occurring on December 25-27, 2006 and the radiation fog occurring on December 14, 2007.

6.1 The advection-radiation fog on December 25-27

An unusually dense regional advection-radiation fog event occurred in eastern China during Dec. 25-27, 2006. It reduced visibility to 100 m or less in much of Anhui, Henan, and Jiangsu provinces, even zero meters in Nanjing, the provincial capital of Jiangsu province, lasting more than 36 hours in some places (Shi et al, 2009).

Fig. 1 shows the distributions of simulated RH and LWC at the lowest model layer and the observed visibility at 08LST on Dec 25. Comparing Fig. 1a with Fig.1b, c, it can be seen that MM5 caught the major part of the dense fog if only LWC was considered; However, if RH>98% was used, the simulated fog area covers all observed fog area with some false alarm.

Fig. 2 presents the variations of simulated and measured ground-level LWC and visibility. It can be seen that MM5 caught the trend of LWC well, especially on Dec 25 and 26, with a correlation coefficient of 0.6. Affected by low clouds by MM5, PAFOG produced lower liquid water on Dec 25; however, the PAFOG produced LWC was consistent with that of MM5 (r=0.74). Also, PAFOG over-estimated the ground-level LWC on Dec 27, like MM5. Although the MM5 simulated fog did not consecutive, it did catch the major fog episodes. PAFOG produced much lower fog water on Dec 25, while its visibilities closely related with the measured ones (r=0.73) on Dec 26-27, although large differences were noted for some times. This might be related to the model spin-up, especially under the situations that fog already existed at the simulation beginning time (Muller et al 2007).

In a word, from the comparisons of ground-level LWC and visibility with measurements, MM5 outperforms PAFOG in this case. The performance of PAFOG depends on the IC/BC provided by MM5.

6.2 The radiation fog on Dec 24, 2007

A strong dense fog event was recorded in Nanjing on Dec 14, 2007. It lasted about 14 hours, with a maximum height of 600 m. The fog was first formed through radiation cooling in the ground-level, and then followed by a cloud layer caused by low-level cold advection (Yang et al, 2010).

Fig. 3 shows the distributions of simulated RH and LWC at the lowest model layer and the observed visibility at 08LST on Dec 14. Comparing Fig. 3a and Fig.3c, it can be seen that MM5 failed to catch the major part of the dense fog, which was located in Anhui and Hubei, if only LWC was considered; However, if RH>98% was used, the simulated fog area covers all observed fog area with some false alarm.

Fig. 4 presents the variations of PAFOG simulated and measured ground-level LWC and visibility, and MM5 simulated ground-level RH. Although MM5 did not produce LWC in Nanjing, it did forecast saturated RH. The MM5 predicted RH steady with 100% from 00LST to 08LST on Dec 14. Therefore, we can say that MM5 also has some capability on this case. Due to the rapid radiation cooling by clear sky, PAFOG produced fog water soon after its startup. The PAFOG simulated LWC reached maximum at about 06 LST. In observations, although high humidity (RH>98%) and low visibility (V<km) were observed quite early (around 21LST on Dec 13) (Fig. 4b), evident liquid water was not measured until 05LST, Dec 14. It is worth noting that both the simulated and observed times with maximum LWC and fog dissipation are quite consistent. Considering the fact that the concentrations of manmade aerosol, especially the hygroscopic aerosol like sulfate, are high in most China, the hygroscopic increase in aerosol size decreases the visibility to under 1km even without liquid water. For example, the observed visibility changed from fog (V<1km) to dense fog (V<500m) from 22LST, Dec 13 to 05LST, Dec14, while the measurable liquid water (0.01g/kg) appeared until 06LST on Dec 14 (Fig 4a). In Fig.4b, due to the earlier formation of liquid water, the simulated visibilities were lower than observations in the initial stage (before 06LST), in the late stage (after 10LST) , the simulated liquid water disappeared and simulated visibilities increased to over 1km soon, while the observed visibilities increased slower than simulation. However, the variation trends were quite consistent with a correlation coefficient of 0.82. Accordingly, we think that PAFOG predicted the formation and dissipation of this radiation fog successfully.

7. Summary and Conclusions

MM5 and a 1-D model (PAFOG) were coupled and used to simulate nine fog events in Nanjing. Through verifications of simulated high RH or LWC area against observed low visibility area, the simulated hourly LWC and visibilities against the measurements in the field observations in NUIST, the performances of MM5 and PAFOG on fog predictability were evaluated. The results show that both models can reproduce most fog events; MM5 performs better for advection-radiation fog than for radiation fog, while PAFOG performs better for radiation fog than for advection-radiation fog; coupling between two models does work in most cases; Cloud cover is a key factor for fog production in the 1D fog model; The LWC-only method by NWP is not enough, both liquid water content and relative humidity should be considered to diagnose fog occurrence. The coupling method still needs improvements.

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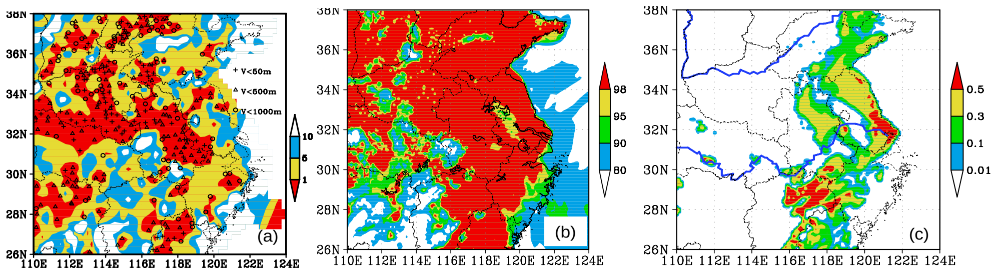

Fig. 1 Distributions of measured visibilities (a), simulated RH (b), and simulated LWC (c) by MM5 at 08LST on Dec 25, 2006

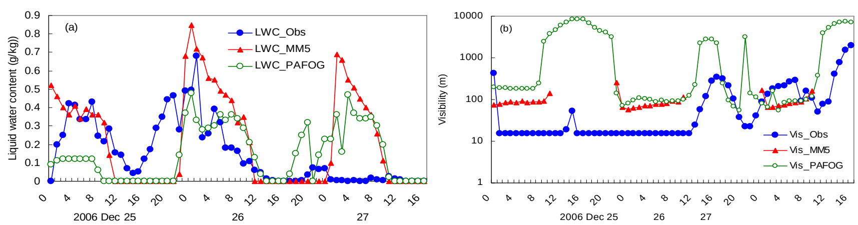

Fig. 2 Variations of simulated and observed LWC (g kg^{-1}) and visibility (m) on the NUIST campus on Dec 25-27,2006

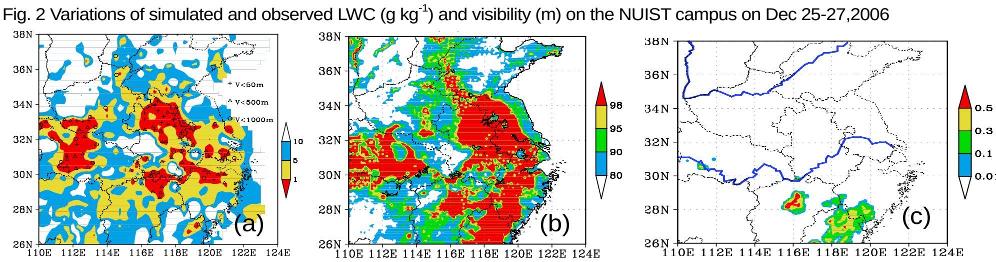

Fig.3 Distributions of measured visibilities (a), simulated RH (b), and simulated LWC (c) by MM5 at 08LST on Dec 14, 2007

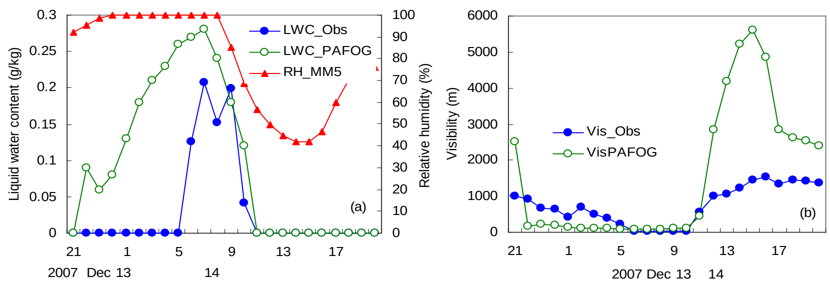

Fig.4 Variations of simulated and observed LWC (g kg^{-1}) (a)and visibility (m) (b)on the NUIST campus on Dec 14,2007

Table 1 General descriptions model performances for Nanjing fog events

Day	Observation (h)	MM5 (h)	PAFOG V<1km	PAFOG CLW>0.01g/kg
12/12,2006	11T23-12T11	***No CLW*** 11T23-12T08	11T22-12T13	11T22-12T12
12/14,2006	13T23-14T12	14T02-09	13T22-14T11	13T22-14T11
*12/25-27, 2006	24T22-27T14	24T22-25T10 25T19-26T11 26T19-27T10	24T22-25T08 25T22-26T12 26T17-27T10	24T22-25T08 25T22-26T12 26T17-27T10
12/14,2007	13T23-14T11	***No CLW*** 13T23-14T08	13T22-14T11	13T22-14T10
12/18,2007	18T03-18T11	17T21-18T09	17T22-18T20	17T23-18T20
12/19,2007	18T16-19T12	18T23-19T08	18T22-19T12	18T22-19T12
12/20,2007	19T17-20T16	20T00-20T10	19T21-20T11	***No CLW***
*12/21,2007	20T18-21T19	20T21-21T20	20T22-21T07	***21T01-21T03***
12/23,2007	23T01-23T05	22T22-23T10	22T22-23T11	22T22-23T11

*: advection-radiation fog