Experimental Numerical Weather Forecasts over Taiwan by the NCEP Nonhydrostatic Mesoscale Spectral Model

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Abstract

It is generally believed that nonhydrostatic numerical weather forecast model is necessary for mesoscale weather prediction with the grid spacing less than 10 km. The feature of the high resolution mesoscale forecast is mainly from the provided high resolution surface conditions, such as terrain, surface roughness, surface planetary etc. It is truth that Taiwan has its unique geographic properties for fine resolution mesoscale modeling, especially that it has several high mountains up to more than 2000 m. The NCEP nonhydrostatic mesoscale spectral model (MSM), the nonhydrostatic version of regional spectral model (RSM), has been evolved into a capability to be used for fine resolution mesoscale weather forecasts. Experimental weather forecast by MSM over Taiwan is a reasonable research plan to improve and evaluate the performance of the MSM. The recently developed prognostic cloud scheme is included in this works for possible improving as well.

One case on the initial date of 0000 UTC 23 December 1997 is tested. The prevailing north-east wind is the common synoptic condition for winter time over Taiwan. This case is selected arbitrary but it has north-east prevailing wind. The model is running by using a workstation. The primary results show that the MSM can catch up with the mesoscale features after 3 hr integration under the condition of no regional data analysis for the initial condition. At 3 hr forecast, it is about noon at local time, the precipitation over the mountains is produced with local maxima along the hills. The snow depth up to 30 mm is over the mountain top where the 2 m air temperature is below frozen point. After 15 hour later, it is about midnight at local time, there is less rainfall over land as compared to the nearby waters. And the snow cover is extended to the southern mountains with frozen 2 m air temperature over larger area. The lack of the observation is the weakness in this work, the collaboration with Taiwan researchers to obtain observation data for model improvement and fine tuning is the future plan.

1. Introduction

The NCEP (National Centers for Environmental Prediction) MSM (Mesoscale Spectral Model) is developed following the structure and numerics of the NCEP RSM (Regional Spectral Model, Juang and Kanamitsu 1994) and nonhydrostatic formulation of Juang (1992) with some modifications. After several years' model improvements (Juang et al. 1997), the flexibility and functionality of the RSM are passing to the MSM. The capability of the MSM for fine resolution in several kilometer grid spacing should be examined, either in sub-synoptic domain or the radar-scale domain. From our experiments, the MSM can be used to integrate up to several days in a sub-synoptical domain without any further difficulty, however, the predictability of the limited area model with the sub-synoptical domain is limited (Warner et al. 1997), thus, in order to have more useful period of forecast, the MSM has to have capability to spin-up the mesoscale in a very short period, say less than 3 hours, for short range forecast. Before it can be proved that the MSM can be used for several days forecast over small domain. The capability of quick spin-up for the mesoscale feature without fine resolution observation should be examined, especially while the lack of fine resolution observation data in the operational normal daily data collection nowadays.

Taiwan has its unique geographic properties, not only it is a island which can be covered easily by any mesoscale model as a sub-synoptic domain, but also it has several high mountains which can represent or result mesoscale feature easily. From the experiments of Juang 1996, the mountain areas can produce different mesoscale features between the MSM and the RSM. And it can be understood that the mountain area can produce vertical motions more than any flat plain and ocean, the hydrostatic system of the RSM may not good enough for these kinds of the forecast, since the vertical motion is constrained by the hydrostatic relation. Thus, for the consideration of 'true' forecast, the solution from the nonhydrostatic system of the MSM should be used, since the nonhydrostatic system is more closed to the real atmospheric behavior.

The model description of the MSM and the experimental design are illustrated in the section 2. Some preliminary results with examination of the 3 hr and 15 hr forecasts are shown in the section 3, then the conclusion is given in the section 4.

2. Model and experimental design

The NCEP nonhydrostatic version of the regional spectral model (RSM) is called mesoscale spectral model (MSM) to represent its functionality. It is a fully compressible nonhydrostatic system in hydrostatic sigma-p coordinate. The preliminary design of the system required a predefined hydrostatic system in order to determine the coordinate, either a time-dependent or time-independent hydrostatic coordinates (Juang, 1992). The disadvantage of the preliminary design is that it has difficulty to relax the upward propagation of the internal gravity wave as those of the most of nonhydrostatic models. A mass conservation of the coordinate is added into the original design without top sponge layers or radiative conditions. It gets rid of most of the top boundary problems, shown in the previous experiments (Juang, 1996).

The perturbation method and the spectral computation used in the RSM are used in MSM. The major routines used by the RSM are modified to be used both for RSM and MSM, thus MSM takes all the advantage of the RSM. The perturbations of the added nonhydrostatic prognostic variables are related to the internal hydrostatic system, which has perturbation related to the coarser resolution model as the base field, either from the global spectral model (GSM) or the RSM.

The model physics are the same as the RSM but modified not to have hydrostatic assumption (Juang et al, 1997). The physics include short-wave and long-wave radiations with cloud interaction, surface energy budget with diurnal cycle, three-layers soil temperature and two-layer soil moisture model with runoff, surface layer physics with non-local vertical diffusion for high resolution planetary boundary layers, gravity wave drag, simplified Arakawa-Shurbert cumulus convection, and larger-scale precipitation with evaporation. Besides the large-scale precipitation, a prognostic cloud scheme is added to replace the large-scale precipitation for use with higher model-grid resolution. The cloud scheme has two options; either three cloud-related prognostic variables or five. The three variables in the first option are specific humidity, specific cloud water or cloud ice, and specific rain water or snow. For a given grid point, either water or ice, and either rain or snow, depends on the temperature. The five variables in the second options are specific humidity, specific cloud water, specific rain water, specific cloud ice, and specific snow. For any given grid, it can have mixed phases.

The model domain is shown in Fig. 1, the model terrain is obtained first interpolation from 5 min by 5 min topographic data set, then applied model spectral transformation to have the same wave number as the model. Lanczos spectral smooth is applied to the spectral-transformed model terrain to reduce the ripples along the coastal waters due to the spectral Gibbs phenomenon. This model scale terrain results two peaks up to 2700 m. It is about 1000 m lower than the real peak. The Mercator projection with true latitude on 23.5N is used. The horizontal grid spacing is 8 km in the mapping coordinate. This model horizontal resolution is selected to satisfy the limitation of the capacity of the workstation with this given domain.

The initial condition for this case is 0000 UTC 23 December 1997. The cubic spline interpolation is used to interpolate GSM T126 analysis (about 106 km horizontal resolution) to the MSM domain for the initial atmospheric condition. Linear interpolation is used for initial surface conditions, which contain surface temperature, soil temperature and moisture, albedo, planetary resistance, snow depth, mountain variance, land-sea mask, and surface roughness. Finally, the model-scale terrain is added into the initial condition by cubic spline interpolation in vertical for the atmospheric data, and some surface data are replaced by the model-scale terrain related data, such as land sea mask, mountain variance for physics computation. The T126 GSM forecasts are used for the lateral boundary and the base fields with linear interpolation in 6 hr interval. No regional fine resolution data analysis or assimilation is performed for the initial condition. For examination of the short range forecast, 36 hour integration is conducted with outputs saved in 3 hour intervals.

3. Case results

Only 3 hr forecast and 15 hr forecast are selected to present here. The 3 hr forecast is valid at local time around 11 am, and the 15 hr forecast is valid at local time around 11 pm. Thus the model responses to day time and night time can be discussed, and the spin-up after 3 hr integration can be examined.

Figure 2 shows the sub-domain of 2 meter temperature and 10 meter wind after (a) 3 hr integration and (b) 15 hr integration. The north-east prevailing wind was covered nearly entire domain initially (not shown), but it is affected by the resolved model-scale terrain after integraton. The 10 meter surface wind is spread along the east and west sides of the island, and makes a convergence line southwest to Taiwan over the ocean. The 2 m surface temperature changes to response to the model-scale high mountains with air temperature below the frozen point on top of the mountain peak. The temperature gradient along the hills and the denser cold air on the top of mountains produce strong downslop wind, especially along the slop where has higher gradients of model terrain. The temperature gradient is produced due to the solar radiation at day time. During the night time, after 15 hr integration in Fig. 2b, the temperature gradient shows in two major areas, one is nearly the top mountains, another one is along the coast line. The surface wind responded to these two temperature gradients becomes a much noisier pattern.

Figure 3 has the same forecast period and the same sub-domain as Fig. 2, but it shows 3 hr accumulated precipitation for (a) day time and (b) night time. In order to examine the location of the heavy precipitation, the model-scale terrain is plotted in Fig. 3a at intervals of 800 m. Precipitation is all over the mountain area, but the maxima of the heavy precipitation are along the hills, not on the top of the mountains. One is over the north-east of the northern high mountain, another is over the south-west of the northern mountain peak and extends into the north-east of the southern mountain peak, the other is over the south-east of the southern mountain peak. This should be verified with observation. During the night time, the rainfall is over the nearby waters, and much less amount of rainfall over the land. These rainfall over waters may be related to the convergences due to the offshore winds and entire island mountain induced flow, see Fig. 2b.

Figure 4, the time and sub-domain as the same as Fig. 2 again, shows snow accumulated depth and model terrain for (a) day time and (b) night time. There is no snow existed in the initial condition (not shown). From the precipitation shown in Fig. 3a and the frozen air temperature shown in Fig. 2a, it can be expected that the precipitation over mountain top should be snow. The accumulated snow depth is extended from the northern mountains to the southern mountains. The pattern of the snow covers is less change after 12 h integration (not shown). Even though there is very light precipitation during night time shown in Fig. 2b and late in day time, the accumulated snow is still over there without totally melting from the night time to the second day time. It may be true in the winter time over high peaks of the mountains, but the area coverage of the snow seems to be too large.

4. Conclusion

This preliminary case result, after merging two source codes from the RSM and the MSM for the workstation version, shows a reasonable model physics behavior. The prognostic cloud scheme is used for this study with a successful reasonable result, but some tunings may be required. The ample amount of precipitation during the first spin-up time, after 3 hour integration, the messy rainfall over the open oceans, and the wider coverage of the snow covers may not be reality. Thus further experiments are required, and observation with fine resolution has to be obtained for model improvement and tuning.

The major features and the advantage of the fine resolution mesoscale modeling are the low atmospheric forecasts in fine resolution due to the fine resolution surface conditions. However, to have fine observation data from the routine daily operational framework is impossible nowadays, except radar data. Radar data may have a fine resolution but may not have sufficient surface data and coverages. Nevertheless, it can be believed that local researchers may have collections of fine resolution data, especially from any specific local field experiment. Thus, the collaboration with local researchers by using fine resolution observation data for improving the MSM performance will be the future plans.

Acknowlegement: This experiment is computed using SGI multi-process workstation at GSFC, NASA through collaboration.

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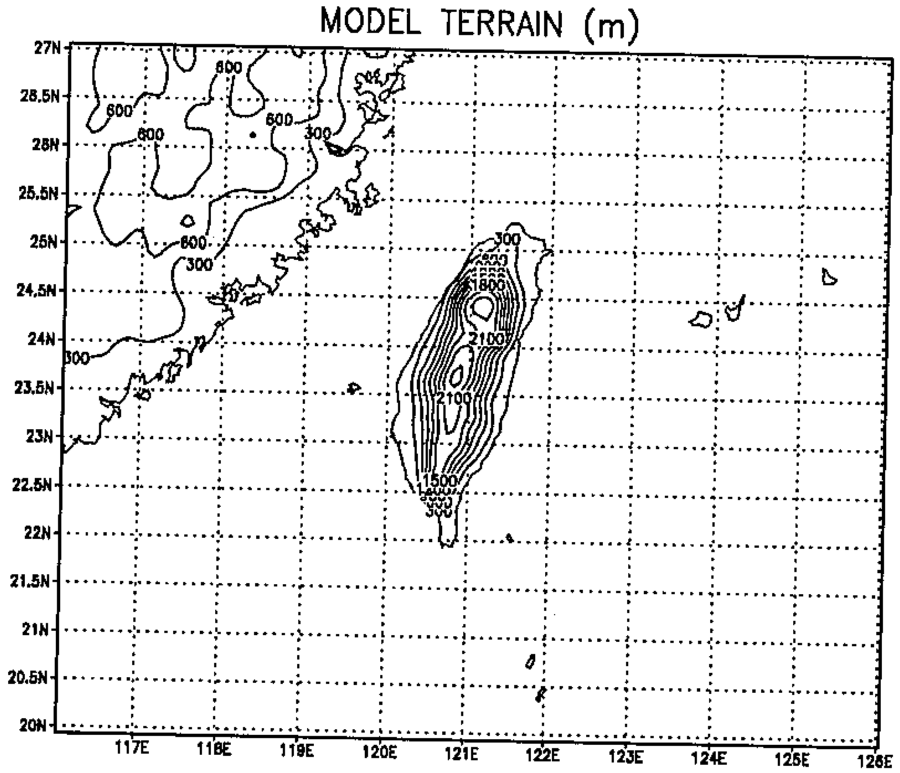

Fig. 1 The model domain with model terrain in meter, contour intervals of 300 m.

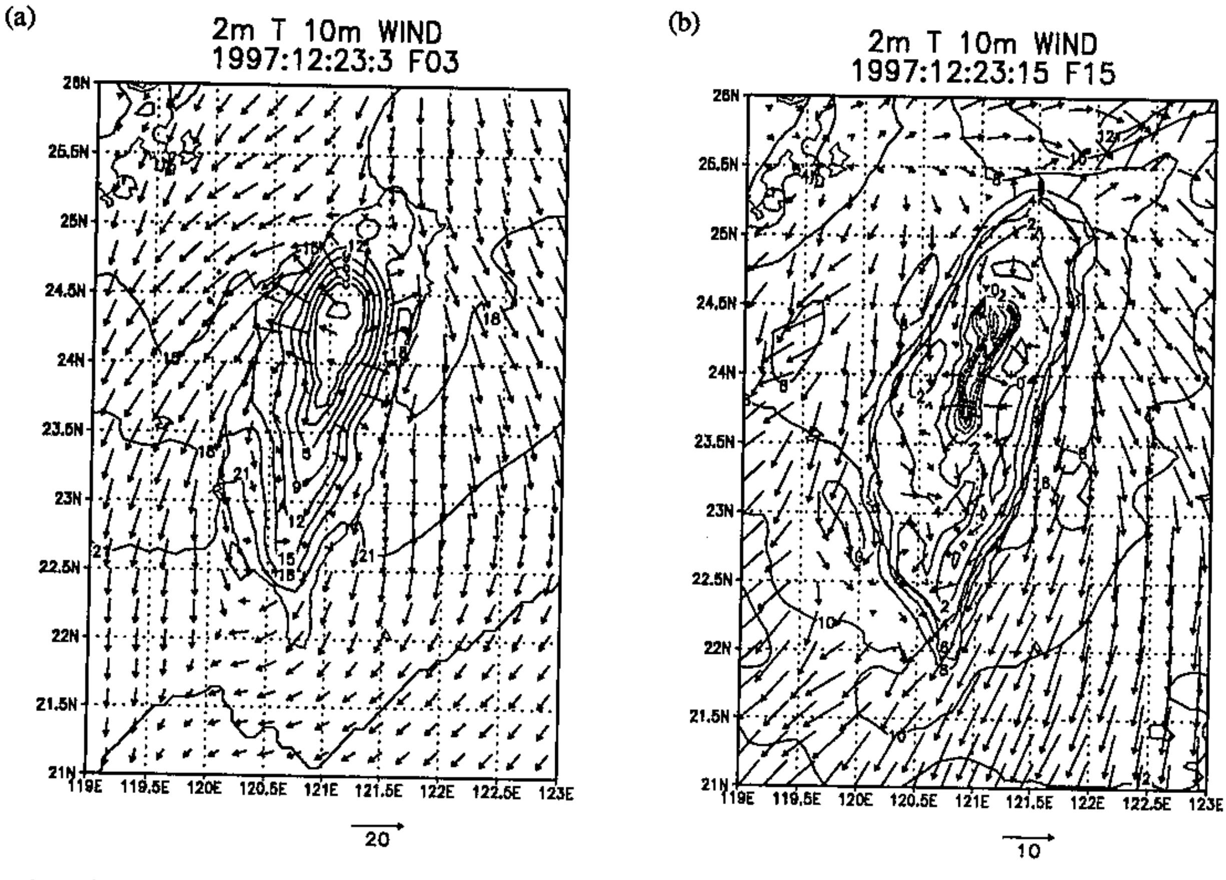

Fig. 2 The 2 meter temperature and 10 meter wind for (a) 3 hr forecast with contour intervasl of 3 °C for temperature and (b) 15 hr forecast with contour interval of 2 °C for temperature over selected sub-domain. Dotted lines indicate temperature below frozen point.

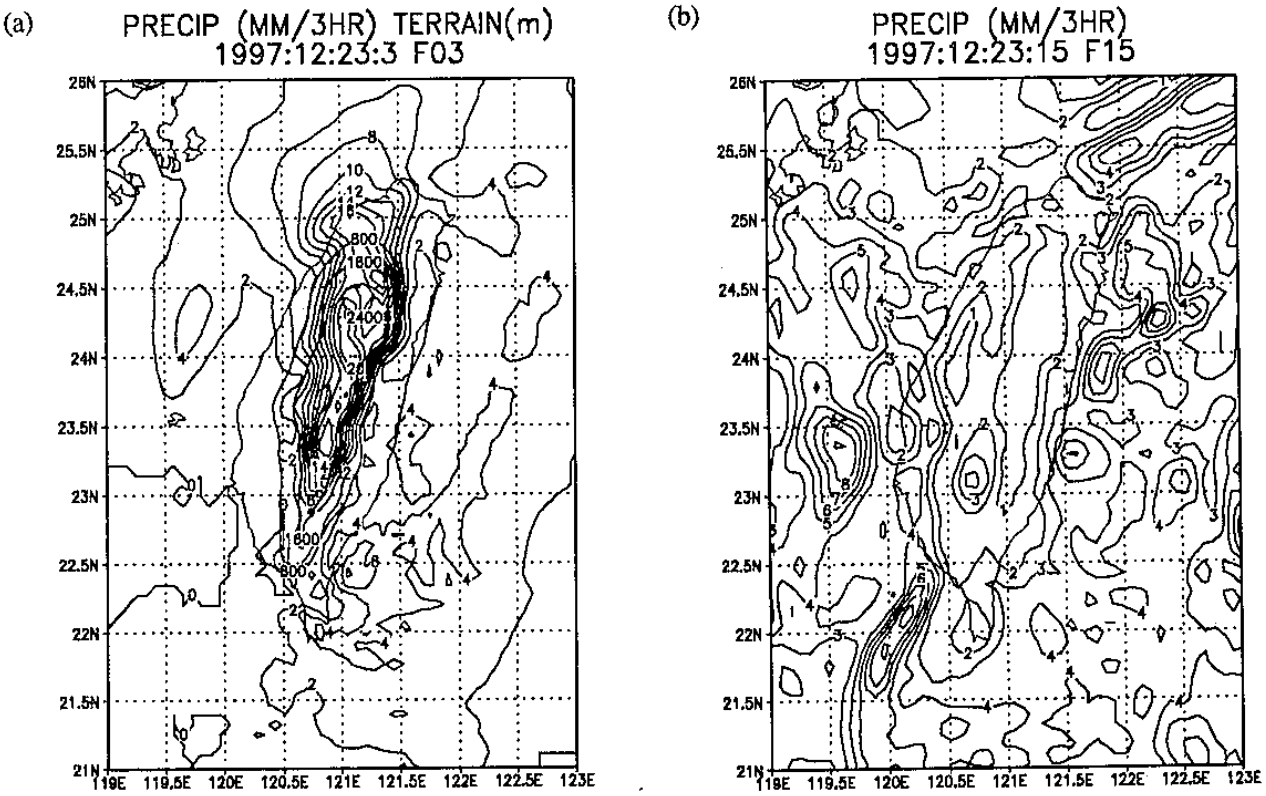

Fig. 3 The 3 hr accumulated precipitation in mm over sub-domain for (a) 3 hr forecast with contour interval of 2 mm, model terrain is plotted with interval of 800 m, and for (b) 15 hr forecast with contour interval of 1 mm, no model terrain is plotted.

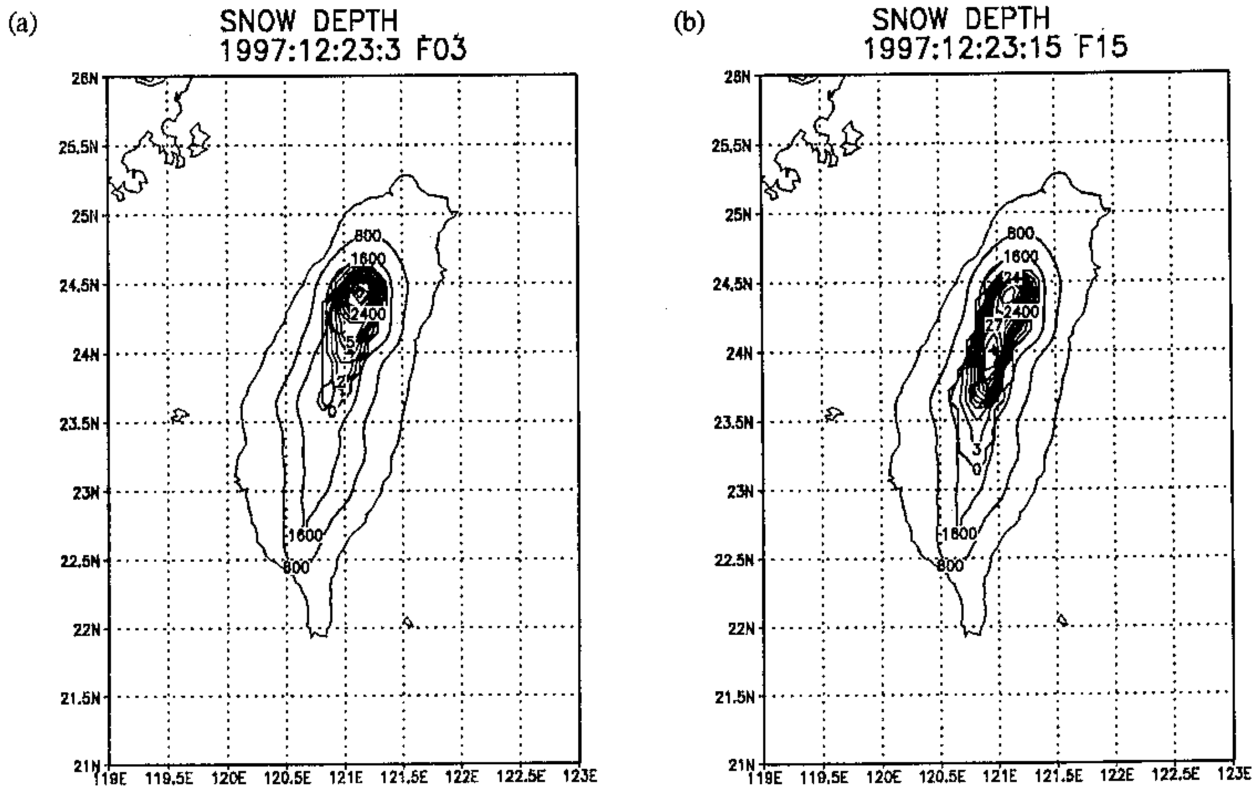

Fig. 4 The same as Fig. 3, but water equivalent accumulated snow depth in mm with (a) contour interval of 2 mm, and (b) of 3 mm.