Mesoscale Ensemble Forecast

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ABSTRACT

This paper first reviews the background and general concept for ensemble model forecasts and discusses the importance of precipitation parameterization on quantitative precipitation forecast (QPF). Then the mesoscale QPF ensemble forecast experiment for the 2000 Mei-Yu season (May and June) is introduced. Finally we elaborate the potential values of real-time mesoscale ensemble forecast for military maneuvers and daily operations in the Taiwan area.

1. Introduction

The concept of ensemble forecasting was first initiated by Lorenz (1963), where he examined the initial state uncertainties in the atmosphere and discussed the well-known "butterfly" or chaos effect. Much progress has been made in ensemble forecasts using numerical weather prediction models (NWPs), especially for global NWP application (Krishnamurti et al. 1999). With the increase of computational power, now is the time to attempt the ensemble forecasting on the mesoscale (Kuo 2000).

Wang and Seaman (1997) performed a comparison study of four cumulus parameterization schemes (CPSs), the Anthes-Kuo, Betts-Miller, Grell, and Kain-Fritsch schemes, using the Penn State/NCAR MM5 model. Performance of these CPSs was examined using six precipitation events over the continental United States for both cold and warm seasons. They found that no one CPS always outperformed the others. The general 6-h precipitation forecast skill for these schemes was fairly good in predicting four out of six cases examined in the study, even for higher threshold. The forecast skill was generally higher for cold-season events than for warm-season events. There was an increase in the forecast skill with the increase of horizontal resolution, and the gain was most obvious in predicting heavier rainfall amounts. The model's precipitation skill is better in rainfall volume than in either the area coverage or the peak amount.

Du et al. (1997) examined the uncertainities of initial condition and cumulus parameterization on quantitative precipitation forecasts (QPFs) for a cyclogenesis case in the United States using the Penn State/NCAR MM4 model. Ensemble QPF had large sensitivity to initial condition uncertainities. Ensemble averaging reduced the root-mean-square error for QPF and nearly 90% of QPF improvement was obtained using ensemble sizes as small as 8-10. Further sensitivity experiments showed that the QPF improvement by ensemble forecasting exceeded the improvement by doubling horizontal resolution.

Mullen et al. (1999) investigated the impact of differences in analysis-forecast systems on dispersion of an ensemble forecast for a cyclogenesis case. Error growth by initial condition uncertainities significantly depended on the analysis-forecast system. QPFs and probabilistic QPFs were extremely sensitive to the choice of precipitation parameterization in the model, similar to the findings of Yang et al. (2000) for a Mei-Yu frontal precipitation event. Therefore, the combined effect of uncertainties in precipitation physics and the initial conditions provides a means to increase the dispersion of QPF ensemble forecast system.

Recently Wandishin et al. (2000) experimented with an ensemble set consisting of

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five members from the Regional Spectral Model (RSM) at the National Centers for Environmental Prediction (NCEP) and 10 members from the 80-km ETA model. They showed that ensemble configurations with as few as five members could significantly outperform the higher-resolution 29-km Meso-ETA model in precipitation forecasts. Clearly, significant effort is required in the designing and testing an optimal set of ensemble members. Also, more work is required to perform ensemble forecasting at mesoscale resolution less than 10 km (Kuo 2000).

Finally, weather information is very important for the military maneuvers and daily operations; a timely and accurate weather forecast may be key to a successful military operation like the D-Day Invasion on Normandy during World War Two (Fuller 1990). Manobianco et al. (1996) described successful examples of using real-time mesoscale modeling for weather support to operations at the Kennedy Space Center in the United States. Therefore, mesoscale-model ensemble forecasts in real time, with focus on precipitation, visibility and wind-shear forecast, can have important impacts on the military operations in the Taiwan area.

2. Ensemble forecast in the 2000 Mei-Yu season

Based on the concept of ensemble forecasting discussed in the introduction, scientists at several universities and operational centers within the Heavy-Rain Research Group, led by Prof. Ben J.-D. Jou, jointed together to conduct the Ensemble Forecast Experiment during the 2000 Mei-Yu season (15 May to 20 June 2000). The participating sites are National Taiwan University (NTU), National Central University (NCU), National Taiwan Normal University (NTNU), Chinese Culture University (CCU), Central Weather Bureau (CWB), and Civil Aeronautic Administration (CAA). There were three sets of ensemble forecasts. The first set was to use the Penn State/NCAR MM5 (Grell et al. 1994) Version 3.3 as a common model and then use different precipitation (cumulus and microphysics) parameterizations at different sites. Table 1 lists the cumulus and microphysics schemes used in the MM5 ensemble experiment. The second set was to use the Limited Forecast System (LFS) and Non-hydrostatic Forecast System (NFS) of the Central Weather Bureau. The third set was to produce the “total ensemble” forecast based on the MM5 ensemble (the first set) and the LFS/NFS ensemble (the second set).

The model configuration for the MM5 ensemble experiment includes a coarse mesh of 45-km grid size and a fine mesh of 15-km grid size. Domain size is 81╳71 for coarse mesh and 79╳79 for fine mesh, with 23 σ levels in the vertical. Each MM5 run is 36 hours. The initial condition for MM5 ensemble is provided by the analysis field of the Central Weather Bureau Global Forecast System (CWBGFS; Liu et al. 1997) as the first-guess field and the boundary condition is provided by the CWBGFS forecast field through the “regrid” package. Surface observations and sounding data are included by objective analysis to improve the first-guess field through the “little-r” package.

From 15 May to 20 June 2000, Miss Hui-Chuan Lin at the Civil Aeronautic Administration put the initial-condition and boundary-condition files for the MM5 ensemble runs at a common ftp site (provided by the Central Weather Bureau) twice a day (00 UTC and 12 UTC). Each participating site came to this ftp site to obtain files for the MM5 ensemble run. Because of the narrow bandwidth of educational network, each participating site only ftped the digital 6-hourly rainfall forecast of 15-km MM5 run back to the Central Weather Bureau (CWB). Dr. Jen-Hsin Teng at CWB produced ensemble rainfall forecasts to be used by forecasters to help their issuing of heavy rainfall warnings based on these three sets of experiments.

3. Results and discussion

To illustrate the ensemble forecasts, Fig. 1a shows the observed 12-hourly (12 UTC 12 June to 00 UTC 13 June) accumulated rainfall (recorded at the automatic rain gauge stations). Figure 1b shows the corresponding MM5 ensemble rainfall forecast, Fig. 1c shows the LFS/NFS ensemble rainfall forecast, and Fig. 1d is the total ensemble forecast with the combination of MM5 ensemble, LFS forecast and NFS forecast. Figure 2 is similar to Fig. 1 but for the next 12-h period (00 UTC to 12 UTC 13 June). Figure 1b and Figure 2b are done by arithmetically averaging the rainfall forecasts of 6 members of MM5 ensemble runs. Fig. 1c and Fig. 2c are produced by simply averaging the NFS forecast and the LFS forecast. Fig. 1d and Fig. 2d are made by arithmetically averaging the rainfall forecasts of MM5 ensemble, LFS run and

NFS run.

For the first 12-h period (12 UTC 12 June to 00 UTC 13 June), it is clear from Fig. 1a that major heavy rainfall centers are along the northwestern coast, northern central mountain area, southern central mountain area and the southwestern coast. The MM5 ensemble forecast (Fig. 1b) captures the rainfall cores along the northwestern coast and southwestern coast quite well, but there are no rainfall cores on the mountain peaks. On the other hand, the LFS/NFS ensemble forecast (Fig. 1c) reproduces the rainfall cores along the Central Mountain Range, but there are no precipitation maximum along the northwestern and southwestern coasts. The total ensemble forecast (Fig. 1d) shows the rainfall maximum along both the coastal and the mountain area, but its intensity is weaker due to the nature of averaging and smoothing.

For the next 12-h period (00 UTC to 12 UTC 13 June), rain gauge observation (Fig. 2a) shows major rainfall cores along the peaks of Central Mountain Range. The MM5 ensemble forecast (Fig. 2b) shows precipitation maximum in the southwestern coast and totally misses the maximum rainfalls along the mountain peaks. However, the NFS/LFS ensemble forecast (Fig. 2c) successfully captures the mountain-peak rainfall maximum. Finally, the total ensemble (Fig. 2d) still produces the rainfall cores along the mountain peaks.

In general, for some rainfall events, the MM5 ensemble forecasts outperform the LFS/NFS forecasts, and for the other events, the LFS/NFS forecast is better than the MM5 ensemble forecasts (at least for the Ensemble Forecast Experiment during the 2000 Mei-Yu season). More detailed analysis of ensemble forecasts is needed in order to understand why and when the ensemble forecast of one set is better than that of the other set.

Figure 3

Figure 4

4. Application in military operations

It is well known that the successfully military maneuvers of the Allies on Normandy on 6 June 1945 (D Day) heavily relied on the accurate weather forecast (Fuller 1990). Within a very short lead time, the Allies used the only few fair-weather time windows (partly overcast and modest visibility) over the Normandy coast during the summer season and conducted the largest-scale join-forces invasion at that time, and then they successfully defeated the German Army and Air Force. As a result, this successfully military maneuver totally changed the world history!

Because Taiwan is an island with steep mountain and rich mesoscale weather features, an accurate and timely weather prediction from a mesoscale model is necessary for a successful execution of military maneuver and daily operations in the Taiwan area. The meteorological information from a mesoscale model that is useful for a military maneuver includes: cloud cover, cloud top/base height, visibility, wind gust, temperature, amount and distribution of precipitation.

Daily military operations such as the fighter jet aviation in the Air Force, the cruise of cargo and fighter ships in the Navy, the missile shutting exercise in the Army all rely on precise and prompt weather forecasts on a daily basis. For an example of daily aviation practice on an Air Force Base, several meteorological predictant events from a mesoscale model can be used to ais in the daily aviation planning and execution: 1) a lightning stroke within 10 km of the Air Force Base site, 2) approaching of a thunderstorm nearby, 3) chance of substantial precipitation to reduce visibility, and 4) cross wind (to the run way) of 15 m/s or higher.

The numerical weather prediction has inherent limitation due to the uncertainties of initial condition and physical parameterization. Taiwan’s rich weather phenomena (Mei-Yu front, Typhoon, Winter-time Cold Front, Summer-time thunderstorm and others) make the NWP limitation more severe. In order to reduce the uncertainties of initial condition and physical parameterization on NWP performance, mesoscale-model ensemble forecast could be useful for the military maneuver and daily operations on the mesoscale island of Taiwan.

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Table 1: Summary of MM5 Ensemble experiments on the 45-km/15-km nested grid.

Site	Cumulus parameterization	Microphysics parameterization
NTU	Grell (1993)	Resiner 1 (Mixed Phase; Reisner et al. 1998)
NCU	Betts-Miller (1993)	Resiner 1 (Mixed Phase; Reisner et al. 1998)
NTNU	Kain-Fritsch (1993)	Simple Ice (Dudhia 1989)
CCU	Kain-Fritsch (1993)	Goddard Graupel (Tao and Simpson 1993)
CWB	Anthes-Kuo (Anthes 1977)	Simple Ice (Dudhia 1989)
CAA	Kain-Fritsch (1993)	Reisner 1 (Mixed Phase; Reisner et al. 1998)

Set A for NTU, NCU, CWB and CAA: MM5 Ensemble of cumulus parameterizations.
Set B for NTNU, CCU and CAA: MM5 Ensemble of microphysics parameterizations.